

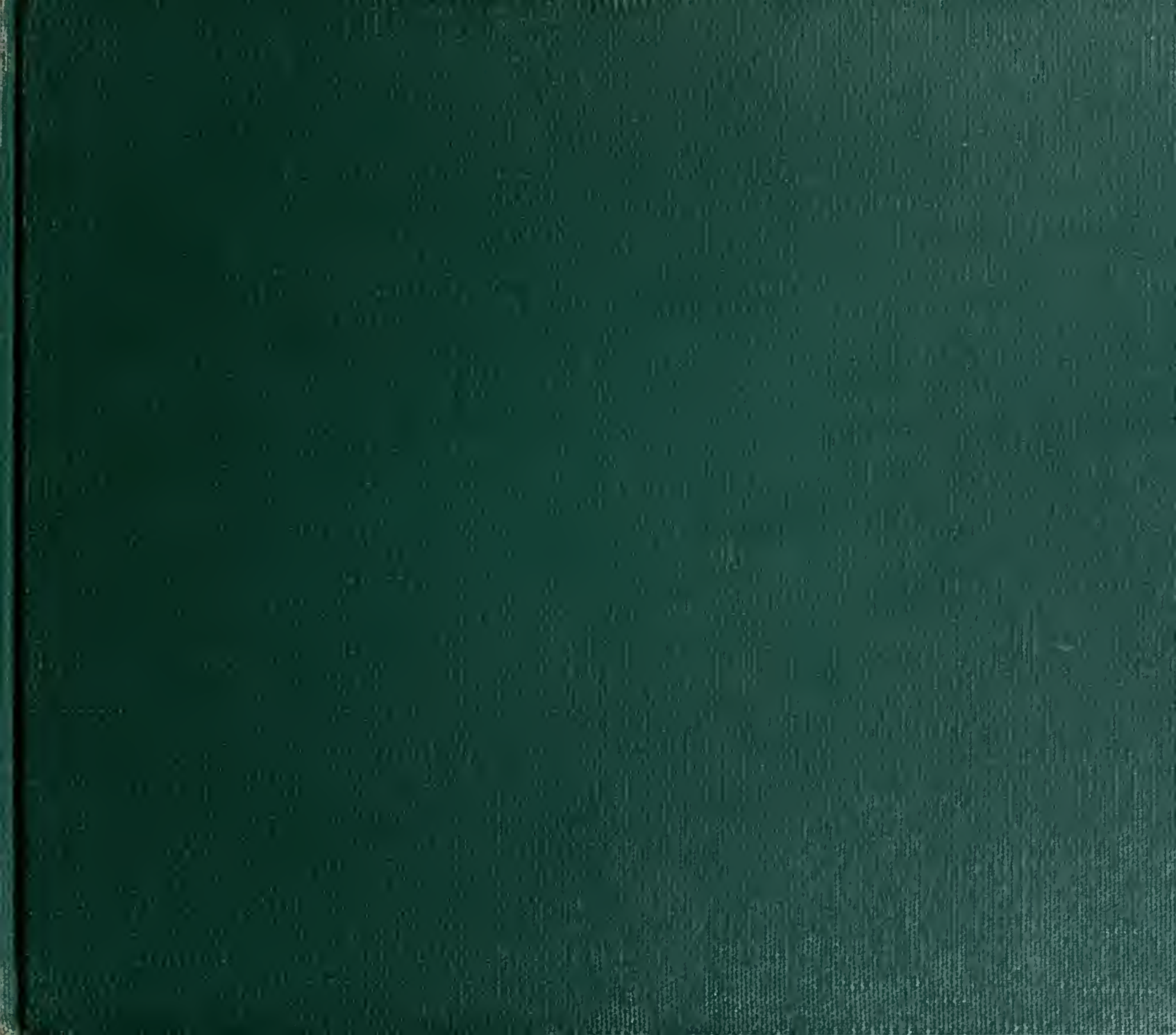
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# GEOLOGIC GUIDEBOOK OF THE SAN FRANCISCO BAY COUNTIES

## HISTORY, LANDSCAPE, GEOLOGY, FOSSILS, MINERALS, INDUSTRY, AND ROUTES TO TRAVEL

*Prepared Under the Direction of*  
OLAF P. JENKINS

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## LETTER OF TRANSMITTAL

To HIS EXCELLENCY

THE HONORABLE EARL WARREN

*Governor of the State of California*

DEAR SIR: I have the honor to transmit herewith Bulletin 154, *Geologic Guidebook of the San Francisco Bay Counties—History, Landscape, Geology, Fossils, Minerals, Industry, and Routes to Travel*, prepared under the direction of Olaf P. Jenkins, Chief of the Division of Mines. The volume contains a sectional geologic map covering twelve counties, a series of geologic travel logs, and a large number of separate articles which cover a broad scope of subjects—history, science, and natural resources—all written by authorities in their subjects, generous with their contributions. The book is profusely illustrated with photographs, tables, charts, and maps and is a storehouse for information concerning earth sciences. As a semi-technical treatise of the bay area, Bulletin 154 will serve to enlighten the public for many years to come. It is an outstanding example of the Division's success in cooperating with various agencies to cover adequately a subject requiring many points of view.

Respectfully submitted,

WARREN T. HANNUM, Director  
Department of Natural Resources

October 10, 1951



The San Francisco Bay country as seen from the air, observer looking north across the broad white expanse of the City of San Francisco. The long black strip cutting east-west across the western half of the city is Golden Gate Park and beyond the eastern end of the park are the Presidio and Golden Gate Bridge. Black, brush-covered Mount Tamalpais in the background to the extreme left overlooks the Pacific Ocean which lies to the left. To the right of and behind the Golden Gate Bridge is Richardson's Bay and beyond Richardson's Bay, Tiburon peninsula which points at Angel Island. Tiny white Alcatraz Island is between Angel Island and San Francisco. In the extreme distance Mount St. Helena, only partly snowcapped, is outlined against a higher snow-covered range on the horizon. At the extreme right Oakland Bay Bridge connects the city with Yerba Buena and (attached) Treasure Island. Lower Crystal Springs reservoir in the left foreground occupies the rift zone of the San Andreas fault; part of Mountara Mountain is in the extreme lower left corner. San Bruno Mountain is the central topographic feature which separates San Francisco from the southern cities in the middle foreground and the airport in the right foreground. The airport is built on land reclaimed from the bay. *Photo by Barney Peterson, courtesy San Francisco Chronicle.*

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## PREFACE

The enthusiastic reception of our first geologic guidebook—*The Mother Lode Country*, Bulletin 141—prompted us to try another such undertaking in the San Francisco Bay area. The natural features of the two areas are totally different, but each is distinctive and both have contributed heavily to the color and character of the West, and both were closely associated throughout the golden history of the State, now over one hundred years old.

The counties treated in this guidebook are the nine (Alameda, Contra Costa, Marin, Napa, San Francisco, San Mateo, Santa Clara, Solano, and Sonoma) which border the shores of San Francisco Bay and three more (Sacramento, San Joaquin, and Yolo) which follow the delta area of the navigable Sacramento and San Joaquin Rivers to the cities of Sacramento and Stockton. These twelve counties are considered by local Chambers of Commerce to form one large industrial unit. Historically they were closely related, especially the counties of Sacramento, San Francisco, and San Joaquin, because of water transportation and economic factors of the Gold Rush. In describing the geology, a much broader scope may be treated if all twelve counties are described rather than only the restricted nine. A geologic section may be followed from the province of the Coast Ranges, across the broad expanse of the Great Valley to the edge of the gold belt in the Sierra Nevada. Thus three distinct, natural geomorphic provinces are crossed, diversified in character and clearly recognized by all who traverse this interesting terrain.

However diversified the natural features may be, there centers about the lovely sprawling water-body of San Francisco Bay and the rivers which flow into it, a single picture naturally unified by early exploration, industry, economic and cultural development, as well as the story told by the rocks and surface relief. The diversity of character which makes this area interesting requires a knowledge of its fundamental geology. This in turn provides explanation of how the rocks and minerals, hills and valleys, streams and broad bodies of water came into being. The varied assortment of natural resources provided material for early exploration and development of civilization. The utilization of natural resources as they were found, the adjustment of man to his natural environment, such as the surface physical features, have shaped and controlled the trend of history. With this knowledge as a background it becomes much easier to visualize the future trends in economic and cultural development. As a bureau of information, the State Division of Mines finds such a study invaluable in its service to people who are interested in developing industries in the state, and in broadening their enjoyment of its natural endowments.

From the air or from any vantage point overlooking the area, the traveler, as he glances long enough to scan the view, cannot help being inwardly inspired by what he sees spread out before him—ocean, mountains, valleys, winding streams, and the controlling arms of San Francisco Bay. Clustered about the bay—a useful silent barrier that has challenged civilization since its earliest day—small towns and great cities arrange themselves to fit nature's environment. The constant roar of traffic, on the ground and in the air, does not let the observer forget for a moment that man's gluttonous feast on nature in this day and age never ceases until the supply is exhausted; but this magnificent scene, though it may change slightly in its details from time to time, will provide permanent inspiration and enjoyment.

To prepare a guidebook such as this, a virtual army of contributors is necessary to provide adequate and authentic information. Twenty-eight technical authors and many more photographers have generously given support to this undertaking. The warmth of friendly interest to make this volume worthwhile as a lasting guide to those of us who love and respect our natural surroundings, is apparent throughout the book. As editors, though proud we may be of our many kind contributors, the best we can do to show appreciation of their cooperation is to indicate credit throughout the text for both composition and illustrations. References to publications have been minimized, but we invite further oral discussion and use of our technical library to clarify points inadequately covered, or to obtain further details which were omitted because space would not permit more expanded discussions. Assistance in technical editing, preparing captions to illustrations, and proofreading for final publication was largely provided by Elisabeth L. Egenhoff and Oliver E. Bowen, Jr., members of our technical staff. Though much pleasure is derived from preparing a volume such as this, the task is far more arduous than the preparation of purely technical dissertations. To cover and balance a subject from all sides and to do so in a manner understandable to the general public, is a challenge to modern specialized science. If this undertaking helps to broaden the scope of understanding and to effect wiser utilization of our natural resources, as well as to excite enjoyment of scientific knowledge, the job will not have been done in vain.

OLAF P. JENKINS  
Chief, Division of Mines

Ferry Building, San Francisco  
October 10, 1951



PART I  
HISTORICAL BACKGROUND

**Editorial Note:**

PART ONE takes the reader back to the time when the broad expanse of San Francisco Bay and the confluent rivers lay concealed behind coastal mountain ranges, unknown except to primitive Indian tribes. Then came discovery—by land, not through the Golden Gate, which only later was opened to the traffic of the venturesome world. Gradually the region, through the development of its natural resources, grew into one of the greatest industrial areas of the nation. The twelve counties described in this guidebook constitute a group economically and historically related. If it were a state, this group, with a population of three million, would now rank seventeenth among the states of the Union. Geologic structures, unique and complex, have so influenced the natural surface features of the region as to give it distinction, character, and beauty which have molded a civilization commanding the respect and admiration of the world. The early history and growth of the San Francisco Bay area are recorded in Indian mounds, in the remains of early building structures, in place names on maps, as well as in voluminous written documents. We hope that this HISTORICAL BACKGROUND will serve as a medium to orient the reader for the geologic discussions which follow.

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## OPENING OF THE GOLDEN GATE

BY DOROTHY G. JENKINS

Within the Golden Gate, surrounding San Francisco Bay and the lower courses of the great rivers that flow into it, lies a province unique in its advantages to mankind, its beauty and variety of landscape, and its rich diversity of historic record. The mountains, which shut it off from the sea, except for the narrow opening of the Golden Gate, preserved for an amazingly long time the secret of this unexcelled harbor. Not until two hundred and twenty-six years after Cabrillo's journey had disclosed the coast of California was the bay discovered by the Portola party in 1769. And six more years passed before any known navigator penetrated from the ocean to the inland sea through the *Boca del Puerto de San Francisco*, as the Spanish called the narrow entry. The mountain barrier had a strong ally in the frequent fog that shrouds the coast, and yet it is difficult to realize that for over two hundred years ships of discoverers, explorers, traders, and pirates sailed the Pacific Ocean, while all the time within the Golden Gate a great safe comfortable harbor lay waiting.

The mountains rise to no great heights in this region but because of the positions they occupy Mt. St. Helena (4336 ft.), Mt. Diablo (3849 ft.), Mt. Tamalpais (2604 ft.), and Mt. Hamilton (4206 ft.) command remarkably extensive views over land and ocean. From Hamilton and Diablo the summits of the high Sierra in the region of Mt. Whitney are frequently visible, and from St. Helena, as well as Diablo, not only are the heights of the more northerly Sierra occasionally in view, but far to the northeast Mt. Shasta and Lassen Peak, most southerly of the giants of the Cascade volcanic chain, appear at times in the clear atmosphere of October or early spring.

More significant, however, than the remarkable distant view is the rich region spread below these mountains of the Coast Ranges—San Francisco Bay itself, the expanse of quiet water broad enough to shelter the fleets of the world, the two great rivers uniting among the channels and islands of the delta and merging into Suisun Bay, the eastern extremity of the inland sea, and the opulent valleys between the ranges of hills and mountains, valleys delightful for habitation and rich in the products of field, tree, and vine.

The central valley with its two giant arms, the Sacramento and the San Joaquin, makes of Yolo, Solano, Sacramento, San Joaquin, and Contra Costa Counties an enormous treasury of grains, fruits, nuts, and vegetables convenient for transportation by water, rail, and highway. The valleys of Napa and Sonoma Counties are filled with vineyards where wines in the best European tradition are produced in great quantity. All kinds of fruits flourish in these sheltered regions.

Miles of apple orchards around Sebastopol vie with the enormous acreage of prune and apricot in Santa Clara valley. Walnut groves and pear orchards cover vast areas of this fertile land. The whole San Francisco Bay region is a succession of rich valleys, favored alike by climate, soil, and the rare recreational advantages of mountain and sea. These natural qualities, in addition to the magnificent harbor with its attendant industrial facilities, could not have failed to create a remarkable center of rural, residential, and metropolitan development.

This was the potential empire that lay so long within the Golden Gate, peopled by Indian tribes but undreamed of by the explorers of the new world, although some of these in their voyages passed close to its portal.

It was only half a century after Columbus had revealed the western world that Juan Rodrigues Cabrillo undertook his exploration of the California coast. Mexico and portions of South America were partially conquered and colonized by Spain, and the peninsula of Lower California already bore the present lovely name. It was from Navidad, a little port on the western coast of Mexico, that Cabrillo, Portuguese although he sailed under Spanish colors, set out to investigate the coast that stretched away to the north. Perhaps a faint hope existed that this voyage into uncharted waters might disclose that hoped-for Strait of Anian which still dominated the wishful thinking of that day, although the width of the Pacific Ocean, demonstrated by Magellan's voyage in 1521, had diminished faith in an easy passage to the Indies.

Although disappointed of Anian, Cabrillo's party sailed and charted the entire coast of California. They reached San Diego on September 28, 1542, remained a few days and then proceeded to the Channel Islands where they stopped for a fairly thorough investigation. Continuing north, charting and naming salient points as they went, they passed unknowing the entrance to San Francisco Bay and went on as far as Point Arena before winter weather became so perilous as to force them back. Somewhere in the voyage Cabrillo's arm was broken. Infection followed, and shortly after they had reached the Channel Islands again and landed on what they had named *La Isla de la Posesión*, now known as San Miguel, the brave admiral died on January 3, 1543, and was buried on the lonely island he had discovered.

Bartolomé Ferrello, pilot of the expedition, took command after Cabrillo's death and the voyage north was resumed, reaching at least as far as the northern border of California. Again San Francisco Bay was passed by, but the Farallones appeared on the charts Ferrello

carried back to Mexico. His reports did not indicate a hospitable land nor convenient harbors on the coast of California.

Twenty-four years later, in 1566, the Manila Galleon made its first trading voyage to the Philippines, and thereafter this heavily laden cargo boat made yearly journeys between the ports of South America and the Indies. In spite of this commercial activity it was not until thirty-seven years after Cabrillo's expedition that further recorded exploration of the shores of California was undertaken. The next visitor sailed under the flag of England and spoke the language of Shakespeare, who was then a fifteen-year-old boy at Stratford. This mariner roved the seas in the interest of Queen Elizabeth and filled the Spanish world with dismay at his piratic thrusts.

Various old records tell the story of the voyage around the world of Francis Drake, a journey in which the five weeks' sojourn in what is now Marin County was only a brief episode. Most of the records are based on the journal of Francis Fletcher, chaplain of the expedition. The first account to appear was probably in Hakluyt's volume, published in London in 1589, *The Principall Navigations Voiages and Discoveries of the English Nation*. A fuller account appeared in 1628 with the title *The World Encompassed by Sir Francis Drake*. For the pirate had been knighted on the deck of his own ship by Queen Elizabeth on his return from the first circumnavigation of a world which was, in the sixteenth and early seventeenth centuries, growing smaller at a breath-taking pace.

Drake had commanded five ships when he set out from England in November 1577 on a voyage designed to investigate the possibilities for wealth in the South Pacific. Weather delayed him in the Atlantic, as well as numerous engagements with Spanish ships, for he could not pass by an opportunity for piracy. Nearly a year later he brought the three vessels that survived through the strait Magellan had discovered fifty-seven years before but through which no other mariner had yet penetrated.

Very soon after reaching the Pacific Ocean they were almost destroyed by a storm. The three ships were scattered and Drake began his journey up the coast of South America with only one, his hundred-ton flagship originally called the *Pelican* but now rechristened the *Golden Hinde*. Fortunately for history, the chaplain Francis Fletcher was with him, and his journal tells a remarkable story of plunder. Spanish ports and ships, one after another, were ravaged in the surprise attacks of these English pirates. The *Golden Hinde* was almost foundered by the treasures in her hold, gold and silver, coin, jewels, charts of trade-routes; and if the special knowledge of some captive seemed serviceable he was added to the loot.

But so much piracy consumed time, and presently it was too late for favorable winds for the long voyage across the Pacific, espe-

cially with a vessel so heavily weighted with stolen cargo. And Drake could not risk returning to the Straits of Magellan. Too many of his recent victims were awaiting his return. There was nothing to do but push on to the north and wait for sailing weather. He swung to the west and must have been well off-shore when he passed the entrance to San Francisco Bay.

At a point somewhere off Del Norte County he turned south again, cruising along the coast in search of a suitable beach on which the *Golden Hinde* could be put into condition for the voyage to the Orient. Fletcher's account relates "we fell with a convenient and fit harborough, and on June 17 (1579) came to anchor therein: where we continued to the 23 day of July following. During all which time, notwithstanding it was the height of Summer, and so near the Sunne; yet were we continually visited with . . . nipping colds . . . neither could we at any time in whole fourteen days together find the air so cleare as to be able to take the height of Sunne or starre."

Most historians agree that this cold summer was spent on the shore of the bay in Marin County that bears Drake's name. It is an open bay with very little shelter, but one good anchorage lies behind the hook on the end of the rugged granite headland of Point Reyes. Across the bay, facing the sheltered cove, a line of white cliffs extends for some miles. These cliffs contribute to the belief that the beach behind the hook was the scene of Drake's Californian sojourn, since Fletcher reports: "This country our Generall named *Albion*, and that for two causes; the one in respect of the white baneks and cliffes, which lie toward the sea: the other that it might have some affinity even in name also, with our owne country, which was sometimes so called."

The white cliffs on the Marin shore are diatomaceous shale (often miscalled "chalk-rock") and are by no means so continuous or so strikingly white as the chalk cliffs of England, but they are the only white cliffs for a long distance up or down the coast and they fit very neatly into Fletcher's description.

The chaplain's story gives a spirited account of the cold weeks the English seadogs spent in the fogs and winds of Point Reyes. The Indian inhabitants of the region met them with surprising friendliness, even regarding them as superior beings, and, as Fletcher declares, voluntarily making over their lands to the strangers. They conferred the title *Hioh* upon Drake, the title borne by their own chief.

The most significant part of the story is that of the departure when, as Fletcher relates, "Our General caused to be set up a monument of our being there, as also of her maiesties and successors right and title to that kingdome, namely a plate of brasse, fast nailed to a great and firme post; whereon is engraven her graces name, and the day and yeare of our arrival there, and of the free giving up, of the

province and kingdom, both by the king and people, into her maiesties hands: together with her highnesse picture and armes in a piece of sixpence current English monies, shewing its selfe by a hole made of purpose through the plate.”

Drake sailed away in his little pirate ship. Landing briefly on the southeast Farallon to supply the *Golden Hinde* with seal meat, he and his party were the first white men known to have set foot in San Francisco County. He went on to the magnificent adventure of encircling the globe and returned to be knighted by his queen—a high honor for the Devon pirate, but not unique, as was the bizarre distinction of being crowned *Hiah* by dancing savages on the Marin shore.

And not until 1936, three hundred and fifty-seven years later did the *plate of brasse* come to light to verify the old account. Then it was discovered, battered and almost unrecognizable, by a party of picnickers. Fortunately it came into the hands of historians and scientists who were able to perform the laborious tests necessary to demonstrate its authenticity. It is now a valued possession of the University of California where it is displayed—a calling card left by a visitor three and a half centuries ago.

History might have taken a different course if Drake had anchored in Marin County in fair weather. If the sun had shone and the mariners had climbed Mt. Tamalpais, looked down on the magnificent landlocked harbor below and the limitless vistas of hills and valleys to the north, east and south, they might have decided that the treasure they were seeking lay below them, and Drake might have persuaded his queen to take physical possession of the empire he had found.

Sixteen years after Drake's visit, in November of 1595, Sebastian Rodrigues Cermeño, in a ship named *San Augustín*, entered the same bay which had sheltered the *Golden Hinde*. A Portuguese navigator, he had been commissioned by Luis de Velasco, Viceroy of New Spain, to make a search for safe ports on the California coast where the Manila Galleons could stop on their perilous homeward cruises to allow their crews to recuperate. To recompense the mariner, Velasco permitted him to combine his exploration with a trip to the East for profit. Cermeño sailed from Acapulco to the Philippines, weighted down his vessel with all the precious wares he could carry—silk, wax, porcelain, spices—and sailed from Cavite on July 5, 1519, directing his course toward northern California. Four months later he sighted some point on the coast, and turned south in stormy weather, rounded the headland of Point Reyes and came to anchor, probably somewhere near the shore across the bay from Drake's landing. He took possession of the land for Spain, and called the bay *La Bahía de San Francisco*, a name it bore for many years to the confusion of historians. A small

launch, more or less dismantled, had been brought from the Philippines on the deck of the *San Augustín*, and Cermeño's crew set about putting it in order on the beach. This was a fortunate circumstance, because late in November a sudden storm wrecked the *San Augustín* in the harbor, with some loss of life and complete loss of the rich cargo. On the eighth of December the seventy survivors crowded into the small boat they had set up, and by extremely competent navigation as well as amazing good luck they reached Acapulco some seven weeks later.

Within the last few years archaeologists from the University of California, excavating Indian shellmounds on the shores of Drake's Bay in search of further evidence of Drake's sojourn there, have uncovered a large number of ship's spikes of corroded iron as well as numerous fragments of Chinese pottery. Examination of these specimens by experts has led to the belief that they accord with the conditions, not of Drake's landing, but of Cermeño's, and it is surmised that the spikes resulted from the breaking up of the *San Augustín* and the porcelain was part of what the Indians salvaged after the shipwreck.

Seven years after Cermeño's disaster one of the survivors of the perilous return to Acapulco, Sebastián Viscaíno, embarked from Navidad on May 5, 1602, to retrace Cabrillo's route in order to discover the safe harbors for the Manila Galleon that Cermeño had sought. He visited most of the possible ports of California but the entrance to San Francisco Bay eluded him on both the journey north and the return. His voyage was fortunate and he was filled with enthusiasm. He mapped and named most of the prominent features along the coast, in many cases setting aside with fine disregard the names Cabrillo had chosen.

He entered Monterey Bay on December 15, 1602, and under a live oak that grew near the shore took possession of the country. He was the first white man known to have set foot in the region. He was so deeply impressed with the beauty and promise of the scene about him that his report indicated an earthly paradise, and created around Monterey Bay and peninsula a romantic tradition that persisted for a hundred and fifty years. It was little wonder that later explorers did not recognize the place when they came upon it.

On the third of January, Viscaíno observed the point farthest south in San Mateo County and in honor of the season he named it *La Punta del Año Nuevo*.

The report of Viscaíno's voyage was so favorable and the need for the northern harbors so real that it is hard to understand why more than a century and a half elapsed before it was thought worth while to explore further on the California coast. Spain still held title to the remote region but, busy with conquest and colonization and absorbed in commercial gain, she thought less and less about Alta California.

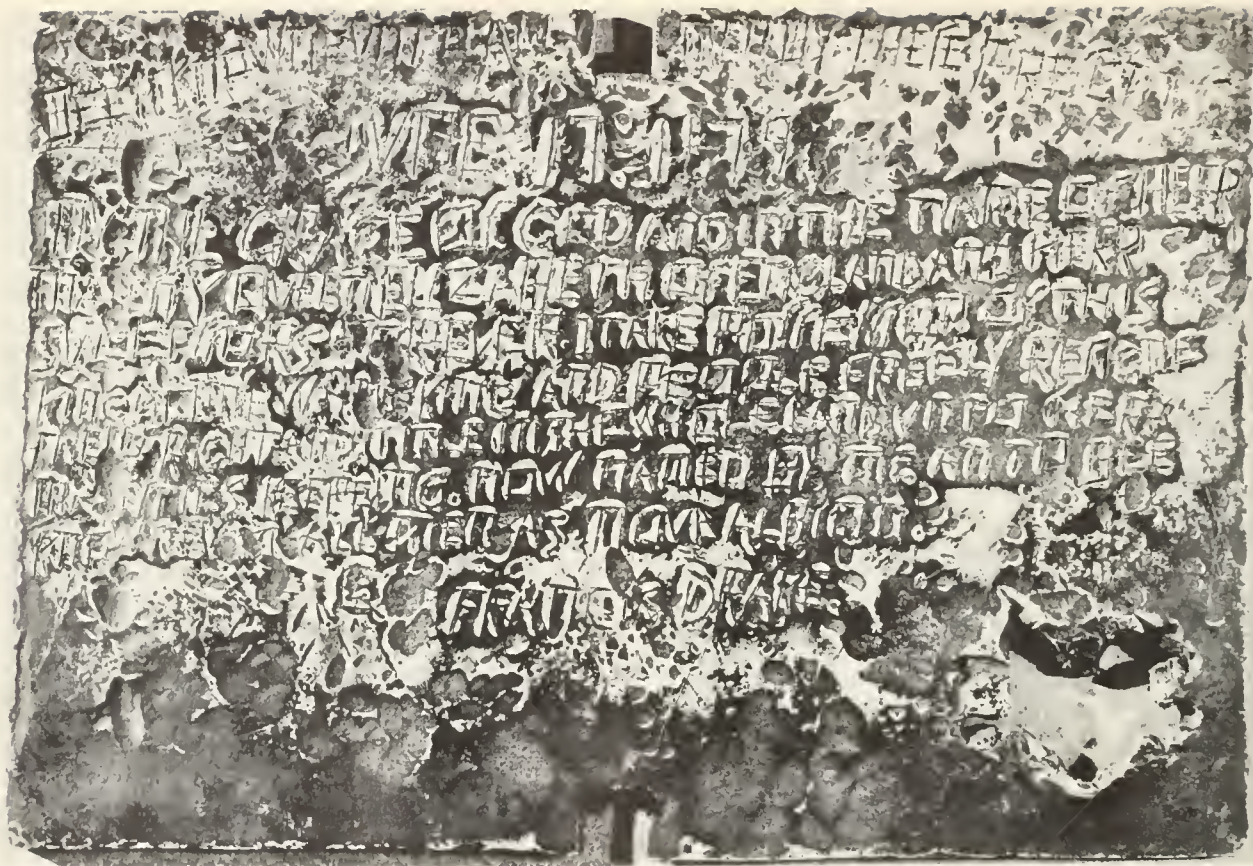


FIG. 1. Drake's plate of brass. The inscription reads: "Bee it knowne vnto all men by these presents iune 17 1579 By the grace of God and in the name of Herr Maiesty Qveen Elizabeth of England and Herr sccessors forever I take possession of this kingdome whose king and people freely resigne their right and title in the whole land vnto Herr Maisties keepinge now named by me an to bee knowne vnto all men as Nova Albjon. Francis Drake." The hole in the lower right-hand corner is the correct size, and probably once held "her highnesse picture and armes in a piece of sixpence current English monies," as recorded by Francis Fletcher.

Not until 1769 was an attempt made to penetrate into the distant province. Charles III, then King of Spain, recognized that his country must assert its claim or be forced to give Alta California up to some more aggressive colonists. The English were in an expansive mood after Captain Cook's journey. The Russians, well established in Alaska, were very likely to encroach. José de Galvos, Visitador General of New Spain, conferred with the Viceroy Marqués Francisco de Croiz and a serious plan was made to colonize. As a result four groups of chosen adventurers set out from Mexico to Alta California, two by land from Loreto and two by sea from La Paz.

Don Gáspar de Portolá was in charge of the whole expedition, and had the honor of being named governor of both the Californias, of which Loreto was the capital. Although most of the region traversed by the overland parties was totally unknown, the marchers fared better than the seafarers, who suffered untold hardship and considerable loss of life.

The four parties met on the site of San Diego and there formed the first permanent settlement in California. And there a few weeks later the first of the Franciscan missions of California was established by Padre Junípero Serra, religious leader of the colonists.

Portolá, who had come overland from Loreto with the second party, remained in the new settlement only two weeks before continuing in quest of the beautiful bay Viscaino had named Monterey. Only half of the three hundred men who had started on the fourfold journey could share the further adventure. Of the other half those who had not died of hardship were disabled. The leader decided to send one group back by sea to Mexico for needed supplies. Another party of soldiers and workers was to remain with Padre Serra to found the mission and presidio. The remaining sixty-three were to proceed with Portolá toward the major objective, Monterey Bay. These seasoned travelers set out from San Diego on the fourteenth of July.

Except when mountain barriers forced them inland, Portolá's men followed the coast. The huge mass of the Santa Lucia Mountains diverted their course into the Salinas Valley, and when they did reach Monterey Bay it was not at the distinctive and beautiful southern end, Monterey peninsula, but farther north near where the Salinas River flows into the sea. Although they camped there for a time and explored the neighborhood they saw nothing at all to suggest the bay Viscaino had described so glowingly. Consequently, although their charts indicated that they were in the right latitude, they concluded that the maps were in error, and they proceeded north in further search for the perfect harbor.

On October 23, 1769, having passed the *Punta del Año Nuevo*, they camped on Gazo's Creek and then for a night or two on San

Gregorio Creek. On the 27th their camp was on Purisima Creek, and on the 28th and 29th at Pilareitos Creek just north of the present town of Half Moon Bay. On the 30th they reached Martini's Creek, and here they were forced to stop for a time, as the great bulk of Montara Mountain blocked their way along the coast.

From this camp they must have climbed to the summit of a westward flank of Montara Mountain, from which, although San Francisco Bay was concealed from them, they looked down on the Gulf of the Farallones with its small and lonesome islets. Forty miles to the north they could discern Point Reyes recognizable like the Farallones from the maps of Viscaino and from the clear description of Cabrero Bueno, pilot of one of the Manila Galleons. Puzzled, they went down the mountain toward the northeast and made camp on San Pedro Creek.

It was from this camp that Sergeant José Ortega, the pathfinder, set out with a few men to blaze a trail to Point Reyes. On November first they climbed to the top of Point Lobos from which they saw their way cut off by a great arm of the sea. Plodding to the east they climbed another height, probably Telegraph Hill, and were rewarded by the view of a great body of quiet water, impassable, and therefore in their eyes hostile. They were the first Europeans to look upon the waters of San Francisco Bay.

Ortega did not reach the base camp until November third; and in the meantime another small party, this time hunting for game, had looked down from a crest of Montara Mountain and seen the southern arm of the bay shimmering below them, and beyond, the long and pleasant valley now called Santa Clara.

The reports of both these parties, great as they were with future significance, failed to relieve the gloom of Portolá's party. They only served to confirm the knowledge that Monterey Bay had not been found. Disheartened, the little band turned south from the San Pedro Creek camp, determined to explore the southern end of the great bay, and accordingly having come down the canyon that contains Crystal Springs Lake and Woodside, they established another base on the southern bank of San Francisco Creek, the boundary between San Mateo and Santa Clara Counties. They camped in the shelter of a lone redwood tree which afterward was associated with the name Palo Alto, first the name of the estate of Senator Leland Stanford, and later of the thriving city which grew up at the gate of Stanford University.

From this base camp beneath the redwood, where the main body of the party rested from November seventh to tenth, Sergeant Ortega with a few men undertook another scouting excursion to see if they might reach Point Reyes from the eastern side of the *estero*. For it had been determined that the bay Drake had called San Francisco was to be reached if possible and a mission and presidio established there.

They rounded the end of the bay and proceeded north through Alameda County, probably reaching Alameda Creek in the neighborhood of Niles, and going on north until from some height they found that their way was again blocked by a water barrier, probably San Pablo Bay. When they had carried this discouraging report back to Portolá, the party retraced its way to San Pedro Creek and from there began their return journey down the coast. They stopped to erect a cross on the beach near Monterey as a token of having been there, and continued their long march, reaching San Diego on January 10, 1770.

Portolá's expedition had been fraught with hardship and disappointment, and he found that Padre Serra and his companions at San Diego had fared little better. Fortunately the ship Portolá had sent back to Baja California for supplies returned opportunely laden with necessities, and both groups were rested and re-inspired with hope.

In the spring of 1770 Portolá organized a second exploration. His party, spiritually guided by the two fathers Serra and Crespi, reached Monterey at the end of May, and on the third of June the Misión San Carlos Borroméo was established, as well as the Presidio of Monterey. The two institutions were dedicated under the live oak beneath which Viscaino had taken possession of the land a hundred and sixty-eight years before. The old oak stood until 1905, and when it died a portion of it was taken to the garden of San Carlos Church where it remains today. The original mission building was on the site of this church at the presidio, but the proximity of the soldiers proved unsatisfactory for the mission and Padre Serra chose a second location in the fertile valley of the Carmel River five miles to the south.

Portolá left Pedro Fages in charge of the new presidio, and presently Fages on his own responsibility undertook an expedition to the region about San Francisco Bay, still believing that an inland route to Point Reyes must be a possibility. Coming from Monterey by way of San José, he reached the point near Niles where Ortega had been, and continued even farther north than the earlier expedition. From somewhere in the Berkeley Hills his party looked west through the Golden Gate and north to where San Pablo Bay made further progress impractical.

Two years later in the spring of 1772 Fages made one more attempt on the elusive route to Point Reyes. With Padre Crespi, a careful keeper of records, and a few soldiers he retraced the trail he had opened two years before. They camped near Hayward, proceeded along San Lorenzo Creek, stopped briefly on the present site of Mills College, and a few days later on Strawberry Creek within the present campus of the University of California. In the intervening days they had made a reconnaissance of the region occupied today by Oakland, Berkeley, Albany, and Richmond. Crespi's description of the views from the heights—Alameda, the Golden Gate, the islands

in the bay, the oak-studded plains—are a delightful feature of the record of this journey, which had again only demonstrated the difficulties of reaching Point Reyes by land.

Another brief visit to the San Francisco peninsula was made in 1773 by Comandante Rivera with the Franciscan Padre Palou and a few men. They stopped where Ortega had first seen the bay, on Point Lobos, and they left a cross there as a monument.

Alta California had now awakened from her long sleep. The foothold was established and it remained for the region to be colonized according to the threefold plan Spain had found effective in subduing and maintaining the lands she conquered. Three coordinated forces, military, religious, and civil, were required by the sovereign plan. Consequently three types of institutions were set up, the presidio or military stronghold, the mission, in which was centered the spiritual life as well as the teaching of the natives and the religious life of the whole community, and the *pueblo* or town where non-military settlers and indoctrinated natives were to live. It was now necessary to develop in Alta California these elements which already had a modest beginning at San Diego and Monterey, San Antonio, San Luis Obispo, and San Gabriel.

In 1774 Juan Bautista de Anza initiated the first large-scale project for colonization. He led a party of willing settlers from Sonora in northern Mexico westward across the deserts by way of the Gila and Colorado Rivers, on to the Misión San Gabriel which had been established three years before, and thence to Monterey.

Two years later, in 1776, when on the eastern coast of the wide continent the United States of America were just coming to birth, Anza led forth his second expedition which was destined to establish the strategic communities on San Francisco Bay. The site for this settlement had been chosen partly because of Crespi's account of the expedition on which he had accompanied Fages on the *Contra Costa*. The eligibility of the peninsula for such a project was still more obvious after the exploration of the bay itself which had taken place in 1775.

The Spanish government, at last awake to the danger represented by the Russian activities on the Pacific coast, had sent a little fleet of four ships to represent Spanish authority in those waters. One of these ships, the *San Carlos* commanded by Juan Manuel de Ayala, reached the *Boca del Puerto de San Francisco* on August fourth and Jose Cañizares, in a small launch, undertook to enter the narrows. Ayala was ill on that day, but when his subordinate, Cañizares, had failed to return on the next evening, the commander piloted the *San Carlos* through the channel and into the bay. These two were the first recorded European navigators of the Golden Gate.

Ayala's party spent more than six weeks in the bay exploring the entire shore line, making maps and recording depths. Study of

their records confirmed the opinion of the authorities who were organizing plans for the new empire that the peninsula Portolá had discovered was a favorable place to colonize.

This destination was well in mind when Anza's second expedition started at Tubac near Tumacacori Mission—territory which was then northern Mexico but is now a part of Arizona. Anza had personally chosen a group of two hundred and forty vigorous pioneers to people the community on San Francisco Bay. Thirty families, parents with their children, even with unborn children, were elected to travel the eight hundred miles across deserts, mountains, and valleys. The labor was enormous but the reward was to be great. The settlers were promised land of their own in the new country when they had served as soldiers for ten years. From this promise of reward for public service came the great land grants so important to California life in the three-quarters of a century of Spanish, and later Mexican, occupancy.

The pilgrimage of Anza's party is one of the epics of America, partaking somewhat of the nature of a crusade. Anza did not in person bring his settlers to their promised land. He left them resting for a little while in Monterey while he himself pushed on to the San Francisco peninsula to choose definite sites for presidio and mission. On the 28th of March, 1776, he erected a cross at Fort Point to mark the area he had chosen for the military establishment, and another about three miles to the south on the shore of a small marshy lake (Laguna de Manantial) in the course of a creek which he called the Arroyo de los Dolores. This second cross was to mark the site of the mission, and it was never changed.

Anza returned to Monterey, turned over the task of settling the pioneers in their new home to Lieutenant José de Moraga, and departed for Mexico. Under Moraga's able command the settlers accomplished the final lap of their long journey and arrived, camping at the mission site, on June twenty-eighth. The following day, just five days before the birth of the American nation, the first mass was conducted by Padre Palou in a rough shelter of boughs.

Weeks passed before the founding of the presidio. The *San Carlos*, which was supposed to sail from Monterey the day after the departure of the overland party, was expected daily, and eagerly awaited, too, for in addition to the numerous soldiers, she carried much needed equipment, tools, and the warm clothing so necessary in the summer fog. When at last she sailed into the bay she had been seventy-three days at sea, driven by storm almost to San Diego and again far to the north before she could effect her entrance.

On the seventeenth of September the presidio was at last occupied, becoming the first permanent settlement in the bay region. And three weeks later, on the ninth of October, the temporary church of the mission was dedicated by Padre Palou, sixth in the chain of twenty-one

Franciscan missions eventually established under the ambitious plan to make Catholic Spanish subjects of the inhabitants of California.

The mission church that exists today, begun in 1782, was completed in 1791. It was simpler in structure than many of the missions and this very simplicity gives it distinction. Fortunately it is in an excellent state of preservation, and with its little graveyard crowded with well-marked graves, it forms San Francisco's best link with her romantic past.

Although the mission and presidio were so favorably situated the Spanish community on the bay grew slowly. Spain never aimed at creating military strength at the presidio. It was modestly manned and equipped. The progress of the mission was slow too, but it was steady, and from a small beginning it became a rich agricultural and industrial community, making always a civilizing background for the gradually developing life on the peninsula.

Only three months after the establishment of Misión San Francisco de Asís the first mass was celebrated on the site of the eighth of the Alta California missions. This was the Misión Santa Clara de Asís, beautifully located on the banks of the Rio Guadalupe, not far from the southern end of San Francisco Bay. Padre Palou pronounced this site the best of any chosen for missions. It had fine level land for farming, numerous oaks and many springs. The abundance of water first appeared a blessing, but it soon proved too plentiful, and a second site was selected, not far from the present Santa Clara Mission Church, and the corner stone of a new building was laid on November 9, 1781. This church, dedicated in 1784, was the finest in Alta California at that time.

In 1812 and again in 1818, however, much of this beautiful church was destroyed by earthquake. A third location was chosen and a new church built and dedicated in 1822. Although little now remains, it forms the nucleus of the present widely known University of Santa Clara. When in 1850 Bishop Alemany came to San Francisco to take charge of the suddenly growing diocese there, Padre Rial, the last of the Franciscan fathers to remain in California after secularization, was still at Santa Clara, reduced now from a flourishing mission to a neglected parish church. The new bishop, wishing to salvage something of Santa Clara, invited the Society of Jesus to come and create an educational institution there. On March 19, 1851, Santa Clara College, now the University of Santa Clara, was begun by Father John Nobile, S. J. A small part of the mission church is incorporated in the buildings of the University, and the olive orchards and vineyards lived long after the mission had grown from a shelter of boughs to a succession of churches, had flourished, disintegrated, and disappeared.





FIG. 2. Mission Dolores (Misión San Francisco de Asís), erected by the Franciscan Fathers in 1776. Photo by Gabriel Moulin Studio, courtesy of San Francisco Chronicle and San Francisco Convention and Tourist Bureau.

Before the missions became self sustaining it was difficult to supply the needs of the settlements in Alta California, hence the plan was made to establish certain agricultural projects and bring settlers to populate them. One of these settlements was founded by Lieutenant José de Moraga near the new mission Santa Clara in the center of the fertile valley that still bears the mission's name. It was an extremely small beginning, but from that tiny *pueblo*, founded on the Rio Guadalupe and taking its name from it—El Pueblo San José de Guadalupe, grew the city of San José which became the first state capital of California.

The tree-lined avenue known as the Alameda that connects Santa Clara and San Jose was originally planted by the mission fathers to make the road pleasant for travelers between pueblo and mission. With the aid of the Indians, they transplanted willows from the river and diverted a ditch to water them until they were well established. That shady stretch of road has survived many changes. Foot-travelers of the first days moved over to make room for horsemen. Carriages came later, and finally a coach line. Still later a horse-car appeared, and the central of the three lines of willows came down to make more room. A steam train followed the horse-car and still later an electric line. Tracks have long given place to the hard surface of the present highway. The Camino Real, highway 101, follows the road the fathers of Santa Clara designed for the comfort of their flock.

No more missions were established in the San Francisco Bay country for twenty years. Before Anza had returned to Mexico after choosing the sites for the mission and presidio on the San Francisco peninsula, he and Moraga had explored the terrain on the east side of the bay from the southern extremity, past Alameda Creek, along the foothills, past the present sites of the cities of the East Bay and along the northern arm of the bay as far as Antioch. After that journey no one is known to have penetrated Alameda County until June, 1795, when Sergeant Pedro Amador explored and reported on the southern portion, using, probably for the first time, the name Alameda for the region. In November of that same year, scouts from Monterey came to search the Alameda described by Amador for a suitable site for a new mission. They chose the location for Misión San José de Guadalupe in the foothills of the Mt. Hamilton range, a comfortable journey from Santa Clara. Not until 1797, however, did Padre Lasuén and a group of soldiers led by Amador arrive to found the new mission. On the eleventh of June of that year, Padre Lasuén celebrated the initial mass in the customary shelter of boughs.

Immediately afterward the temporary buildings for the mission were constructed. By the end of 1797 there were thirty-three converts, and three years later they numbered two hundred and eighty-six.

Livestock flourished and rich crops were harvested. In 1824 there were eighteen hundred and six people at the mission. Only Misión San Luis Rey boasted a larger population. There were more baptisms at Misión San José than at any other. It was among the most successful in the field of agriculture. Socially it was extremely useful, a delightful center for the pleasant country life on the land grants of the eastern side of the bay. It was moreover a convenient spot for temporary rest for the numerous explorers as well as for military parties sent out against Indians.

Visitors to California availed themselves of the hospitality of the missions, and spread their fame by means of the appreciative comments sent home. Among the early guests was Captain George Vancouver who entered San Francisco Bay on November 12, 1792, probably anchoring his little ship *Discovery* close to where the Ferry Building stands today. Yerba Buena, the later port, hardly existed then, but the mission and presidio were going concerns and Vancouver was welcomed and favorably impressed. He described the magnitude, architecture, and interior decoration of the Misión San Francisco de Asís as doing great credit to those who had constructed it. The coarse wool blankets woven by the neophytes on mission looms from wool produced in the mission *potreros* surprised him with their excellence.

Vancouver was accompanied on a visit to the sister mission at Santa Clara, and it did not escape his notice that these mission lands were rich and promising, the country around them most favorable for future development, the climate delightful, and the oak-studded plains remarkably adapted to homes after the English fashion. Nor did Vancouver feel that the somewhat loose hold that Spain held on these distant domains would be difficult to break, and he so advised his government. Under different circumstances England might have taken steps to overthrow Spain, her ancient enemy, and annex these promising shores for her own use. However, she was tired of the long struggles with Spain, and was having trouble enough to keep out of the French Revolution. And she had not had time enough to forget her uncomfortable experiences with the English colonies on the east coast. American colonization had no charm for her. Hence Vancouver's advice to take possession of this rich realm was never followed.

Other visitors came. A German explorer Von Langsdorff, personal physician to the Russian Count Rezanoff on his first visit to California, arrived in 1806. In a small Indian boat he sailed down the bay, and was the first foreigner known to have landed on the southeastern shore. He was a well-known naturalist and employed every opportunity to observe and collect specimens. He visited at Misión San José and wrote with the greatest enthusiasm of its flourishing gardens and crops, prophesying that this would be, as it later was, the most prosperous of the missions.

Two other famous scientists came in 1816 on the Russian ship *Rurik* commanded by Captain von Kotzebue and spent some time observing the plants of the region. These were von Chamisso and Frederick Eschscholtz. The name of the latter, with its remarkable concentration of consonants, was given by von Chamisso to the golden poppy so riotously spread over the landscape. The California poppy, however, has flourished none the less for being named *Eschscholtzia californica*.

Jedediah Strong Smith with a small group of followers was a guest at Mission San José in 1827 after his epoch-making first crossing of the Sierra Nevada. In fact he was actually held captive there for some twelve days. Padre Duran, then in charge of the mission, distrusted him and was unwilling to help him collect the supplies Governor Echeandía had allowed him for his expedition from California to the northwest. At the end of December, however, Smith left the mission and proceeded on his journey through Mission Pass and the Livermore Valley, up the great central valley as far as Tehama and then on an entirely new trail into Oregon by way of Trinity, Humboldt, and Del Norte Counties.

In the meantime the last two missions of the chain in Alta California had been established in the San Francisco Bay area, San Rafael Arcángel on December fourth, 1817, and San Francisco Solano at Sonoma on July fourth, 1823. These later missions differed in purpose from the earlier ones. San Rafael Arcángel was in a sheltered spot on the north shore of the bay, chosen as an experiment to see if the less exposed situation might be helpful in the care of the sick. Much sickness, often fatal, developed at Mission San Francisco de Asís. A group of ailing neophytes was sent to the new location, and when their improvement indicated the value of the project it was determined to establish a small mission community there. At first only an *asistencia* to the mission at San Francisco, San Rafael soon became self-sustaining and came to be considered an independent mission. It was a plain building, long and low and unornamented, obviously designed for utility. The adobe walls, unprotected, crumbled rapidly away after secularization, and no remains exist today. On the site of the mission chapel a Catholic church stands, and all around the site of the mission and its *embarcadero* grew the pleasant city of San Rafael, county seat of Marin County.

The last of the twenty-one missions, San Francisco Solano was founded in 1823 in the present city of Sonoma. One hundred of the people at Mission San Rafael were sent to establish it. The timber church they set up at first was followed the next year by the handsome structure that remains today. It was only ten years later that the move to secularize the missions began. At that time, colonists were sent from



FIG. 3. Sonoma Mission (Misión San Francisco de Solano), completed July 4, 1823. *Photo courtesy of San Francisco Chronicle.*

Mexico to take over the agricultural activities of this youngest of the missions, and in order to protect the new colonists, soldiers were sent from the presidio in San Francisco, hence the mission soon became a *pueblo* and was later the scene of the brief episode of the Bear Flag Republic. The church passed through several hands until in 1903 William R. Hearst purchased it and presented it to the State of California.

The whole history of the missions in Alta California covered a period of only about sixty-five years, dwindling away in the years of secularization that followed. The efforts of Padre Serra and his successors were untiring, and they showed remarkable administration as well as devotion. These religious leaders created prosperous domains peopled with large numbers of converted Indians. They amassed property worth millions of dollars in land, stock, and produce. Workers in the many industries had been only yesterday primitive tribesmen but they learned from the mission teachers, as well as from experts in various industrial fields who came from Mexico to instruct in specialized arts, to create excellent products of many kinds—cloth and blankets, pottery, tiles, sun-dried and burned bricks, farming implements, soap and candles—all the articles needed in the daily life of

the community, as well as furnishings for the buildings, made in the carpenter-shops. Some of these, designed for use in the churches, showed much fine and skillful carving. It was a remarkable and at least partially successful educational experiment. The material prosperity attained was, however, far in advance of the permanent advantage to the Indians.

The doom of the missions was sealed when in 1821 Mexico revolted against Spain and set up an independent republic. Spain's energy had been failing for years and the new world, like the distant regions of the Roman Empire, was too remote for slack control. California had been found a delightful place to live. Vast grants of land had been given to public servants, whose children and children's children settled into comfortable estates. New settlers of good quality had made homes in the rich valleys. The period of Mexican control was entered upon under most favorable circumstances.

Most of the landowners were of Mexican heritage and the new regime was satisfactory to them. With the Franciscan fathers at the missions it was different. They were nearly all cultivated scholarly men from Spain, conservatives at heart and opposed to the overthrow of Spain in the new world. Like the loyalists in many other revolutions,

they did not yield in spirit to the new government, though outwardly they were bound to obey its mandates.

The Mexicans were understandably jealous of the power of the Franciscan fathers as well as the great wealth amassed under their rule, and they very soon began to consider secularizing the missions, though the project presented inevitable difficulties. Indian converts, accustomed to the rule of their Franciscan teachers, could hardly be expected to shift their submission to a new set of masters. However, Mexico decided to take the step, and after 1833 power was stripped from the fathers and the missions were reduced to parish churches. The padres tried to leave things in order when they departed, but mismanagement soon destroyed the structure that had been slowly built up during the sixty-three years of Franciscan control. No government could take the place of the religious fervor which had been the strong sub-structure of the missions.

Naturally the breaking-up of the mission foundations supplied rich sources of wealth for new officials, and unlimited opportunities for greed and graft. Although the Mexicans based the secularization on the theory that the mission lands should be returned to the Indians and the neophytes freed from what was, in Mexican opinion, virtual slavery, in practice the Indians derived little good from the change. Deprived of the guidance of the padres who had directed their whole existence, they hardly knew what to do with the little learning they had acquired. They became debased, and few of them were willing to go to the trouble of maintaining the life they had been trained to live.

As the missions weakened and disappeared, other strong forces were gathering in this region of destiny. A few settlers other than Spanish began to appear. In order to acquire land it was necessary for them to become naturalized citizens, and most of them embraced Catholicism, married the daughters of landowners and became landowners in their own right. The first foreigner to settle permanently within the limits of these San Francisco Bay counties, and indeed in all of California, was one John Cameron, a native of Invernesshire in the north of Scotland. He chose to follow the sea as a quite young man, and in 1813 he was one of the crew of a ship that entered Monterey Bay. Apparently he was suffering from scurvy, and let his ship sail without him, later making his way through some pass to the Santa Clara Valley. He ceased to use the name to which he was born and used instead his mother's name, Gilroy. In 1821 he married the daughter of Ignacio Ortega, a well-to-do landowner, received land and settled down to a long and comfortable life in the valley around the present town that bears his name.

On San Francisco Bay the forerunner of the city of San Francisco began to appear when Captain William A. Richardson, an Eng-

lishman, left his ship and arrived at the presidio which already was under Mexican control. Governor Sola, last of the Spanish governors, had not yet left his post, and Richardson, who was a master mariner as well as an expert in shipcraft, had obtained the permission of the retiring governor to remain at the presidio in return for teaching the soldiers the art of navigation. The bay appeared to Richardson as the strategic feature of the whole California coast, and he presently began to develop communication and trading by water among such bay communities as the San Francisco settlements and the missions on the southern end of the bay.

Comandante General Vallejo recognized Richardson's value as a pilot and navigator, and made him captain of the port with authority to choose the situation he thought most fitting to develop port facilities. Captain Richardson chose Yerba Buena, the little cove under Telegraph Hill, and thus he became the founding father of San Francisco, setting up the first dwelling in the form of a tent on the gentle heights above the cove, about where Grant Avenue passes between Washington and Clay Streets today. This was in 1835. After three months the tent gave way to a board house, and a year later a still larger and finer dwelling housed Richardson's family. At first he had no nearer neighbors than the mission and presidio, but in 1836 Jacob Leese, Yankee settler, arrived. Eight years later the port was provided with a customs house on the plaza of the new town, now Portsmouth Square.

Before California became a part of the United States, however, she was destined to undergo in part another foreign incursion under the Russians, who entered peacefully in 1812 and remained for thirty years, making for themselves a settled industrial and agricultural community in the region of Bodega Bay.

Russia had been personally concerned with the western world and its potential richness ever since Admiral Vitus Bering's voyage in 1741, when he discovered the narrow strait between Siberia and North America. He discovered Alaska too and recognized the richness of her seas in fur-bearing seals. Naturally the Russians applied themselves to the development of that source of wealth, and by the end of the eighteenth century, they were well established in the Aleutian Islands and in Alaska. It is certain that the activities of Russia in those northern waters and fear of her inevitable expansion to the south spurred Spain to her efforts to colonize and develop Alta California.

The Russian colonies, centered at Sitka, had an unlimited field for exploitation in their waters. The Russian-American Fur Company became very rich, but the communities suffered great hardships. The colonies were remote from trade routes, and food supplies were extremely difficult to obtain. It was natural that California,



FIG. 4. Early French drawing of Fort Ross as it looked in 1828. *Reproduction courtesy of San Francisco Chronicle.*

blessed by climate and fertility, should appear to Russia as the natural answer to her needs.

A chamberlain of the Czar of Russia, Count Nikolai Rezánoff, arrived in Sitka in 1806 and found the community in serious danger of ruin. The people were starving, scurvy was rife, and remedies were unobtainable. Rezánoff knew that the Spanish permitted no foreign entry into San Francisco Bay and forbade foreign trade, but this was an emergency, and he felt that an exception would certainly be made and aid would be given. Accordingly he appeared at the presidio and presented his petition. He was received with courtesy although anybody would have surmised that his visit portended a possible attempt to establish a settlement in California. Ostensibly, however, he came only to seek relief for the starving settlement at Sitka, and in that quest he was successful. He was also successful in winning the heart of Concepción Argüello, the daughter of the Comandante of the Presidio. Their betrothal, which was of the utmost diplomatic advantage to the Russians, was, however, not followed by marriage. Rezánoff returned to Sitka with his cargo of necessities and set out on his return to St. Petersburg but he met with a fatal accident on his journey across Siberia. Concepción Argüello entered a religious order and devoted her life to deeds of mercy.

The next Russian visitor was an agent of the fur company named Kuskoff. He was definitely committed to make at least temporary set-

tlements on the California coast with the purpose of planting and harvesting some crops to relieve the continued needs of Sitka. Rezánoff had made careful observations in 1806, and following these Kuskoff chose the bay which had been discovered in 1775 by Juan Francisco de la Bodega y Cuadra and given his name, fortunately abbreviated. In addition to the little settlement Kuskoff placed on Bodega Bay, he chose another site a few miles inland in the Salmon Creek Valley. The Russians stayed long enough on this first entry to plant and harvest a crop of wheat, and to kill an enormous number of sea otter, and then, laden with grain and otter skins, they returned to Alaska.

In 1812 Kuskoff returned with another party to the Bodega country and peacefully annexed the entire territory. The Russians partook somewhat of the nature of squatters on the land, but they were friendly to the inhabitants and carried on their own business without inconveniencing anybody. An old Sonoma County report gives the Russian occupation credit for being the only instance in which the original owners were ever paid anything for their lands. An agreement was drawn up, to which the Indians were apparently glad to subscribe, to exchange the broad lands of Sonoma County for three pairs of breeches, three hoes, two axes, and four strings of beads. In early September, 1812, the Russians took possession of the province so generously paid for. In 1841, having cleaned out all the

fur-bearing seals in the region, they sold all that was left of Russia in America to the Swiss empire builder Sutter for thirty thousand dollars.

In the interval of thirty years, the Russians had maintained an orderly and effective domain. Fort Roseia, the third settlement established, became headquarters for Governor Kuskoff and his three successors. It was built on a bluff above a little cove about twelve miles north of the mouth of the Russian River, which they called by the name Slavianki. The name Fort Ross grew out of the name Roseia, but no trace seems to be left of the name Roumiantzof which was applied to the whole Russian realm.

The stronghold on the bluff overlooking the sea, was strongly built of timber from a nearby redwood forest. A stockade of thick planks enclosed a rectangle about two acres in extent. Two angles of the rectangle were provided with eight-sided blockhouses, two stories high, with conical roofs. Another angle contained the Greek Catholic chapel, which was really a part of the fortification because its two outer walls formed part of the stockade. There were two domes, one eight-sided, the other circular, and a Russian cross crowned the sturdy little structure. There were barraeks and officers' quarters among the nine buildings within the walls, and outside there were at least fifty buildings—shops for various crafts, stables, and a landing and boat-house on the beach below.

Many of the colonists were Aleut Indians, and the Russians and Aleuts alike mingled freely with the native Indians. They were resourceful, industrious, and self-sustaining. In spite of the prohibition placed by Spain on commercial relations with foreigners, it was not long before a flourishing contraband trade was carried on almost openly between the Russian squatters and the Spanish settlers on San Francisco Bay. The Spanish did not like the foreign encroachment, but did very little to prevent it. Probably anxiety in regard to these northern neighbors influenced the establishment of the two missions north of the bay, and certainly it hastened somewhat the settlement of Marin, Sonoma, and Napa Counties.

After the revolution the Mexican authorities liked the Russians no more than the Spanish had, and even the United States, with no immediate personal stake in the matter, regarded the Russian foothold in California as a menace to the western hemisphere. The Monroe Doctrine recognized this menace as well as those that endangered the South American countries.

It was not, however, any unfriendliness of her Californian neighbors nor any political consideration that led to the withdrawal of the Russian colonists in 1841. It was a simple matter of economics. The waters had been pretty well denuded of furbearing seals and otters by ruthless exploitation. As a purely agricultural community the

settlement was too remote to be useful to the mother country, and accordingly orders were given to sell the physical possessions of Russia in California and depart. An offer to the Mexicans in Yerba Buena was refused. Consequently the opportunity to purchase the Russian holdings was given to Sutter for a consideration of \$30,000, and they became a part of the brief but important empire, New Helvetia.

Four Russian governors had been resident at Fort Ross—Kuskoff, Klebnikoff, Kostromitinoff, and finally Roteloff, who is said to have given the name of his beautiful wife Helena, Princess of Gagarin, to the high peak in the Mayaemas Ridge at about the junction of Napa, Sonoma, and Lake Counties. This is one of several ways of accounting for the name of Mt. St. Helena. Another often repeated story, probably apocryphal, gives the Princess Helena herself credit for the achievement of climbing to the top of the mountain and on its summit naming it for the patron saint of Russia, as well as of herself. A third account states that the Yankee ship-captain Stephen Smith acquired from the Russians when they withdrew a boat with the name St. Helena painted on her bow, and that he christened the mountain in honor of his boat.

Some Russians, it seems certain, whether or not including the Princess Helena, climbed to the commanding peak, for they left a copper plate engraved with the date of their visit, June 1841. The plate was discovered and removed in 1853 and a copy of it was preserved; the original was destroyed in the San Francisco fire of 1906. A reproduction of it, on an octagonal metal slab, is displayed at the observation tower on the top of the mountain. Besides the date the slab bears the word *Russians* and the names of two persons, E. L. Voznesensky III and E. L. Chernieh, who have been supposed to be members of the party, who, presumably with Roteloff, climbed the mountain.

During the Mexican period, while the Russians were still at Fort Ross and Mariano Guadalupe Vallejo at Sonoma was the most important Californian north of Monterey, an infiltration of foreign settlers began to appear. Many of these married the daughters of Californian landowners, after becoming naturalized citizens as well as Catholics, and settled down on land grants for the rest of their days.

The well-known Wolfskill party which had immigrated to Los Angeles over the Old Spanish Trail in 1831 had numbered some members who wanted to continue to the north. Some of these were among the earliest settlers in the counties north of San Francisco Bay. George C. Yount, a native of North Carolina, was the earliest to arrive. He had come from Los Angeles by degrees, working his way at different trades. In 1833 at Santa Barbara, he made what were probably the earliest shingles in California. Then he did a little trapping, and late in 1833 he appeared at the two missions on the north side of the bay,

where his various skills were put to work at repairing the buildings. He made shingles here, too, for the Sonoma home of General Vallejo.

Anticipating making his home in California, Yount was baptized at San Rafael and his name became Jorge Concepción Yount. In 1835 he went to the Napa Valley, and the next year the first land granted in the region became his—Rancho Caymus, 11,814 acres in the heart of the Napa Valley.

At first Yount had no other neighbors but the Indians and they became his friends. In order to protect himself and the neighboring Indians, who were friendly to him, from forays of hostile natives he built a blockhouse with living quarters above and a fortification below. He kept it well stocked in case of emergency, but he seldom had to use it. In 1837 he built an adobe fort to take the place of the earlier timber one. His rancho was important as a community center—he built a sawmill and a gristmill among other enterprises, and his home was long a welcome stopping place for travelers in the north bay country.

In 1843 another great land grant, the *Rancho Carne Humana*, in the Napa Valley was given to Dr. Edward Turner Bale, an English surgeon who had been practicing both privately and for the Californian army for several years in Monterey. He had been naturalized in 1841 and had married a niece of General Vallejo. Dr. Bale was a cultivated man and lived a country gentleman's life. His well-managed acres were fruitful and he amassed a comfortable fortune. He had a sawmill and also built a gristmill between 1840 and 1842 which for twenty-five years ground the meal for the settlers in the Napa Valley. This mill with its great water wheel has been very successfully preserved and restored and is a frequently visited landmark close to the left side of the highway three miles northeast of St. Helena on the road to Calistoga.

Thus between 1835 and 1840 in addition to the growing Spanish population in the north bay country settlers of various nationalities arrived: a Frenchman, Victor Prudon; Scotsmen, John Wilson, James Scott, and Mark West; Irishmen, Edward McIntosh and Tim Murphy; Englishmen, J. B. R. Cooper, James Black, and James Dawson. There were Americans too—Henry Fitch, Jacob Leese, the several Wolfskills. The Californians were glad to have this bulwark of settlers between their more important settlements and the Indians to the northeast.

The settlers, however, who looked into the future and came to play a conspicuous part in the American possession of California were not these comfortable newly made nationals of Mexican California in the northern valleys. The two outstanding foreign settlers during the Mexican period acquired land in the great central valley—

the New Englander John Marsh who bought his huge rancho at the foot of Mt. Diablo in 1837, and Johann Augustus Sutter who appeared in Yerba Buena in 1839 preparatory to creating his New Helvetia on the Sacramento.

John Marsh was a unique pioneer. A graduate of Phillips Academy and of Harvard, he represented the intellectual tradition of New England. Six generations of New Englanders were behind him. With his two diplomas which he is said to have cherished, he set out to the West after his graduation from Harvard in 1823, and spent some years at various occupations in the Indian country of Minnesota and Wisconsin. He had a common-law wife, half French, half Sioux, to whom he was devoted until her death, after which, leaving a son, Charles, with a kinsman in Illinois, Marsh set out for the far West.

He kept a store at Independence, Missouri, for a time, but it was a disastrous failure and his departure from Independence was practically flight. He was then thirty-six years old, and stripped of almost everything but his diplomas. He made his way through New Mexico and succeeded in joining a party of explorers on the way to California, and in February of 1836, he reached the *pueblo* of Los Angeles which was then the capital of Alta California—although living conditions there were so poor that the governor had his home in Monterey.

The Mexican government in California was not going well. It was a hotbed of intrigue and subject to frequent insurrection. Marsh had no intention of remaining in Los Angeles, but he had to appear before the *Ayuntamiento* there to register as a foreigner. He stated that he was a physician and surgeon, and presented his diploma to the officials, who happily for him were not able to read much of it, but recognizing that it had been given by Harvard they accepted it for the medical degree he had claimed and issued him a license to practice—the first licensed physician in California.

He began his medical career there finding ample opportunity to gain experience. There were about fifty foreigners in the *pueblo*, and they were glad to have a doctor settle there. He managed to provide himself with plenty of vaccine against the prevalent smallpox, quinine, and brandy. His fees were paid in hides, each worth about two dollars.

Marsh had no desire, however, to stay long in the southern *pueblo*. He aspired to own a rancho farther north, and before long he sold his hides for about five hundred dollars and started for Yerba Buena, which was now going by the name of San Francisco much of the time. It was hardly more than a village when Marsh arrived, above a pleasant beach at high tide, mud flats at low. There were only three buildings—Richardson's *Casa Grande* the most imposing. Jacob

Leese who lived and kept a store next to Richardson opened his house to Marsh for many weeks.

Revolution and anarchy made great confusion among the Californians. Marsh could see clearly that Russia or the United States would inevitably annex the loosely governed country. He had chosen California for his home, and he greatly hoped that it would be the United States that would bring order out of the chaos that existed.

Early in 1837, having filed papers for naturalization and having been baptized a Catholic with the new name Juan Maria, Marsh bought a great rancho called *Los Meganos* (the Dunes), which had been granted to José Noriega two years before. Noriega had come to dislike the wildness and remoteness of his great territory, which extended from the base of Mt. Diablo to the San Joaquin River nine miles away. Marsh took possession of *Los Meganos* in the spring of 1837 and there he lived until he was murdered in 1856 by squatters who were stealing and killing his stock and attempting to take his land.

During the two decades he lived at his rancho, Marsh played an influential part in the development of California. His medical practice grew. Wealthy Californians as far away as Monterey and Fresno would insist on his coming when illness struck, and he must have had inherent skill, for he seems to have given satisfaction. His clients paid him well, and in addition his crops and stock flourished and he became very prosperous. He was always a friend to the Indians, who rewarded his friendship with loyalty and eagerness to be of use to him.

In 1839 Johann Sutter was granted his immense province on the Sacramento River. He and Marsh, though neighbors, were not always friendly although they were in regular communication, and Sutter sent Marsh medical cases he felt unable to deal with in spite of the great medical dictionary he kept at hand in lieu of a physician.

Marsh's desire to have the United States move in on California came more and more to possess him. He wrote many letters to eastern acquaintances urging them to migrate to the West, describing California as if it were Paradise. Once he was arrested for his efforts to encourage American settlers to make their homes in what the Californians reasonably considered their own country. Naturally his efforts at propaganda were unwelcome, but he went on quietly working toward annexation by the United States. The Bidwell-Bartleson party was organized largely as a result of Marsh's letters.

There were many more visitors now. Frémont and Kit Carson stopped at *Los Meganos*, and all these Americans foresaw an enormous wave of immigration. It was Frémont who gave the name Golden Gate to the *Boca del Puerto de San Francisco*, and it was said that he prophesied that the wealth of the world would flow in through that narrow passage.

The President of the United States, James K. Polk, was an expansionist and he intended to acquire California by revolution, purchase, or war. Even if war had not been determined on, however, it could have been only a little while before California would have passed relatively peacefully into the hands of the stronger nation. The whole country was seething with revolt. Mexico had sent a new governor, Micheltorena, with an army of convicts to take over the government from Governor Alvarado, who with Castro, was friendly to Americans. Micheltorena put Sutter in charge of the army of the northern frontier, hence Sutter, and under him, Marsh, being a loyal Californian, found himself an enemy of the American settlers. This alliance with the new governor was especially painful to Marsh who had been on most friendly terms with Alvarado, the deposed governor. It turned out that Marsh with one hand was cooperating with the government officials to keep the Americans out of California while with the other he was doing all he could to further the cause of American annexation.

He was not, however, by any means in favor of the action taken by Frémont's band of adventurers combined with a not very presentable group of settlers in the Sacramento Valley. On June 14, 1846, thirty-three of these oddly assorted insurgents seized General Vallejo's fortified headquarters at Sonoma and, forgetting that Vallejo had been the best friend the Americans had, took him prisoner, as well as his brother Don Salvador and Victor Prudon, the French settler from the Napa Valley. These peaceable Californians were submitted to the indignity of imprisonment at Sutter's Fort.

The insurgents raised a flag at Sonoma and proclaimed the California Republic. They could not use the American flag since this seizure was entirely their own unauthorized idea, but they created a new flag—a bear on a white field, and it waved proudly over the fort at Sonoma.

Marsh was shocked at this ill-timed violence, knowing that it had permanently destroyed the goodwill of the Californians toward the Americans. He set off for Sutter's fort where Vallejo was confined. During the night of his arrival, however, news came that Commodore Sloat had raised an American flag at Monterey, that another was floating at Yerba Buena, and that, although America was officially at war with Mexico, a bloodless conquest had taken place. At dawn twenty-one guns saluted the Stars and Stripes that rose over Fort Sutter.

After the annexation by America and later the discovery of gold, the whole picture of California was changed overnight. Marsh became one of the argonauts. His Indian friends were of inestimable advantage to him, with their special knowledge of the valley and mountains. He washed gold from the Yuba River near Marysville, and from



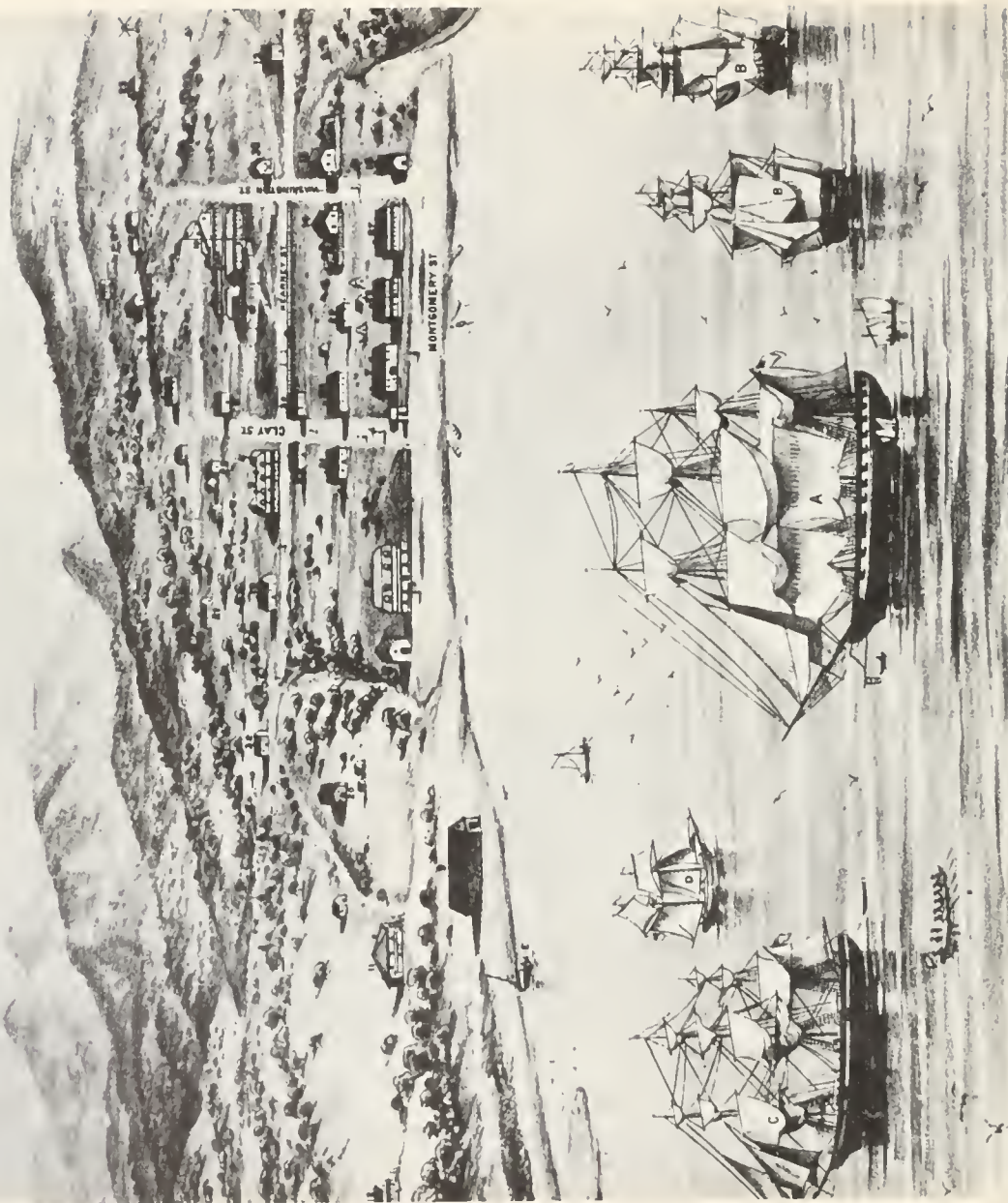


FIG. 5. San Francisco, originally called Yerba Buena, as it was in March, 1847. Reproduction of a drawing by Cabot W. F. Searcy, *George Hyde, and others*, courtesy of *San Francisco Chronicle*.

Marsh's Diggings, later called Park's Bar, he carried home to *Los Meganos* \$40,000 worth of gold. This he concealed so thoroughly that though it was diligently sought for after his death it was never recovered.

Marsh preferred to live at his adobe in the valley with his gold salted away, rather than to seek for more. He was now a very rich man and he wanted to establish a family. This unique pioneer with his New England heritage and education had almost absurdly good luck in finding the only woman in California who could have fulfilled his high requirements. Almost by chance he met a young woman from Massachusetts who had suffered from a cough and had come out to Santa Clara with a group of Baptist missionaries, combining benefit to her health with a little teaching. She was good-looking, accomplished, religious, and fond of adventure. She was fascinated by the pioneer with the Harvard background, his varied history, his riches. They were married in 1850 and lived happily and increasingly prosperously.

Marsh had every thing now, a great estate, a wife, presently a daughter. He began to plan and build the finest house in California—the Stone House that remains today on the Marsh Creek Road about four miles from Brentwood in Contra Costa County. It was a fine manorial house in English style, with arched windows, gables, a piazza on three sides with ornamental pillars, a living-room forty feet long with a white marble fireplace.

Marsh's good fortune ended, however, before the house was occupied. His wife died when their child was four years old, and Marsh had no taste for living in the Stone House alone. His son, Charles, whom he had left in Illinois twenty years before and had long thought dead, appeared and was with his father for a time and later lived in the mansion Marsh had built at the height of his prosperity.

Marsh had serious difficulties with squatters who tried to possess themselves of his lands, and with some Mexican *vaqueros*. It was one of these who surprised and killed him on the road from his ranch to Martinez in 1856.

The other settler, in the great central valley whose fortunes were irrevocably bound with the growth of California, was the Swiss Johann Augustus Sutter. He was born of Swiss parentage in the German town Kandern. At twenty-three he married, bought a house, and set up a business in cloth and yarn. By nature he was expansive, and his business grew too large for him. He failed utterly, undone, as he was years later in California, by over-development. A warrant was out for his arrest for debt, and he fled to the United States leaving his wife and several children until such a time as he might be

able to repay his debts and make a new start. It was fifteen years before he saw his family again.

Sutter reached New York in July 1834, and with the idea of becoming a farmer, proceeded west to Missouri, where the lure of the far West overcame him and he set out on the trail to Oregon, expecting to use it as a step to California. His route to the Sacramento River was as devious as the seapaths of Ulysses returning from Troy. In Ft. Vancouver he was informed that the surest means of reaching San Francisco Bay was by way of the Sandwich Islands.

And once in Honolulu his opportunity to gain passage to Yerba Buena was very slow in appearing. He employed his time by making friends with influential people, hoping to suppress the story of financial disaster in Switzerland. Like John Marsh he invented a career, successfully representing himself as an army captain.

It was five months before he could get away, and then only by managing to finance the purchase of a brig, the *Clementine*, which he loaded with freight to make it pay for itself. He sailed in April 1839 for Sitka, where he knew his cargo would be eagerly bought.

During the month he spent among the Russians, Sutter's dream of colonizing in the Sacramento Valley was born. He studied Kotzebue's account of his survey of the Sacramento to the mouth of the American River in 1824, and also Belcher's exploration of the river in 1837. Without the careful directions in Belcher's survey he declared he never would have been able to navigate the difficult entrance to San Francisco, for at the time of his arrival the weather was very bad. He did effect his entrance, however, and anchored at Yerba Buena on the second of July, only to be summarily informed by port authorities that this was not a port of entry and he should try his luck at Monterey. This he did, with better success. He had letters of introduction from influential people in Honolulu, and Governor Alvarado was glad to have a reputable settler for the interior valley. So far there were no inland settlements, and Alvarado considered that a quieting influence would be useful in the upset state of affairs in Mexican California. Sutter was told to go and choose his land and return in a year to become a citizen and apply for his grant.

The *Clementine* was too large to use in the Sacramento, so he arranged to sell her, and chartered a little schooner, the *Isabella*, manning her with a crew made up of two German carpenters he had brought from Honolulu, several odd sailors and mechanics he picked up in Yerba Buena, and eight Kanakas who had been presented to him by King Kamehameha in the Islands. These last he had offered to pay off and return whenever they wished, but they never had any desire to leave him.

With the *Isabella* and two more small boats Sutter set out to explore Suisun Bay for the mouth of the river. When this had been



FIG. 6. The stone mansion built by John Marsh in 1855 still stands close to the Marsh Creek road a few miles south of Brentwood, Contra Costa County. *Photo courtesy of Pacific Gas and Electric Company.*

accomplished the rest of the journey proceeded without undue difficulty. There were occasional meetings with Indians but Sutter was successful in dealing with them.

The beginnings of this project were so small that it is matter for amazement that the empire, once started, grew so rapidly.

In August, 1840, Sutter went to Monterey to complete his naturalization. In being confirmed a citizen he was appointed judge and representative of government on the frontier at Rio Sacramento.

By 1841 New Helvetia, as the settlement was called, was no longer an experiment. In June of that year Sutter went back to Monterey to receive his grant from Alvarado—a mighty gift, eleven square leagues of fertile valley and foothill land.

When he reached home, unquestioned master of his domain, he began to build his fort, surmising that he might eventually need it for protection against Californians as well as Indians. There was a large house surrounded by eighteen-foot walls, two and a half feet

thick, which enclosed a space of 75,000 square feet. Within the walls were barraeks, dwellings, workshops, a bakery, a mill, a blanket factory. Without, there was a tannery near the landing, and a wide scattering of eabins for *vaqueros* and other laborers.

The fort, which took four years to build, was provided with twelve cannon. There was no organized religion. Sutter himself officiated at marriages, and burials. He administered the community rather as a patriarch, dispensing justice and ordering the life of his people in an effective and kindly fashion. There was an abundance of good food, and although the working day began very early in the morning there was a comfortable rest in the heat of the day.

On the fourth of September, 1841, a Russian schooner appeared at the landing. Governor Rotchhoff had come from Fort Ross to offer the Russian properties in California to Sutter. The fur business had come to a standstill and he had been directed to withdraw the colony. Anxious to finish the transaction he put the modest price of \$30,000

on the whole establishment—building, chattels, livestock, even the schooner *Constantine* in which his party had come up the Sacramento. Very little was said about the land itself. Russia had actually never held any title to her domain.

Sutter loved expansion and recognized a bargain. He went back to Bodega with Rotchoff to make the agreement official. It was arranged that he should pay \$2,000 down and the rest in yearly shipments of wheat and other products, to transport which Russia would send a vessel. A formal banquet was held and Sutter was toasted as the new owner of Ross and Bodega.

In after years Sutter is said to have regretted that he did not move his community to Fort Ross. Although the Gold Rush was initiated on his own property, the gold first discerned in the race of his own mill by one of his own workmen, it ultimately ruined him and spoiled the empire he had wrested from the wilderness. At the time of the purchase of Fort Ross, however, he did not have enough cash at hand to buy from Mexico the title to the Russian holdings.

And New Helvetia had some years to flourish before its end marked the beginning of California as we know it. Sutter's empire increased rapidly, year by year. The community grew in fame as explorers who were now finding their way across the Sierra Nevada stopped for provisions and rest. Sutter was famous for his ready aid to these travelers, and the comfort of his shaded, well-ordered community must have been the greatest refreshment. The Chiles-Walker party was among his guests in 1842 and in 1844 Frémont and Kit Carson stopped in the course of their second expedition. In 1846 Sutter had the opportunity to send help—too little and too late to avert disaster, but nevertheless indispensable to the survivors—to the Donner party caught in the grasp of winter on the eastern side of the Sierra summit.

The Californians, although they liked Sutter, were not blind to the danger presented by his power. It was a warning from Vallejo concerning the growth of New Helvetia that had precipitated the sending of Micheltorena to supersede the Alvarado-Castro party. Sutter was obliged to support Micheltorena throughout that episode which closed with the battle of Cahuenga, after which both Micheltorena and Alvarado were removed.

In 1846 President Polk declared war on Mexico. Sutter was in favor of the United States, but could not forget that he was a Mexican citizen, hence he could not take part in the revolt of the settlers. He played a passive part, but was very glad to take the oath of allegiance when the annexation occurred, and to see the American flag waving over his fort.

In 1847 everything was promising and profitable in New Helvetia. Sixty houses were clustered around the fort, all kinds of industries flourished. There was an enormous harvest of wheat. Hundreds of head of livestock pastured in the fields. Everything that could be produced or manufactured found a ready market, and there was need for more of everything—more sawmills—more gristmills.

The sawmill that was building in January 1848 near Coloma on the American River was the scene of the beginning of the end of Sutter's empire. The gold that James Marshall discovered in the mill-race did not arouse in Sutter the joyful anticipation that it spread elsewhere. Sutter foresaw what would happen, and it was only a short time until his premonitions became facts.

For a little while Sutter's fort was a center for outfitting the parties that at once began to overrun the canyons and hills, and a transportation and distribution center, but presently materials were exhausted and there was no one left to produce or manufacture any more. Everybody had dropped his tools and rushed to the diggings. Everybody was washing gold out of one stream after another.

Sutter rented a portion of his fort for a hotel for goldseekers, receiving five hundred dollars a month for it. Suddenly a real estate boom broke out on the river and the city of Sacramento was born. Sutter had fathered the town, but because of unfortunate management he was not one of those who profited. Everybody made money except Sutter. In 1849 he retired to a property he had set aside for a homestead on the Feather River, and, reunited with his wife and children, he settled down as a country gentleman. His land claims were lost in the readjustment that followed statehood, and in his later years he devoted much time to unsuccessful attempts to recover some part of the fortune that had been created by him.

In 1865 Sutter's country home, the Hock Farm, was burned, and after that he made his home in Washington in order to be near the houses of legislature, whose help he still sought in his efforts to recover his fortune. Later he lived quietly in a comfortable house in the little town of Lilitz in Pennsylvania, where he died in 1880.

Like Sutter, James Marshall made nothing out of the gold he discovered, living and dying a poor man.

The old order had changed in California. From a scarcely settled outland she had grown overnight into a sovereign state. The gold Frémont had foreseen flowing into the Golden Gate from all the world was flowing out to all the world. All at once harbor, valleys, and hills were full of people, houses, cities, industries, means of travel and communication. There was no question of the fact that the Golden Gate had swung wide open.



FIG. 7. The famous *palo alto* or Big Tree (*Sequoia sempervirens*), which is on the edge of San Francisquito Creek at the northwest border of the town of Palo Alto. Portolá camped under this or a similar lone redwood in 1769. Photo by Berton W. Crandall, Palo Alto, courtesy of Palo Alto Chamber of Commerce.

## PLACE NAMES IN THE SAN FRANCISCO BAY COUNTIES

BY ERWIN G. GUDDE \*

The chief purpose of a geographical name is to identify a geographic location—a city or a county, a hill or a river, a bay or a cape. Place names are an essential element in our daily life and in our general human relationships as well as in agriculture, industry, commerce, and most other fields of human endeavor. In physical sciences like geology and zoology or in social sciences like anthropology and history, indeed in all sciences where geographic distribution is involved, place names play an important and significant role. Geographical names existed when human beings were only hunters and foragers, and as our culture grew from the primitive stages to complicated and involved processes they increased in number and importance. In the course of time these names became part of our language, reflecting the nature of the country and the history of the people.

The geographical names in the twelve counties adjacent to San Francisco Bay, considered from their origin, fall roughly into three categories: Indian names, Spanish names, and American names. The Indian names which are still in use today are in part genuine descriptive terms as used by the Indians themselves, and in part Indian or Indian-sounding names as understood or interpreted by the white man. Spanish names, unless they are descriptive, mirror more or less the religious fervor of the conquerors. American names show the universal range and the cosmopolitan nature which are essential elements in the culture called "American." † Many including Eastern Indian names, are transfer names; many preserve the name of an early settler or the first postmaster; some honor great men; others reflect the nature and history of California; still others commemorate some incident or were coined. The stock is English, but Scotch and Irish, French and German, Dutch and Scandinavian names testify to the composite character of our nation.

The civilization which the Indians had attained when the white man came required only a primitive, purely descriptive nomenclature: 'the people to our west,' 'the people who live in caves,' 'water' for a lake or river, 'clam place' for a place where they found clams. Heroic and sentimental stories behind Indian names are only inventions of American romanticists.

The three northernmost of the counties in the bay region, named when the original 27 counties were created on February 18, 1850, bear Indian names: Napa, Sonoma, Yolo. The word *napo* or *napa* apparently meant 'houses,' that is, 'village,' in the dialect of the Pat-

win Indians south of Clear Lake, and was still used in this sense in the early 1850's. The Spaniards took it for the tribal name of the Indians in Napa Valley and used it as early as 1795. The name Sonoma was apparently derived from Patwin *sono*, 'nose.' This may have been the nickname given to a chief with a prominent protuberance. The Spaniards often named a village or tribe after the name of its chief, hence Sonoma would mean 'land or tribe of chief Nose.' The tribe is mentioned as early as 1815. The interpretation of the name as 'Valley of the Moon' is more romantic but less authentic. The name Yolo seems likewise to have been derived from the name of an Indian chief. A *Rancho del Ioleo* on the south side of Cache Creek is shown on a map of 1844.

Among other important geographical names of Indian origin, those of hydrographic features are most common. This is easily explained: a lake or a watercourse meant much more to the Indians than a hill or a mountain, and their settlements were invariably located near water. The Miwok Indian ending *-umne*, meaning 'tribe' or 'people' is found in the names of several important rivers, and indicates that these were named for the Indians on their shores. Thus Cosumnes River may be translated as 'stream of the people of Cosum,' "Cosum" meaning perhaps 'salmon,' and Mokelumne River becomes 'stream of the people of Mokel.' Putah Creek, which traverses Napa and Solano Counties, was likewise named for the Indians who lived on its shore. It is only coincidental that the name resembles the Spanish word *puta*, 'harlot.' The origin of the name Gualala River in Sonoma County will probably never be satisfactorily explained. It appears to be a Spanish rendering of the German *Walhalla* applied to the stream by Ernst Rufus, owner of the Hermann (later German) land grant. Since this cannot be proved conclusively the anthropologists' theory that it comes from a Pomo word, 'where the waters meet,' cannot be discarded entirely.

Many other still existing Indian names were derived from native villages located at or near the edge of water: Suisun Bay, Carquinez Strait, Tomales Bay and Mount Tamalpais, Bolinas Bay, Acalanes [Contra Costa], Mayacmas, Cotati, Guilecos, Petaluma, Yulupa [Sonoma], Lokoya, Huichica, Suscol [Napa], Tolenas, Ulati [Solano], Ulista [Santa Clara]. Various interpretations have been offered for these Indian names but the etymology of only a few can be traced with any fair degree of certainty. Capay [Yolo], probably contains the word for 'stream,' *pais* may mean 'mountain,' and Tulcay [Napa] may be derived from *tuluka*, 'red.' *Ole* in Olema [Marin] was the Indian word for 'coyote,' and *olom* in Olompali [Marin] meant 'south.'

\* Author of *California Place Names: A Geographical Dictionary*.

† Throughout this paper quotations have been placed in double quotes ("..."); translations of foreign names in single quotes ('...'); obsolete and foreign names in italics; and county names in brackets [...] when given after a place name.

Natoma [Sacramento] contains the Maidu Indian root *noto*, 'east' or 'upstream.' Some names sound Indian, but nothing is known of their origin, as for example, Elicuera Creek [Napa], Buriburi Ridge [San Mateo], Mount Umunhum [Santa Clara].

Since these Indian names contain roots which for the most part existed before the coming of the white man, they may be considered the oldest place names of the bay region. As far as the actual geographical record is concerned, the first names were those bestowed upon coastal features by navigators and cartographers.

The oldest of these names is San Francisco, honoring the holy Francis of Assisi. The Bay of San Francisco was not discovered until 1769 but the name appears in the general latitude on maps as early as 1590. In 1595 the name *Bahia de San Francisco* was given to what is now Drakes Bay. When the Portolá expedition in 1769 saw the wonderful natural harbor which we now call San Francisco Bay they believed they had re-discovered the old *Bahia de San Francisco*, which for a century and a half had just been a vague geographical conception. The name San Francisco was also applied to the mission and the presidio when the district was settled. The pueblo, the nucleus of the modern city, was founded in 1835 and was called Yerba Buena, for the 'good herb,' *Micromeria chamissonis*, which once grew there in profusion and which also provided the name of the present Yerba Buena Island. The settlement itself was not called San Francisco until the American occupation.

Two important headlands were named in 1603 by the Vizcaino expedition. When the explorer sighted the point north of Santa Cruz on the third of January he called it *Punta de Año Nuevo* (Newyear's point) because it was the first promontory seen in the new year. When three days later Vizcaino anchored in what is now Drakes Bay, disregarding the older name, he named the bay and the point *de los Reyes*, 'of the Kings,' because it was the day of the "holy three kings." Only the cape is still known as Point Reyes; the bay is now known as Drakes Bay for Francis Drake who probably anchored there in 1579. Drake's name became identified with this port after 1625 when British map-makers began to use the name in support of the British claim to the coast of California, which had been named New Albion by Drake himself. Farallon Islands were first referred to as *Los Farallones* in 1734, although Vizcaino had already described them as "farallones," meaning 'little rocky islands in the sea.' Bodega Bay was named for Juan Francisco de la Bodega, who commanded an expedition which brought him to Alaska and which anchored in the bay on October 3, 1775.

When the Spaniards took possession of the bay region in the 1770's, many still current place names came into existence. The padres who accompanied the first expeditions usually applied the name of a

saint to a place which was reached on or near his feast day. Santa Clara, San Jose, San Andreas, San Mateo, San Bruno are the oldest of these holy names. Later inland expeditions named San Pablo for St. Paul, Sacramento River for the Holy Sacrament, San Joaquin River for St. Joachim, honored by Roman Catholics as the father of the Virgin Mary. San Rafael, named for the archangel, came into being when the mission was founded in 1817. Saints' names were also bestowed upon many minor features, such as sheep or cattle ranches of presidios and missions, and many of these names survived because they were incorporated in the names of private land grants. San Leandro, San Lorenzo, San Geronimo, San Gregorio, Santa Rosa, Santa Teresa Hills, San Tomas Aquinas Creek, San Francisquito Creek, San Antonio Creek are names which were preserved through land grant plats and papers. San Martin in Santa Clara County, however, was named by an Irishman, Martin Murphy, for his patron saint. San Carlos [San Mateo] was named in 1887 because it was believed that Portolá's men saw San Francisco Bay from the nearby hills on St. Charles' day.

Not all the "holy" names were given for holy men or women; very often the "San" was simply added to conform with the general trend. San Anselmo was named for a baptized Indian, San Ramon for a caretaker of Mission San Jose; San Quentin for a notorious Indian who was captured there in 1824. The site of the penitentiary would thus bear a most appropriate name, were it not for the "San" in front of it. Solano County owes its name to the chief of the Suisun Indians, Francisco Solano, who in turn had been named for the famous apostle in South America. Nicasio, Novato [Marin], and Tolay Creek [Sonoma] were likewise named for Indian chiefs. Pomponio Creek [San Mateo] and Canada Pomponio [Marin], on the other hand, preserve (like San Quentin) the name of a renegade Indian whose depredations between San Rafael and Santa Cruz ended with his execution in 1824.

Besides these there are in the twelve bay counties numerous descriptive and accidental names which have come to us from Spanish times, mostly again preserved through land grant papers. Point Bonita is a misspelling of *Punta de Bonetas*, so named after 1800 because the three hills there resembled the bonnets of elergymen. One was later leveled off for the erection of the lighthouse. Angel Island is an Americanization of *Isla de los Angeles*, probably the oldest still existing place name in San Francisco Bay, given at the time of the first harbor survey in 1775. The name Montara on the San Mateo coast is a pleasant sounding name, apparently without meaning; it may be a misspelling of *montosa*, meaning 'woody.' Pilar Point and Pilarcitos Lake, south of Montara, were apparently named after the pillar-like rock formations. The name Pescadero, found in Santa Clara, San Mateo, and San Joaquin Counties, meant 'fishing place'

in maritime Spanish; Carnadero Creek in Santa Clara County was probably once the sight of a 'slaughter place,' and Matanzas Creek [Sonoma] was so named because there the annual killing of cattle for the market took place. Cazadero [Sonoma] was California Spanish for 'hunting place;' but the equally melodious name Ataseadero means 'miry place.' Rodeo has become an American word for an annual cowboy show but originally it meant an enclosure where cattle were exhibited for sale. Rodeo [Contra Costa] was named after such an enclosure. *Laguna*, 'lake' and *lagunita*, 'little lake' are found in a number of place names, as specific as well as generic terms. Lake Lagunitas means literally 'little lakes lake.' Contra Costa was a name applied by the Spanish residents of early San Francisco to the 'opposite coast,' that is, Marin County and the East Bay. Later it was restricted to the latter and it really lost its appropriateness when Alameda County was created. El Camino Real is usually translated as 'the King's highway' but it actually means 'public highway' and has no more relation to the Spanish king than the American administrative unit, "county," to an English count.

Mount Diablo is one of the most important and most interesting names of the district around San Francisco Bay. It was applied by American explorers in the 1840's because they believed that *monte* meant 'mountain.' Monte, however, is the Spanish term for 'thicket' or 'woods,' and the name *Monte Diablo* was that of an Indian village at the site of present-day Concord. According to the story, this *Monte Diablo* was a willow thicket where in the early 1800's a fight took place. An Indian medicine man, dressed most fantastically, appeared from the thicket, and the Spanish soldiers, believing that the devil himself had become an ally of the Indians, beat a hasty retreat.

Many descriptive Spanish adjectives have been preserved and are still actively used as specific or generic place names in the bay counties. *Alta*, 'high,' is probably the most common, followed by *nuevo*, 'new,' *honda*, 'deep,' *caliente*, 'hot,' *buena*, 'good,' *seco*, 'dry,' *hedionda*, 'fetid,' *permanente*, 'permanent,' *gordo*, 'large,' *mocho*, 'cut-off.' Spanish adjectives of color still used are *blanco*, 'white,' *verde*, 'green,' *prieto*, 'dark,' *azul*, 'blue.'

Finally, there are a number of Spanish names which were abbreviated after the American conquest and which in many cases become meaningless, retaining, however, their pleasing sound. Cupertino [Santa Clara] was named after a creek, *Arroyo de San Jose Cupertino*; Guadalupe River [Santa Clara] was *Rio de Nuestra Señora de Guadalupe*, the patron saint of Catholic Mexico; Lake Merced [San Francisco] was *Laguna de Nuestra Señora de la Merced*.

Many of our interesting names which are neither native Indian nor Spanish were brought from Mexico and have an Aztec root. The name Tule, which is found in several geographic areas, is derived from

the Aztec name for plants with sword-like leaves like the cat-tail and the bull-rush; Stockton was once called appropriately "Tuleburg" Montezuma, the name of the Aztec chief at the time of the Spanish conquest of Mexico, was adopted in 1827 as a new name for the province of Alta California, and might have become the name of our State if the Mexican government had confirmed the name. Montezuma Landing, Hills, and Island in Solano County preserve the memory of Montezuma City, started in 1847 as one of the many Mormon settlements in the State. Lake Temescal between Oakland and Berkeley is so called because it was once the site of an Indian sweat-house called *temescal* by the Mexicans. Milpitas is derived from the Mexican word for 'truck garden,' and Pinole from the Aztec name of a dish of toasted grain prepared by the Indians of the district. Tomales Bay and Mount Tamalpais were named for the Tamal Indians, who in turn might have received their name from the Mexican *tamal*, originally a dish similar to the *pinole*. Coyote River in the Santa Clara Valley and other coyote place names contain the Aztec root *coyotl*, 'prairie wolf.' Also of Aztec or at least of Mexican origin is the word *tassajero*, 'place where meat is cut in strips and hung in the sun to cure'; it is still found in Tassajara Valley [Alameda, Contra Costa].

After the occupation by the United States the old names were scrupulously kept. Here and there a Spanish name was garbled or translated but the vast majority of all the old names which existed in 1847 were left untouched. General Vallejo in 1849 was the chairman of the committee appointed by the legislature to establish the names of the newly created counties. With one exception, Sutter, all of the original 27 counties received Spanish or Indian names.

Many Spanish names do not go back to early times but were applied by Americans who wished to preserve the Spanish flavor of California nomenclature: Mantea (butter), Avena (oats), Almonte (by the woods), Milagro (miracle), Rio Nido (river and nest), Los Altos (the heights), El Verano (summer) and the many combinations with loma (hill), mar (ocean), del rey (of the king!), camino (road), vista (view)—not always grammatically correct, but satisfying the Californians' desire for romantic names.

Most of the important Spanish and Mexican pioneers who had participated in building up the province have their names commemorated in the geography of the bay region: Alvarado and Alviso; Berryessa and Castro; Martinez, Miramontes, and Moraga; Pacheco, Suñol, and Vallejo. Benicia bears one of the names of General Vallejo's wife. Many of the American and European pioneers who settled in the bay region in Mexican times are likewise honored in place names: John Gilroy, a Scotch sailor, who came in 1814 and was the first non-Spanish settler; Robert Livermore, an Englishman who came in the 1820's and settled in what is now Livermore Valley in 1839; Johann



Augustus Sutter, a German Swiss, who was the first settler in the interior valley in 1839; Joseph B. Chiles and William Wolfskill, Kentuckians who received land grants in the early 1840's; Elisha Stevens of the famous immigrant party of 1844. Dr. John Marsh, a graduate of Harvard, the pioneer of the Mount Diablo district, is remembered in Marsh Creek; and W. A. Richardson, first harbor captain of San Francisco, in Richardsons Bay. Several places in Marin County commemorate John Black, another Scotch sailor, who became a large landholder in the 1840's. Two other early Marin County pioneers, John Reed and "Dutch Bill" Bihler, are remembered in the railroad station Reed and in Bihler Landing. Knights Landing was named for William Knight of Indiana, who settled here in 1843; Kolmer Creek and Coleman Valley in Sonoma County were named for a German immigrant in 1846, the first permanent settler of the region. Folsom [Sacramento] bears the name of Captain J. L. Folsom of the New York Volunteers in the Mexican Wars.

Numerous also are the names which keep alive the memory of pioneers in the formative period after the discovery of gold. The name of James Lick, the Pennsylvania-German piano maker and California benefactor is commemorated in Lick Observatory. The mountain on which the observatory is situated was named in 1861 for Rev. Laurentine Hamilton, who accompanied a party of the State Geological Survey to the summit. One of the finest stands of redwood in central California, Muir Woods, was named for John Muir, a native of Scotland and pioneer naturalist of California. Millbrae and Stanford, Niles and Hayward, Atherton and Daly City, Davis and Dixon, Morgan Hill and Tracy, Guerneville and Healdsburg, Bloomfield and Stinson Beach are among the better known places commemorating later pioneers. Many other equally deserving men, to be sure, are not found in the nomenclature of California geography.

These names of pioneers and early settlers reflect a part of our history. They are outnumbered, however, by place names which show the nature of the country, its flora, fauna, and natural resources. The grizzly has disappeared completely from the California scene, and the cinnamon bear is no longer found in the counties around San Francisco Bay. Yet, all these counties still have their Bear Creeks and Grizzly Peaks. The elk, the antelope, the beaver, the wolf, the coyote, the rabbit, the coon and other representatives of our native animal kingdom likewise live on in many districts only as place names. The horse and the hog, though not native in California, roamed the country in late Mexican and early American times, descendants of domesticated animals which had escaped from missions and ranchos. The Mexican word for hog, *coche*, is still found in place names in San Mateo and Santa Clara Counties. Mare Island became known as *Isla de la Yegua* when one of Vallejo's maids found her way to the

island (probably from a capsized boat) and joined a band of elk which lived there.

The most common place names originating from the native fauna are those of the rattlesnake and the wildcat. The Spanish name of the latter is preserved in Los Gatos. There are also many Deer and Deerhorn place names, and occasionally the Spanish equivalent Venado is encountered. The seals along the coast have namesakes in a number of Seal Rocks and Seal Coves, and the Spanish form of the word seal is found in Point Lobos and Lobitos Creek. The abundance of fish in the region is shown in a number of Peseaderos (fishing places), and Salmon and Trout Creeks; and along the coast we find the names Abalone and Mussel.

The name Aleatraz Island was originally applied to Yerba Buena Island because of large numbers of pelicans nesting there. Later the name was changed to Goat Island because the island was inhabited by goats, descended from a few animals which a San Francisco merchant had placed there. Codornices Creek [Alameda] was so named because some hungry Mexicans found there the nest of a quail (*codorniz*) and ate the eggs. Tiburon [Marin] is derived from *Punta de Tiburon*, 'shark's point.' Raecoon Strait between Tiburon and Angel Island, however, has nothing to do with the animal; it was named for the British ship *Raccoon* which anchored there in 1814. Even the names of obnoxious insects—the mosquito, the tick, the flea—occur in place names. Indeed, the Spanish word for flea, *pulga*, was a favorite name for places and has survived in several instances.

Even more numerous are the names given for trees, shrubs, and plants, again often no longer appropriate, but historically interesting and significant. Of the native silva the willow, the pine, and the oak are naturally represented most frequently in place names. The Spanish forms of these names are still found: encinitas is the Spanish name for live oaks, and robles the one for deciduous oaks; Sausalito is Spanish for 'little grove of willows'; Point Reyes was once known as *Cabo de Pinos*, 'cape of the pines.' The site of Oakland was known in Spanish times as *Eneinal del Temescal*, 'oak grove by the sweat-house.' The cottonwood (or poplar) is likewise found in both the American and the Spanish versions. The southern part of present Alameda County was known as *la Alameda*, 'place where poplars grow,' as early as 1795. Alamo, for the tree itself, is still actively used as a geographic name.

The proudest native tree of California along the coast, the *Sequoia sempervirens*, is represented in nomenclature in a number of Sequoia and Redwood names. The site of Redwood City was once surrounded by a beautiful stand of sequoias, but here as in other places the trees are gone and only the name remains. The city of Palo Alto (high tree) received its name from a towering redwood

first noticed by the Anza expedition in 1774. The madrone, the laurel, the sycamore are other members of our silva which are sufficiently conspicuous to have found their way into geographical nomenclature. Walnut Creek was not named because of the numerous walnut orchards there; but it owes its name to the native black walnut, having been known as *Arroyo de los Nogales* as early as 1810.

Among the native shrubs represented in nomenclature of the bay counties the manzanita is the most popular. This is because of its natural beauty, its frequent occurrence, and its melodious name. The shrub is appropriately called *manzanita* in Spanish (meaning 'little apple') because the fruit clusters actually look like miniature apples. The Indian names of three native shrubs, islay (holly-leaved cherry), chamise (greasewood), and toyon, are occasionally found as place names in this district. Islais Creek in San Francisco is probably the best known. It was once a water course from Twin Peaks to the bay lined with the islay shrub, and its name is now preserved in the estuary and the bridge. On older maps a number of localities in the bay district are called Chamisal, i. e., place where the chamise and similar shrubs grow; today we use the name Chaparral, from the Spanish *chaparo*, 'scrub oak,' to describe dense undergrowth.

Among plants with edible fruit the strawberry, here as elsewhere, is the most popular for place names. The grape, sometimes in its Spanish form, *uva*, is a poor second. The twenty-seven native species of the genus *Allium* account for a number of Onion, Leek, and Garlic creeks, hills, and flats. Mount Chual [Santa Clara] preserves the Indian name for the *Chenopodium album*, the common pigweed, valued by the natives as food.

We find reflected in the names of a country not only the stories of its exploration and settlement, its flora and fauna, but also its industrial development. The oldest name of this last group is Almaden in Santa Clara County. In 1845 Andres Castillero identified the Almaden quicksilver deposits and was granted the right of exploiting them. When the mine proved profitable the name New Almaden was applied. *Almaden* is a Spanish word for 'mine' but was used as a geographical term for the famous quicksilver mines in southeastern Spain. In 1937 the California town dropped the prefix "New."

Pittsburg, the industrial city at the confluence of the Sacramento and the San Joaquin, is the only living witness of one of the greatest mining booms in the San Francisco Bay region. When Robert Semple, in February 1848, heard of the discovery of gold at Sutter's mill he remarked dryly that he considered a good coal mine more valuable than all the gold mines. Until the wholesale exploitation of our oil resources the discovery of coal beds was foremost in the minds of mining engineers and industrialists. There were at least four heavily financed coal booms in the State before 1890—booms which

always collapsed because the coal proved to be inferior. The oldest of these was the Mount Diablo coal boom. In 1852 coal was discovered in the hills which form the northernmost end of the Mount Diablo Range, but their commercial exploitation did not start until 1858. The Pittsburg Coal Company, one of the leading organizations, had a railroad built from their mines in the hills, terminating where today is Pittsburg Landing. With the collapse of the boom Pittsburg remained as a geographical name until the steel industry after 1900 brought new life into the district and renamed old New York of the Pacific, Pittsburg, and the old Pittsburg, Pittsburg Landing. Somersville, Nortonville, and Stewartville, ghost towns on the road from Antioch to Clayton, were named for men who were interested in the largest of the mines, the Black Diamond. A fateful explosion in this mine on July 24, 1876, marked dramatically the end of the venture.

Numerous are the names which tell of the existence of mineral springs. The healing qualities of many of them had been recognized by the natives although no Indian names for them are known. In Spanish times quite a number of the springs were designated as *Agua Caliente*, 'hot water,' and some of these names have been carried over into American times. Most of these springs were not developed until the 1850's and 1860's. The majority bear the name of the owner or discoverer; others are simply called Hot Springs or Warm Springs, Mineral, Soda or Sulphur Springs. Aetna Springs in Napa County were so named because they were discovered while the owner was prospecting for quicksilver in his Aetna mine, which in turn had doubtless been named after Mount Aetna. Saratoga in Santa Clara County was named, in 1876, because the waters of Pacific Congress Springs resemble those of Congress Springs at Saratoga in New York. The name Calistoga [Napa] was coined in 1859 by Sam Brannan from *California* and *Saratoga*.

Salada Beach [San Mateo] and a number of combinations with salt and saline refer to salt deposits or at least to the salty taste of the water of stream and lakes. The Calera names in San Mateo and Santa Clara Counties, and several Lime, Limestone, and Limekiln names indicate that mining and burning of limestone was once an important industry. Other names, such as Slate, Rock, Sandstone, and Piedra, refer to rock quarries. Freestone [Sonoma] was named in 1870 for a quarry of easily worked sandstone. Several names containing the word adobe indicate the composition of the soil or the presence of an adobe building.

A number of combinations with Mill, and at least one Molino [Sonoma] (the Spanish word for 'mill') indicate the presence or former presence of a stamp, grist, or lumber mill. Mill Valley is probably the best known of these places. John Reed, grantee of rancho Corte Madera, operated a saw mill there as early as 1834 and sup-

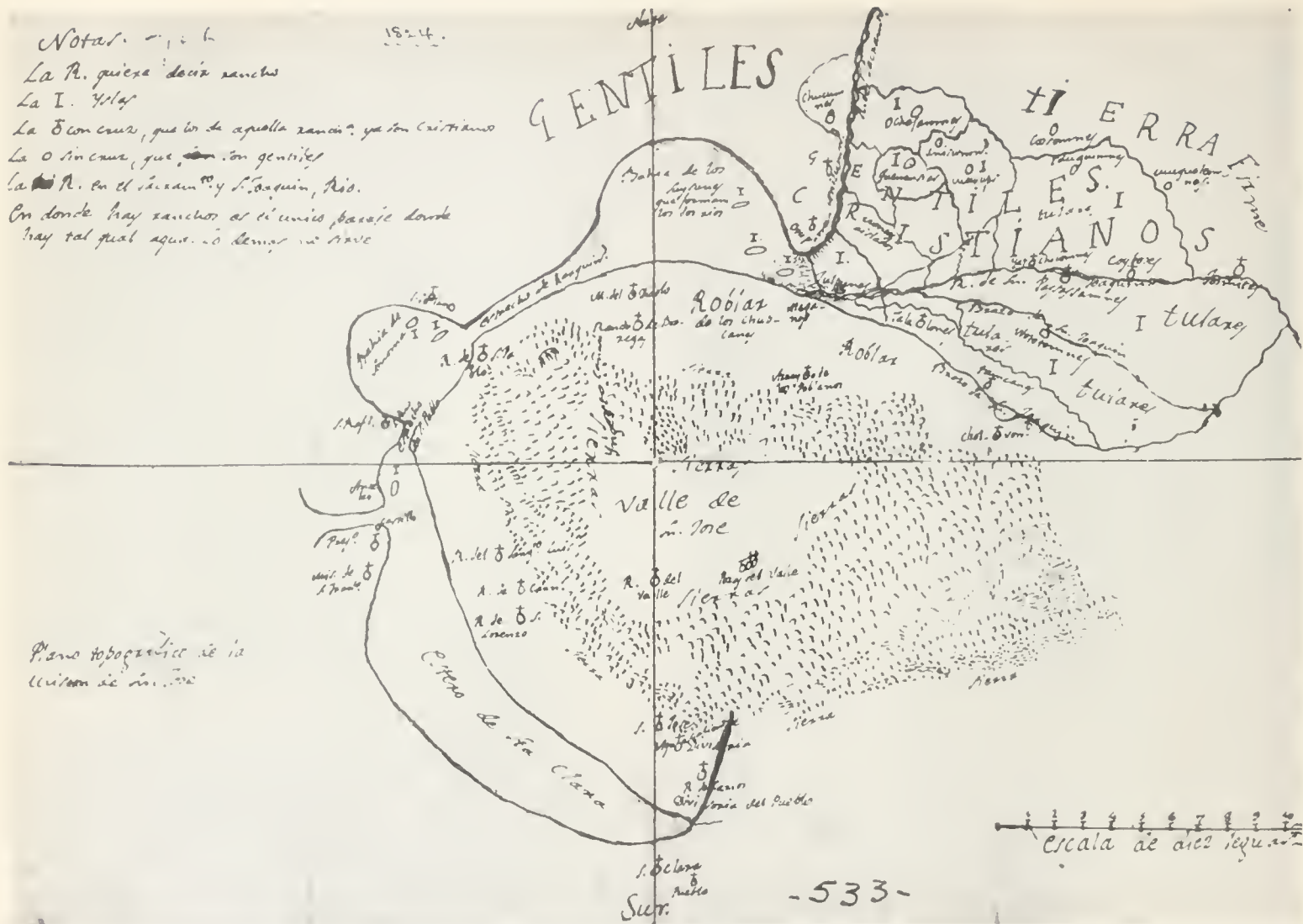


FIG. 1. Plano topografico de la Mision de San Jose. This map, made about 1824, shows many of the place names still in use today: San Rafael, Sonoma, Solano, Carquinez, Suisun, Sacramento, San Joaquin, Cosumnes, Mokelumne, Santa Clara, San Jose, San Lorenzo, etc. The lower part of the bay is called Estero de Sta Clara, and M. del Diablo is the name of an Indian village near Suisun Bay. Photo courtesy Bancroft Library, University of California.

plied most of the lumber with which the early houses of San Francisco were built. Corte Madera means 'place where lumber is cut,' and is found as a place name not only in Marin but also in San Mateo and Santa Clara Counties.

A number of places in Contra Costa County reflect the modern industrial development of this county. Associated was named in 1913 when the Tidewater Associated Oil Company built the town, and Oleum was clipped from *Petroleum* when the Union Oil Company built the refinery before 1912. The powder industry is represented by Hercules, Herpoco (from *Hercules Powder Company*), and Giant; the last is reminiscent of the early name of dynamite, giant powder. Mococo was coined from *Mountain Copper Company* which had a smelter at Bulls Head Point. Hastings Creek was named for the man who discovered quicksilver on the east side of Mount Diablo.

Often place names owe their origin to an incident. Among these are a number of points along the coast which were named for shipwrecks. Duxbury Reef and Point, west of Bolinas, were named because the *Duxbury* grounded on the reef on August 21, 1849. Just south of it the wreck of the steamer *Tennessee* in 1853 gave the names to the point, cove, and valley. Pigeon Point [San Mateo] owes its origin to the wreck of the clipper ship *Carrier Pigeon*, May 6, 1853. On Noonday Rock, one of the Farallones, a clipper by that name ran upon a submarine rock and sank within an hour on January 2, 1863. Southampton Bay, however, was so named because the U.S.S. *Southampton* led the fleet to anchorage at Benicia in the spring of 1849.

Sebastapol was named shortly after the siege of the Russian seaport of Sebastapol in the Crimean War of 1854. According to local tradition there was actually a local fight, and the general store became the Sebastapol of one party. Chickahominy Slough [Yolo] is said to have been named because two ranchers had a fight there at the time the battle of Chickahominy in Virginia was fought, June 27, 1862. A third battle is commemorated in Waterloo [San Joaquin], where there was a fight over a land title in the early 1860's. Cache Creek [Yolo] was named sometime before 1832 because Hudson's Bay Company trappers had a cache or hiding place for their furs on its banks. The name of American River was derived by Sutter from *El Paso de los Americanos*, a ford in the river where Canadian trappers, called *Americanos* by the Spanish-speaking Indians, crossed the stream. Patterson Pass [Alameda] is said to have received its name in the 1850's when Andrew Jackson Patterson and his wife were driving over the pass in a heavy wind storm which upset his wagon, severely injuring Mrs. Patterson. Austrian Gulch [Santa Clara] is reminiscent of another tragedy. In 1889 a cloudburst undermined a large winery operated by Austrians and swept thousands of gallons of wine into Los Gatos Creek.

Every country has a number of names which were deliberately coined and which defy all interpretations unless their origin is known. The siding Subect [Solano], located in a sugar-beet region, took its name from *sugar beet*. Yolano [Solano] was coined from *Yolo and Solano*, and Saranap [Contra Costa] from the name of Mrs. *Sara Naphthaly*. Calistoga, Herpoco, and Mococo have already been mentioned, and other puzzling names like Colma [San Mateo] and Orinda [Contra Costa] may be of similar origin.

The number of names in the San Francisco Bay region the origin of which may forever be shrouded in mystery is relatively small. Gualala and a number of Indian names have already been mentioned. Only two of the important names cannot be satisfactorily explained: Marin County and Mount Saint Helena.

The county was named after the Marin Islands off San Rafael. These islands in turn were named for an Indian chief called Marin, who according to Vallejo lived on one of the islands. In view of the lack of conclusive evidence of this tradition another theory seems just as plausible. The bay in which the two islands lie was called *Bahia de Nuestra Señora del Rosario la Marinera* in 1775, for the patron saint of the *San Carlos*, the first boat to enter San Francisco Bay. It is quite possible that the name of the islands, of the Indian, and finally of the county go back to the Virgin's by-name, *Marinera*. As usual in such doubtful cases there are a number of other theories about the origin of the name.

Mount Saint Helena was ascended by Russians in June, 1841, and, according to the story current in the 1860's, was named in honor of the Russian empress by the Russian scientist J. G. Woznesenski. When it was shown that the name of the empress in 1841 was Alexandra the story was changed to read that a princess, Helena de Gagarin, climbed the mountain and christened it in honor of her patron saint, the mother of Constantin the Great. No evidence has ever been produced to prove these stories. If the Russians (whose occupation of the region from 1812 to 1841 is still remembered in the names Russian River and Fort Ross) named the mountain at all, they probably did it from one of their vessels which bore the name *Saint Helena*.

A brief survey of the geographical nomenclature of as large an area as that of the twelve bay counties can naturally treat only such names as are of importance or of particular interest. It cannot even include all classes of names. There are the many transfer names from other states of the United States and other parts of the world: Albany, Menlo Park, Baden Station, Inverness, Brighton, Dublin, Fairfield, Antioch, Brentwood, Richmond, and hundreds of others. Many names of our military leaders are found in geography: Stockton, Fremont, Hooker, Halleck, Ord, Barry, Cronkhite, Funston, Baker, Winfield Scott. Some places were named for well-known

historical characters: Berkeley, Lafayette, Copernicus Peak, Tesla, Marconi; others honor men who rendered public services: Vollmer Peak, Kentfield, Hecker Pass, Tilden Park, McLaren Park, Reinhardt Meadows, Mount Davidson, Stanford. Still others are purely descriptive: Twin Peaks, Saddleback, Halfmoon Bay, Rocky Ridge.

There are, finally, those names which were chosen because of their sound or their design to be attractive and impressive. In this class belong all such international names as Piedmont, Glorietta, Montecello, Belvedere, Marina, Belmont, as well as names like Mount

Eden, Paradise Valley, and Newhope Landing, and even names containing the word devil or diablo. The greatest of such names given with the purpose of attracting and impressing is the name of the entrance to San Francisco Bay: Golden Gate. Frémont bestowed this name in 1846 in analogy to Golden Horn in Europe. He believed that the Golden Gate would play in the future a similar role for commerce as the strait between Europe and Asia Minor had played for centuries past. He did not foresee that only two years later the discovery of gold would give it new significance and importance and prove the name-giver to be a true prophet.



FIG. 2. Summit of Mount St. Helena. View southeast and downward from State Division of Forestry fire lookout tower. In the center of the fenced plot is the precisely located triangulation monument which marks the corner common to Napa, Sonoma, and Lake Counties, as well as the summit of the mountain. Two monuments and their tablets, in the right foreground commemorate the 100th anniversary of the founding of Fort Ross and the June, 1841, ascent of the mountain by the Russians Wosnesenski and Tseherneec. Other surveying monuments and weather-recording installations may be seen near the middle of the picture. *Photo by Olaf P. Jenkins.*

## INDIANS OF THE SAN FRANCISCO BAY AREA

BY ROBERT F. HEIZER \*

Aboriginal California was remarkable for the number and diversity of its Indian tribes, and the San Francisco Bay region was no exception. The bay constituted a natural boundary, and no less than four Indian nations claimed portions of its shore. The Pomo held the bulk of Sonoma County and the territory to the north. The Coast Miwok occupied southern Sonoma County and Marin County. The Napa Valley region was the heart of Wappo territory, and to the east as far as the Sacramento River the southern Wintun (sometimes called Patwin) held sway. The San Francisco peninsula, western Contra Costa County, and Alameda and Santa Clara Counties were the home of the Costanoan tribes. To the east, in eastern Contra Costa and southern San Joaquin Counties, was the home of the northerly Yokuts tribes. North along the east bank of the Sacramento River in northern San Joaquin and Sacramento Counties were the villages of the Interior Miwok, tribes using the same speech but detached geographically from their coastal relatives of Marin County. The northern portion of Sacramento County marked the southernmost territory of the Maidu tribe. Thus, no less than eight important tribes, at the time of Spanish settlement in the late eighteenth century, occupied the twelve counties which constitute the San Francisco Bay region. Members of the above-named tribes furnished neophytes for the several Spanish missions at San Rafael, Sonoma, San Francisco, Santa Clara, and San Jose.

In one important respect, topography and terrain as delimiting political boundaries were viewed somewhat differently by the California Indians than by ourselves. The Indian did not think, like a modern and literate person of today, of his people owning an area enclosed by a sharply drawn line within whose compass were so many mountain ranges and watercourses. This would have been viewing the land through a map, either actual or mental, and such maps were foreign to the natives' psychology. Tribal habitats were defined by drainage blocks. The primitive Indian knew that he had been born, and would probably die, in a village situated on a certain stream; and that this stream, or a portion of it, and all the creeks flowing into it, and all the land on or between those creeks, belonged to his people. Upstream and downstream or across certain hills were other streams and their affluents, along which other people lived with proprietary rights to their drainage area. As a result of this interpretation of surface topography, aboriginal boundaries generally ran along the

crests of hills which marked watersheds, and not, as among ourselves, down the center of streams. Thus, the apparent inconsistency between the present county boundaries and tribal lines (fig. 1) reflects alternative interpretations and utilization of environmental features. Even the Sacramento River was no exception, for the tribe which held one bank also claimed the opposite shore. For large bodies of water such as San Francisco Bay, different tribes held opposite shores.

Those tribes which lived near salt-water bodies (either the ocean or bay) placed heavy dependence upon sea products for food. Thus, their former village sites are marked by accumulations of mussel and clam shells, some of very large size. In Emeryville, on the site of the present Sherwin-Williams Paint Company plant, was an extensive shellmound measuring 1,000 feet in length, 300 feet in width, and 22 feet above the surrounding plain. The volume of this accumulation of shell, earth, ash, stone, implements, and burials was computed at 39,000 cubic meters. The total weight of the accumulation was 55,885 short tons, of which about 60 percent was shell and 8 percent ash. North along the east shore of the bay, at Ellis Landing in Richmond, was situated another shellmound with a content of 35,649 cubic meters, or about 51,085 short tons. Specific gravity of the refuse material of the shellmound was 1.3. These huge mounds of refuse left by the former occupants of the bay area have been subjected to careful quantitative and qualitative analysis in an attempt to estimate their antiquity. The average composition of 15 shellmounds around San Francisco Bay is: fishbone, 0.031 percent; other vertebrate remains, 0.055 percent; shell, 52.07 percent; charcoal, 0.22 percent; ash, 12.27 percent; rock, 7.5 percent; residue, 27.84 percent. The consensus is that the earliest occupation of these spots may have been about 3,500 years ago.

The interior tribes, whose cultures were developed around the exploitation of the Coast Ranges and Interior Valley environments, placed chief reliance upon elk, deer, and acorns for food; the shellfish used were limited to freshwater species (*Gonidea*, *Margaritifera*). Former village sites are marked by mounds of earth consisting of ash, broken stone, discarded bones of animals eaten for food, and the like. These mounds are great refuse heaps, ranging from eminences a few feet in diameter to earth domes several hundred feet in diameter and many feet thick, upon which the former inhabitants lived, and in which they interred their dead. Several of the more prominent Valley mounds contain about 50,000 cubic meters of material.

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FIG. 1. Map showing distribution of Indian tribes in area of the 12 counties of the San Francisco Bay region.

The first physical and cultural remains of which there is any record in the bay area are those of the "Early Horizon," whose estimated antiquity is about 5,000 years. This first culture is known from a limited series of burial spots enclosed in the great bend of the Mokelumne River between Thornton and Walnut Grove in San Joaquin County, but has thus far not been discovered on the ocean coast or on the shores of San Francisco Bay. The skeletal remains are so heavily mineralized as to almost deserve the term "fossilized." Following the Early period, a new culture called the "Middle Horizon" appears whose estimated dates are 1500 B.C. to 500 A.D. This is succeeded by a Late Horizon, in which a new people created different implement forms and utilized distinctive techniques of working raw materials in the production of these forms.

In order to give some objective indication of the utilization of primitive resources by the primitive peoples of the bay area,

Date *	Sequence of aboriginal cultures	
	Son Francisco Bay and adjacent coast	Interior Valley and adjacent Sierra foothills
1770 A.D.	Costanoan tribe	Maidu, Wintun, Miwok tribes
500 A.D.	Late Horizon	Late Horizon
1500 B.C.	Middle Horizon	Middle Horizon
2500 B.C. (Unoccupied?)		Early Horizon

\* Dates are approximations based on available evidence.

representative artifacts from prehistoric village and burial sites are here discussed and illustrated. The discussion below is developed primarily around the rocks and minerals used, and the industrial or technological methods employed in fashioning them into serviceable implements for household, military, or economic functions.

Literally hundreds of different rocks and minerals were utilized for special purposes by the prehistoric Indians. Obsidian (black volcanic glass) was especially favored as a material for making arrow-points, because the natural glass could be easily flaked. Outcrops of massive obsidian occur near Anadel about 7 miles southeast of Santa Rosa, Sonoma County; around Clear Lake, Lake County (fig. 3a,b); and at Glass Mountain on the east side of Napa River near St. Helena in Napa County (fig. 3c,d). Here large areas covered with chips, flakes, and rejected implements give evidence of extensive exploitation of the obsidian outcrops. Throughout the whole bay area obsidian was secured in trade from the Napa and Sonoma quarries in the form of flat flakes or "blanks" (fig. 4a-d). Aboriginal obsidian quarrying technique is shown in figure 4e. Examples of obsidian chipped implements are shown in figure 4f-i and figure 5.

Steatite or soapstone did not, so far as is known, occur in the bay area, but was imported from the Coast Ranges to the north and the Sierra Nevada to the east in considerable quantity. It was chiefly employed in the manufacture of tubular smoking pipes, spool-shaped earplugs, beads, and ornaments (fig. 6). In the vicinity of Stockton, cylindrical jars of steatite were manufactured (fig. 14k). Globular, thin-walled cooking pots, which could be placed directly on a fire, were made farther south in the Santa Barbara region. Figure 7a shows two natives working steatite: the man with a hafted pick working a blank vessel from the outcrop, and the woman hollowing out the interior of the soft stone with a heavy chipped chisel-pick.

Various tribes scraped steatite with a sharp-edged flint flake and used the dust thus produced as talcum powder. Two such scraped lumps of milk-colored steatite from the Sacramento Valley are shown in figures 11d-e. Flat pieces of sandstone ranging from sizable slabs to small slender bars were much used for grinding, abrading, and polishing of circular discs of clam shell which were the common currency of the central California Indians (fig. 7c). These were ground on a sandstone slab in the manner shown in figure 7b and drilled with a pump drill (fig. 7f). Shown in figure 14b is a flat sandstone slab with



a, Site Sac-6, near Franklin, Sacramento County.



b, Small shellmound near China Camp, Marin County.



c, Mound near Stockton.



d, Site Son-299, west shore of Bodega Bay (site is under light-colored vegetation in center to left of tents).

FIG. 2. Archeological sites.





*a, b*, The obsidian quarry at Borax Lake, near Clear Lake Highlands, Lake County.



*c, d*, Obsidian nodules in pumice mixed with Indian workshop flakes near St. Helena, Napa County.

nically squared sides and a rectangular central depression. The entire surface is encrusted with hematite, and from this it may be inferred that the slab was a palette used for grinding red paint. The flat, fine-grained, decorated sandstone pieces shown in figure 8 come from Napa Valley, and probably represent highly conventionalized human figures. They may portray infants tied in cradles with straps.

Although pottery vessels were neither made nor used, clay was modelled and fired in lumps or balls of various sizes. This rudimentary fired-clay industry was practiced in the delta region east of Carquinez Straits, where stone was absent from the alluvial-plain soils. The clay balls served as substitutes for rocks in the "stone boiling" process where mush was boiled in watertight baskets by dropping in rocks heated in an open fire. Figure 9*a,d-f* shows typical "ball" forms employed in stone boiling. Tubular pipes (fig. 7*h*) in which a species of wild tobacco (*Nicotiana bigelovii*) was smoked, and spool-shaped net-sinkers (fig. 9*b-c*), were made of baked clay.

Magnesite was quarried by the Indians in Napa and Lake Counties, and was fashioned into barrel-shaped beads which were considered very valuable. The aborigines baked the milky white chunks or finished beads of raw magnesite in the ashes of a fire to turn them salmon pink (fig. 7*g*).

Clear quartz crystals were eagerly sought and saved. From testimony recorded from recent Indians, it is known that such crystals were endowed with magical or supernatural power, and were so charged with this quality that only medicine men could safely handle and control them. Crystals were generally employed in curing illness. Figure 7*d,i,j*, and figure 12*d* illustrate quartz crystals whose sharp edges have, through some abrading process, been ground down. The terminus of one is decorated with shell beads affixed in an asphaltum mastic. It is probable that the famed Mokelumne Hill deposits were the source of these crystals.

All of the California Indians daubed their faces and bodies with colored mineral paints upon certain occasions—for ceremonial performances, while in mourning for a deceased relative, when engaged in war, and the like. Red color was most widely used, and hematite and cinnabar were mined and traded for long distances from tribe to tribe. One source was a deposit on the east side of Mount Diablo, but the main locality was the New Almaden mine near San Jose. In 1845, when a shaft was sunk and white men first began mining, there was discovered an ancient tunnel some 50 or 60 feet in length at whose face, covered with caved roof material, were several Indian skeletons and rude stone mining tools. Cinnabar lumps and powder have been recovered from prehistoric Indian graves in Contra Costa County, and it is reliably attested that as early as 1800 some of the Columbia River tribes, among them the Walla Walla, knew of the New Almaden

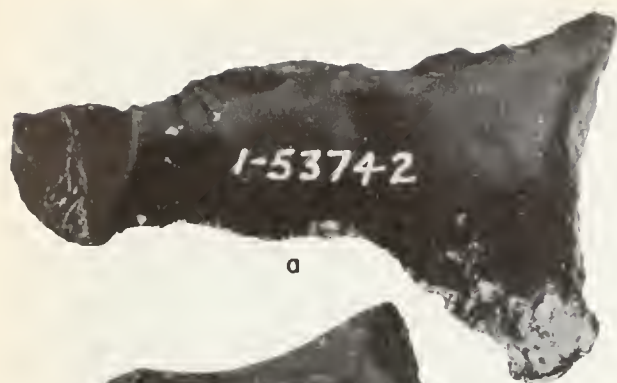
deposit and made the long journey to secure this valuable and brilliant pigment. Hematite (ferric oxide) occurs commonly in nature, and few archaeological sites fail to produce chunks of this red mineral. Figure 11*a,b* illustrates two lumps of native hematite with ground surfaces from which powder has been rubbed or filed off, perhaps with a sandstone file such as that shown in figure 7*e*. Limonite (ferric hydroxide), a yellow mineral, and various white minerals such as diatomaceous earth, were used as body paint.

Everywhere in the bay area except on the sea-level plain of the Sacramento-San Joaquin delta region where stone is absent, pebbles were picked up in stream beds or from gravel exposures, carried home to the village, and put to various uses. They were employed as hammerstones for striking off percussion flakes in the manufacture of chipped implements (fig. 17*e*), as longitudinally grooved net sinkers (fig. 11*g,h*), and as miniature mortars for grinding paint minerals or tobacco (fig. 11*i*). Concretions and odd-shaped rocks resulting from differential weathering (fig. 12*g-k*) were used as "charmstones" at religious functions.

Various micas, which occur in nature in the form of flat plates, were known and used by the Indians. Ancient village sites on the shores of San Francisco Bay and the Marin County coast produce graves in which are quantities of clear muscovite plates with holes drilled through them for suspension (fig. 12*e,f*). Dark lustrous green biotite plates (fig. 12*e*) were used in the central valley area as pendants, the source of this mineral probably being the Sierra Nevada immediately to the east.

Asphaltum, which can be secured from tar seeps, is an excellent adhesive and mastic. It was much used by the Indians of the San Francisco Bay region, though the exact location of the source of this substance remains unknown. Three examples of the use of asphaltum adhesive are shown in figure 12*a,b,d*. These represent, respectively, a charmstone or fishing sinker which still shows the cord impressions, a flat polished steatite ornament with *Olivella* shell disc beads imbedded in the mastic, and a quartz crystal whose base is similarly decorated. All three pieces are from San Francisco Bay shellmounds.

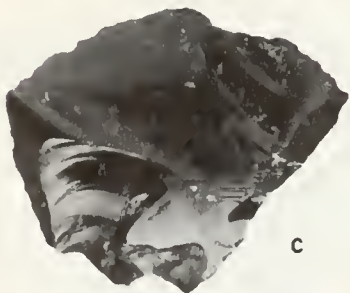
A class of prehistoric implement whose use may only be conjectured comprises the beautifully made charmstones shown in figure 13. Recent Indians profess great reluctance to touch them, and say that only medicine men (i.e. doctors) have sufficient power to handle them with safety. The Indian doctors profess to be able, by manipulating charmstones, to cure the sick, extinguish forest fires, secure hunting and fishing luck, bring rain, and the like. The charmstone of the Early culture period was almost invariably drilled, and a cord was probably passed through the hole so that the stone could be suspended. Most examples from the later civilizations (Middle and Late Horizons) are not drilled. In nearly every instance some attractive rock



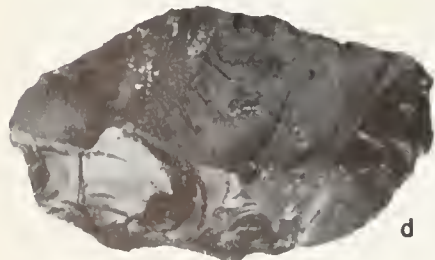
a



b



c



d



e

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f

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g

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h

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i

FIG. 4. Obsidian quarrying and chipping, after life group in U. S. National Museum, and obsidian artifacts (slightly less than natural size).

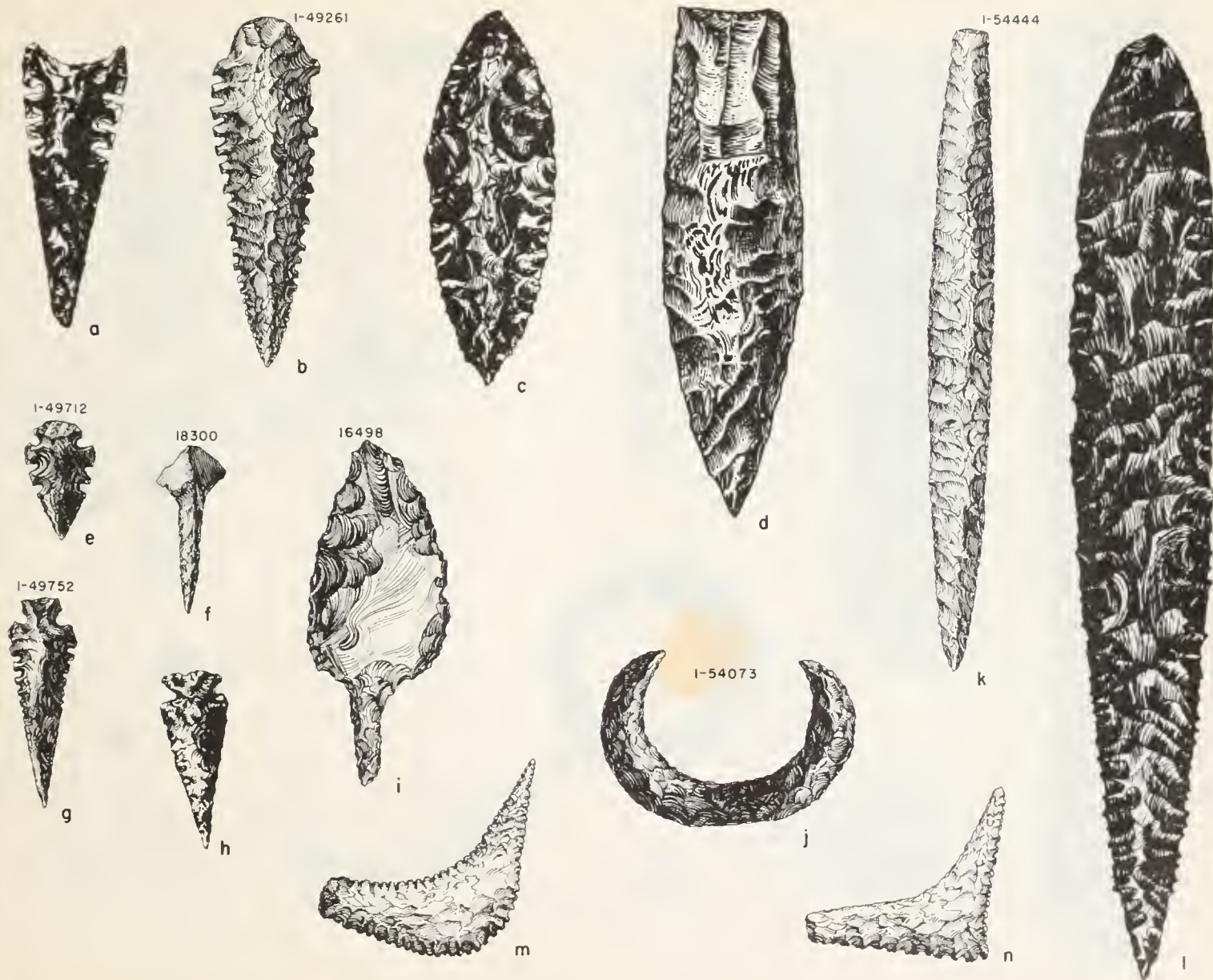


FIG. 5. Chipped obsidian implements (slightly less than natural size).

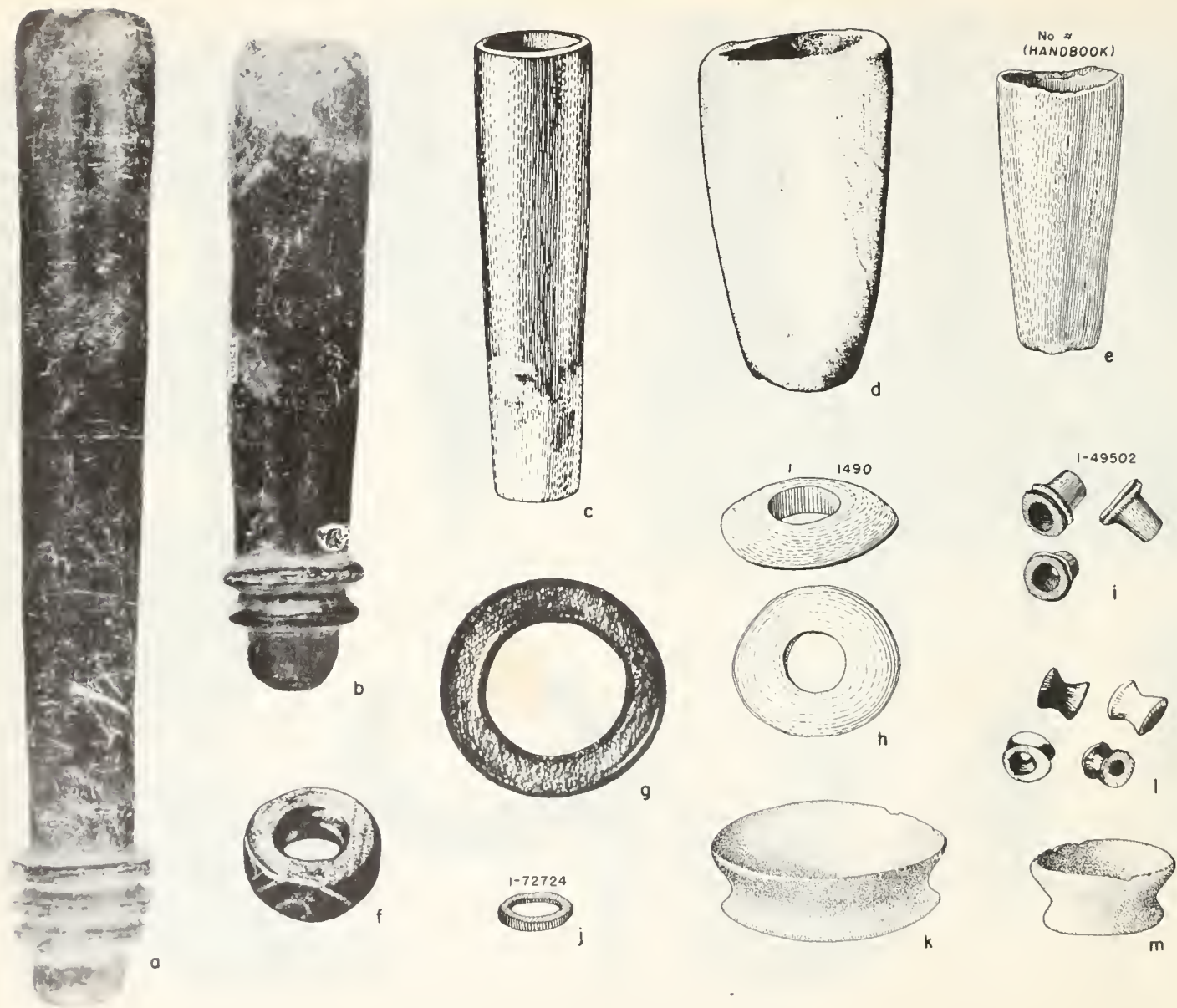


FIG. 6. Aboriginal artifacts made of steatite (slightly less than natural size).

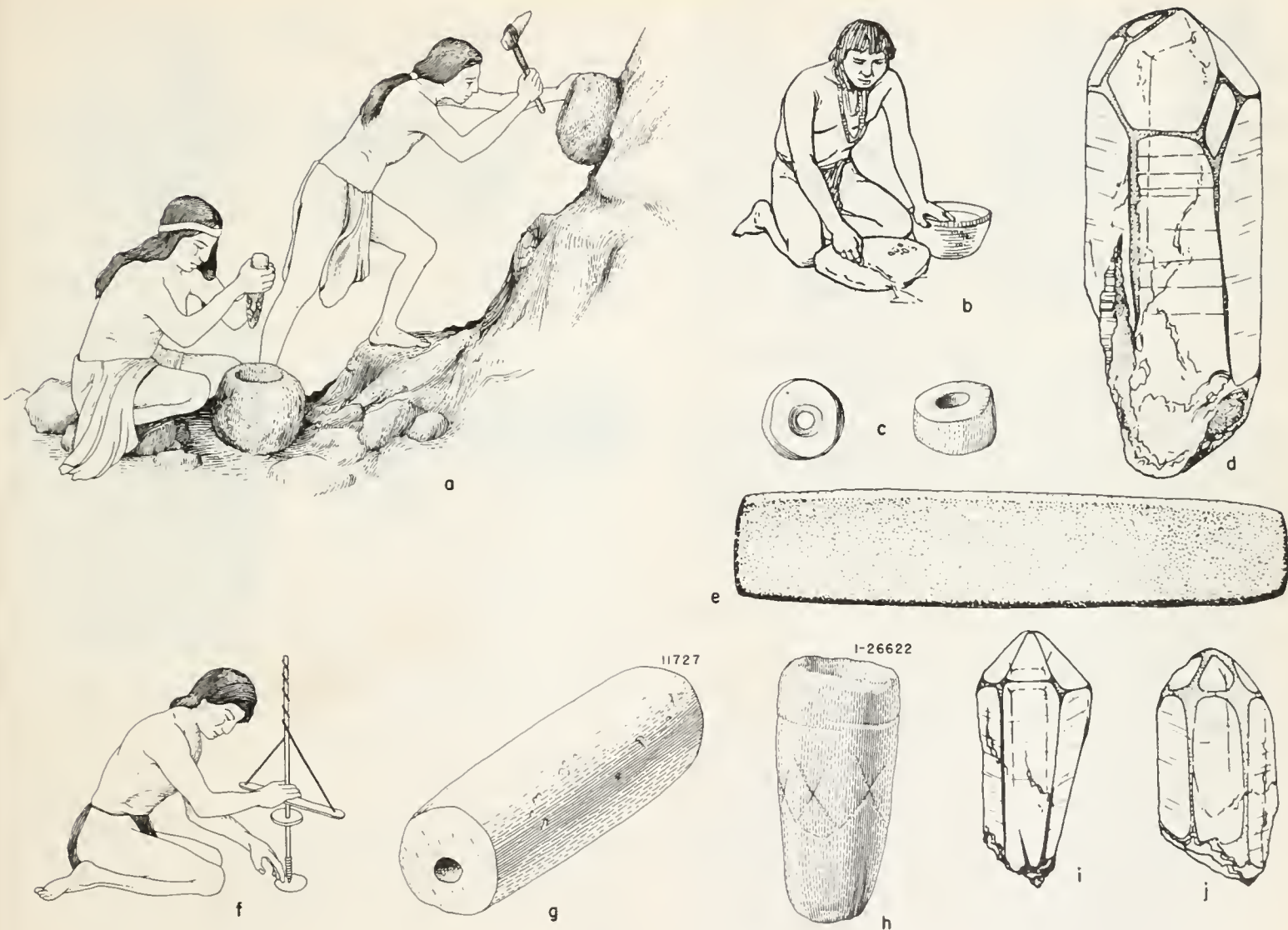


FIG. 7. California Indians quarrying steatite, grinding and drilling shell disc beads, and various artifacts. (Artifacts are slightly less than natural size.)

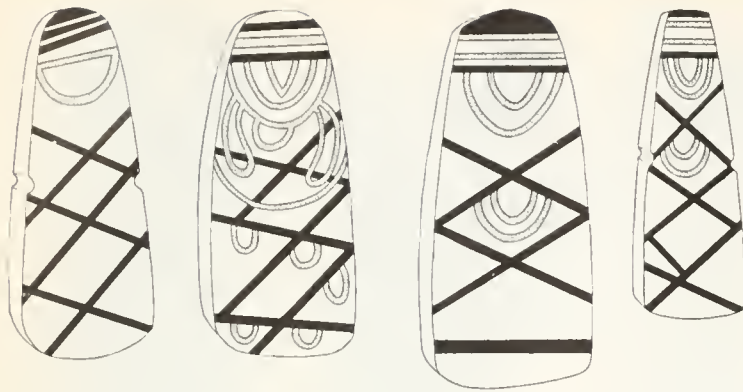


FIG. 8. Painted sandstone tablets which probably represent the human figure. Solid black represents red; stippled lines represent white.

was selected from which to make these pieces. Thus, the charmstones shown in figure 13*a,g* are made of translucent alabaster which is milky white; the example in figure 13*b* is made of blue amphibolite schist; that in figure 13*c* is composed of a dense black granite; and the specimen shown in figure 13*d* is a mottled greenish granite. All of these charmstones, because of their symmetry, finish, and color, are truly objects of beauty, and they must have been so considered by their makers, people of the Early culture.

The biconeical grooved object shown in figure 13*f* is made of sea-green chrysotile asbestos; it perhaps served as an ornament or amulet worn on a string around the neck.

Wild grass seeds, acorns, and small bulbs were important articles of diet; and because these had to be cooked before being eaten, instruments for grinding and pulverizing were necessary to prepare them for boiling or baking. Two implements, the metate or quern (a flat grinding plate upon which is moved a small stone held in the hand), and the mortar (a stone bowl in whose cavity is raised and lowered a cylindrical blunt-ended pestle), were the main grinding implements utilized. Examples of these are shown in figure 14*a,e-j*. Volcanic rocks were used for these tools when possible, because they are tough and long wearing. Vesicular basalt was preferred, and mortars of this material are plentiful in shellmounds on the shores of San Francisco Bay (fig. 14*i-j*). Such mortars must have been carried for miles from quarry sources near Mount Diablo or across the bay from the north.

Objects of perishable materials, such as horn, leather, sinew, feathers, and wood, must have been extremely abundant in prehistoric times, judging from the material culture items known to have been used by the California Indians at the time of the coming of the whites. Occasionally there will be preserved a carbonized fragment

of an ancient basket; or a chance imprint of a basket on a piece of moist clay which became baked in a fire will attest to the former presence of a textile container; but beyond this no direct evidence of perishable items has been found.

Bone as an implement material has an excellent rating among primitives. It is abundant (particularly among hunting peoples), is easily worked, and possesses durability. In figure 15 are illustrated a very small selection of the numerous varieties of bone objects from prehistoric village sites in the San Francisco Bay region. Figure 15*a* is a dagger made of the ulna (large bone of the lower front leg) of an elk; 15*b-e* shows harpoons once used to secure fish; 15*f-g* shows whistles made of hollow bone; 15*h* is a basketry awl or punch; 15*i-j* shows neatly incised birdbone tubes; 15*k* is a perforated needle; and 15*l-m* shows bone bodkins or pins.

Shells of both freshwater and marine molluscan species were employed for tools and ornaments, the latter use being the most important. The shells of salt-water forms are thicker, more dense, and more durable, and were, for these reasons, most favored. The red-backed abalone (*Haliotis rufescens*), green-backed abalone (*H. eracherodii*), and various clams (*Macoma*, *Saxidomus*) were used for ornaments (fig. 16) and beads (fig. 7*c*). Figure 16*h* illustrates a spoon made from a freshwater mussel (*Margaritifera*) shell in which a hole has been drilled near one end. Such a spoon of iridescent shell could have been worn around the neck on a string to serve as an ornament, and put to other use at mealtimes.

Few primitive peoples excelled the California Indians in stone-flaking. Delicately and symmetrically chipped ornaments, drills, knives, and arrowpoints such as those shown in figures 4 and 5 have rarely been equalled by primitive peoples. So fragile are some of the shiny black obsidian arrowheads that one may wonder whether they were actually employed as projectile tips; yet numerous human bones, like the human vertebra shown in figure 17*f*, bear such delicate stone weapon points imbedded intact. The stones which lent themselves to flaking were necessarily those with a high silica content, and in California these were obsidian (black volcanic glass), and cryptocrystalline chert, jasper, chalcedony, and flint. These last are tougher and less brittle than obsidian, and less subject to delicate flaking. A large gray flint blade with serrated edges is shown in figure 17*g*.

Obsidian was broken out of massive flows in the manner shown in figure 1*e*. The large chunks of obsidian, or boulders of chert or flint, were then struck in the way shown in figure 17*a* to secure thin flakes of convenient size. Finally, the arrowpoint was formed by one of several methods of chipping: two are shown in figure 17*b-e*.

For fashioning ground or polished stone tools the shaping process entailed careful pecking to wear away the stone. This procedure was utilized in making the various artifacts shown in figures 6, 11, 13, and

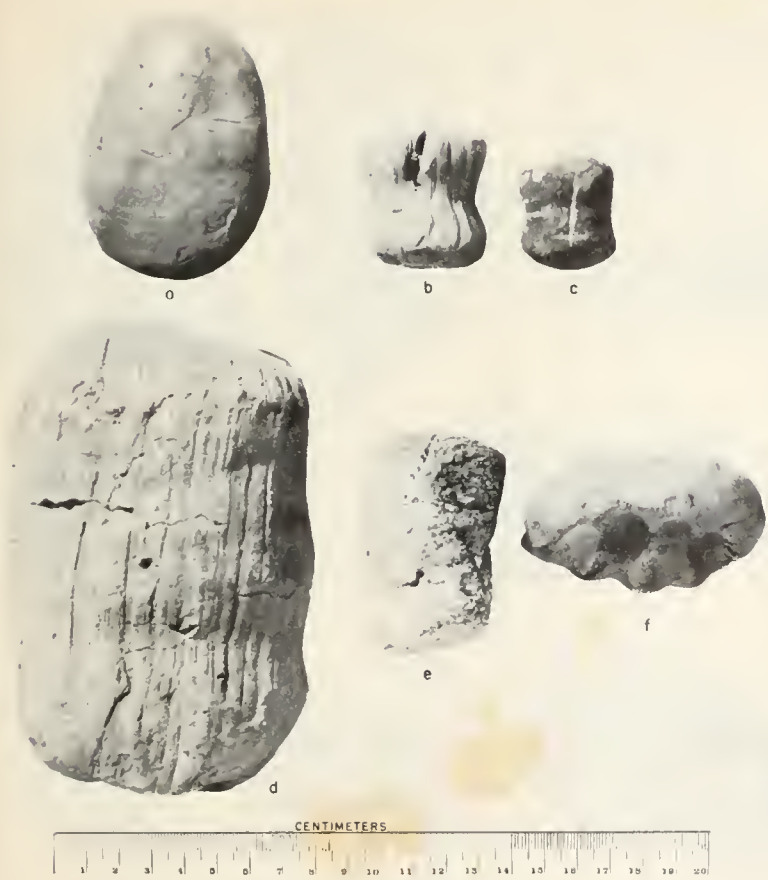


FIG. 9. Objects of baked clay.

14. A tough brown jasper hammer-stone with battered ends is shown in figure 17c.

Because many persons believe that the arrow-chipping process is a lost art, it may be worthwhile to reproduce here two of the score of recorded eyewitness accounts of this process among California Indians.

Caleb Lyon, in 1860, witnessed the making of an obsidian arrowpoint by a member of the Shasta tribe of northern California and described the process as follows:

"The Shasta Indian seated himself on the floor, and placing the stone anvil upon his knee, which was of compact talcose slate, with one blow of his agate chisel he separated the obsidian pebble into two parts, then giving another blow to the fractured side he split off a slab a fourth of an inch in thickness. Holding the piece against the anvil with the

thumb and finger of his left hand, he commenced a series of continuous blows, every one of which chipped off fragments of the brittle substance. It gradually assumed the required shape. After finishing the base of the arrowhead (the whole being only a little over an inch in length), he began striking gentler blows, every one of which I expected would break it into pieces. Yet such was their adroit application, his skill and dexterity, that in little over an hour he produced a perfect obsidian arrowhead. I then requested him to carve me one from the remains of a broken port bottle, which (after two failures) he succeeded in doing. He gave as a reason for his ill success, he did not understand the grain of the glass. No sculptor ever handled a chisel with greater precision, or more carefully measured the weight and effect of every blow, than this ingenious Indian; for, even among them, arrow making is a distinct trade or profession, which many attempt, but in which few attain excellence."

J. F. Snyder published in 1897 a graphic account of the Maidu Indian method of making an arrowpoint. The Indian, having broken his arrowhead when shooting at a hare, proceeded, in Snyder's presence, to manufacture another. Searching the creek gravel, he obtained a fragment of quartz. Snyder's account runs:

"Seating himself on a boulder near me, his next move was to unfasten and unwrap the sinew thread from the end of the arrow shaft and detach and remove the piece of stone arrowhead remaining in it, for it had broken when it struck the rocky ground. He placed the thread of sinew in his mouth to soften it and render it pliable. Then holding the quartz splinter on its edge with his left hand, on a smooth boulder as an anvil, he gently tapped the stone, first on one edge, then on the other (a percussive process), striking off a tiny chip at each stroke until he soon had it reduced approximately to the dimensions he required. He had before seating himself removed his quiver from his shoulder, and at this stage untied from its strap a buckskin string that suspended the point of a deer's horn, 7 or 8 inches in length, notched or grooved at its small end in a peculiar manner that I had not before noticed. The savage saw that I was intensely interested in his work, and executed every movement deliberately and plainly in my view, as though he felt pride in his knowledge of the stone art. Now spreading the broad tail flap on his quiver in the palm of his left hand, with its inner or dressed side up he placed upon it the quartz splinter he had blocked out, and held it firmly in place with the two smaller fingers of the hand clasped over it. With the point of his horn punch he then, by firm and careful pressure, broke from the edges flake after flake from the point of the embryo arrowhead along to its base. Stopping for a moment to inspect the stone, he would reverse it and repeat the cautious pressing on the other edge until directly its outline was that of the ordinary leaf-shaped, flint implement. He now reversed the deerhorn punch, when I noticed that it was grooved, at its upper or large end, to an obtuse or diamond point at one side, somewhat like that of a wood carver's burin. Applying this stout point, by the same mode of pressure as before, to each side of the broad end of the stone alternately, the stone now resting for solid support on the heavy muscles at the base of the thumb, he soon chipped out the indented lateral notches, defining the shank of the arrowhead, which was now finished as completely, and perfectly proportioned, as any I ever saw. Fitting it in the cleft of the arrow shaft, he took the slender thong from his mouth and soon had the new weapon securely fastened, his horn punch tied to its place again, and gathering up his quiver and bow, quickly vanished from view.

"The whole process, from his selection of the stone adapted for his purpose to the last tuck of the sinew strand in adjusting the finished implement to its shaft, did not exceed 25 minutes of time."



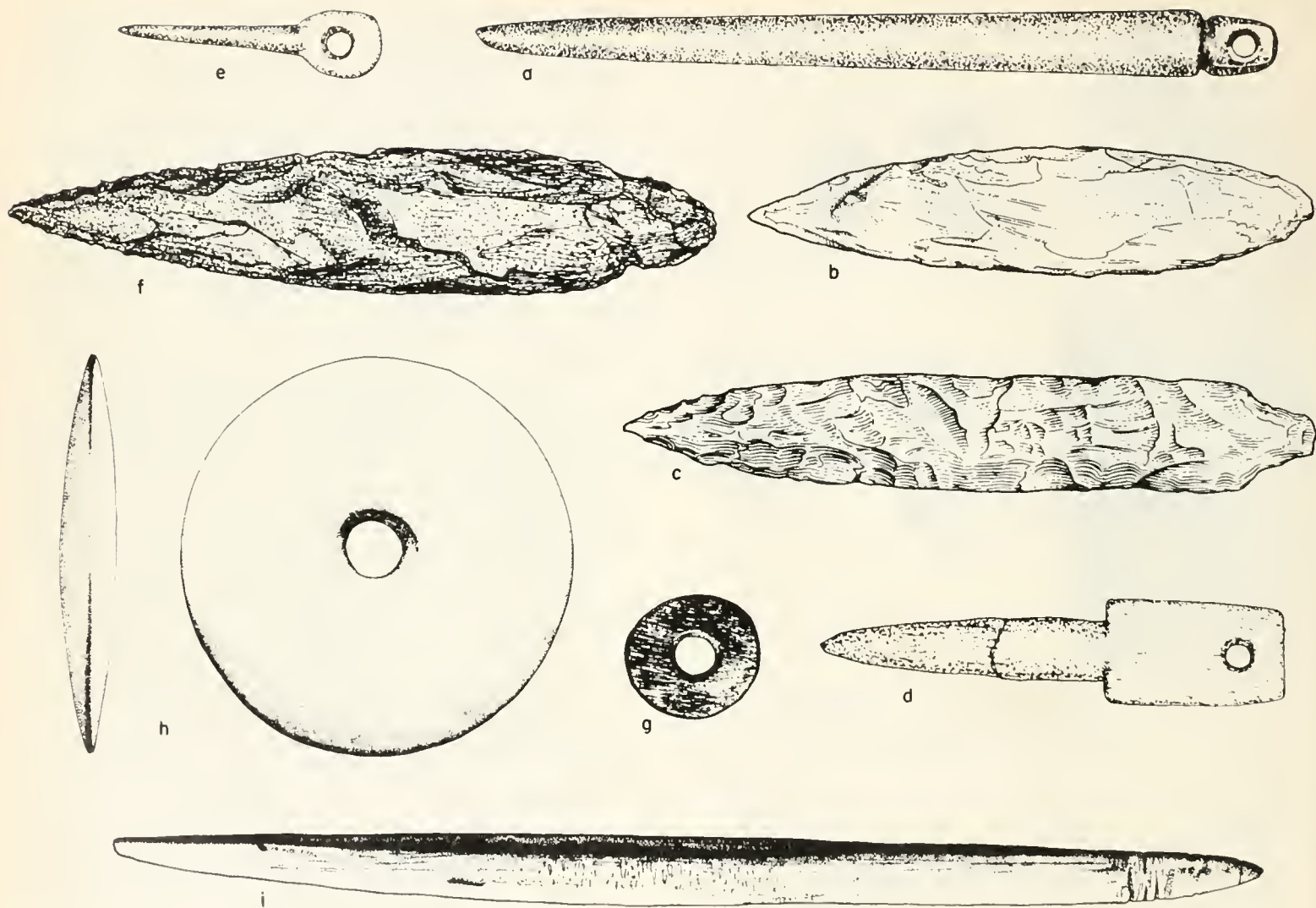


FIG. 10. Prehistoric Indian artifacts of slate and schist (slightly less than natural size).

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FIG. 11. Stone artifacts of the ancient inhabitants of the San Francisco Bay counties (slightly more than half natural size).

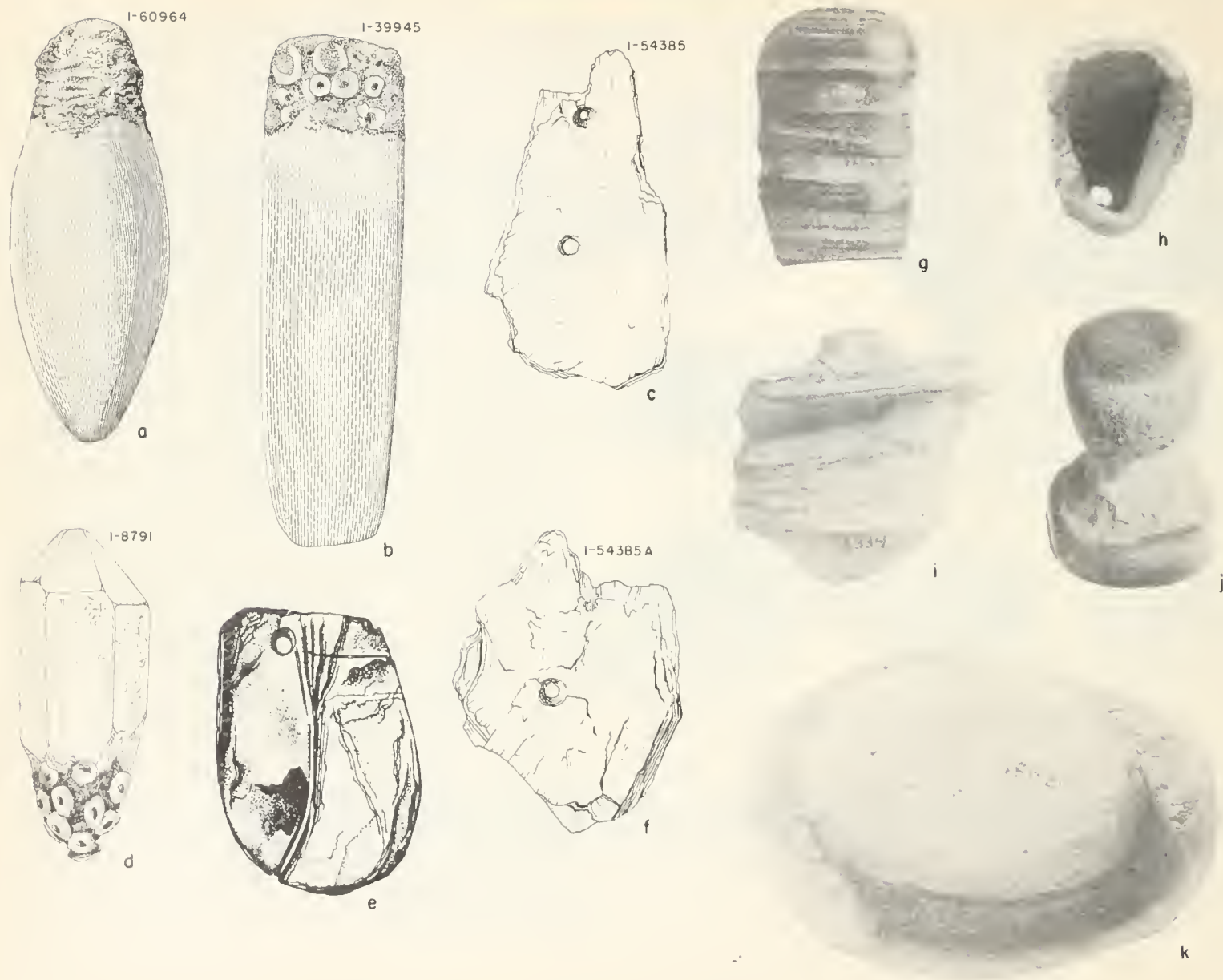


FIG. 12. Artifacts showing asphaltum adhesive, mica, and odd-shaped stones used as magical talismans (slightly less than natural size).

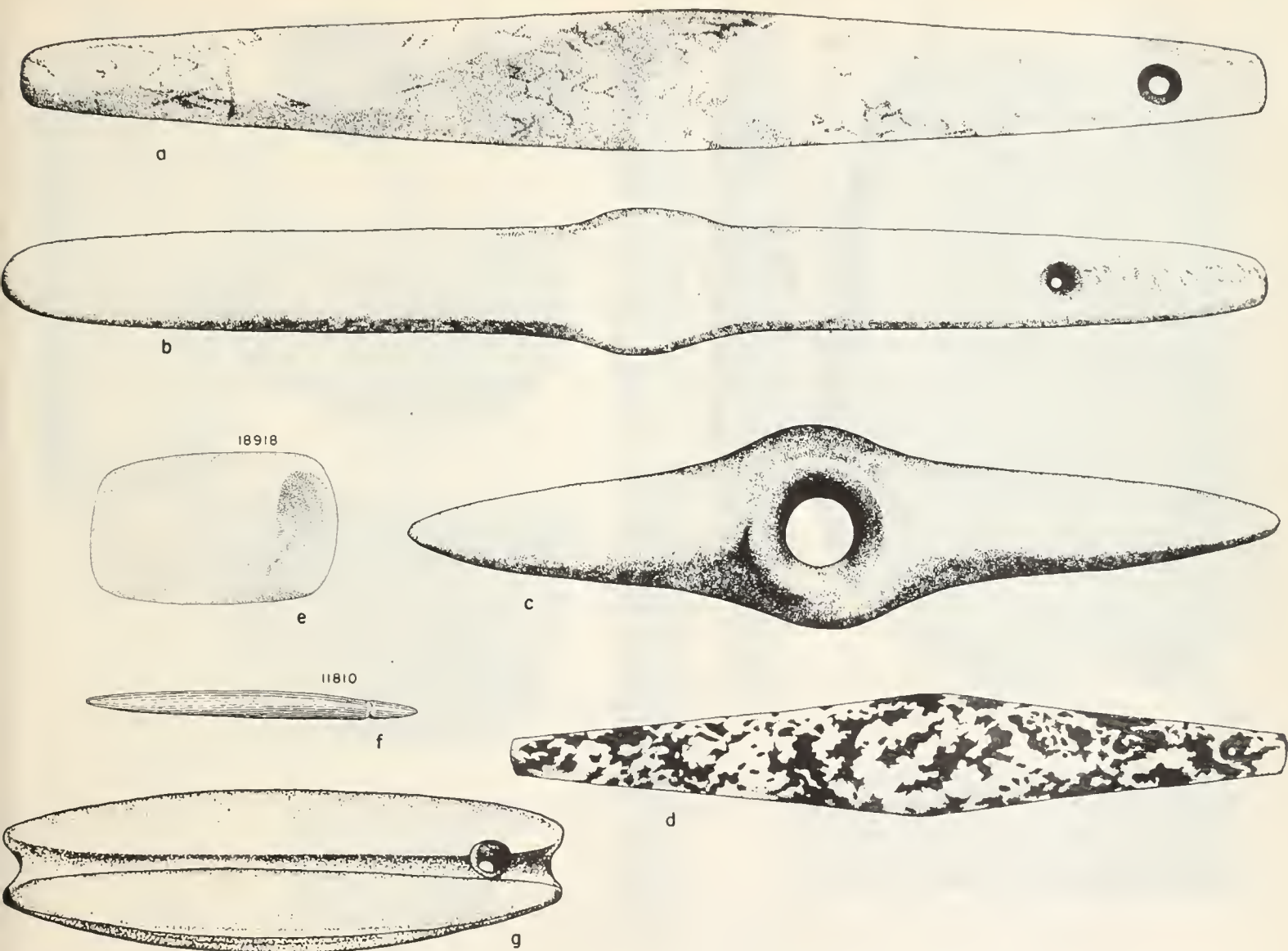


FIG. 13. Charmstones used by prehistoric central California medicine men (slightly less than natural size).



FIG. 14. Stone seed-grinding implements (slightly less than one-eighth natural size).

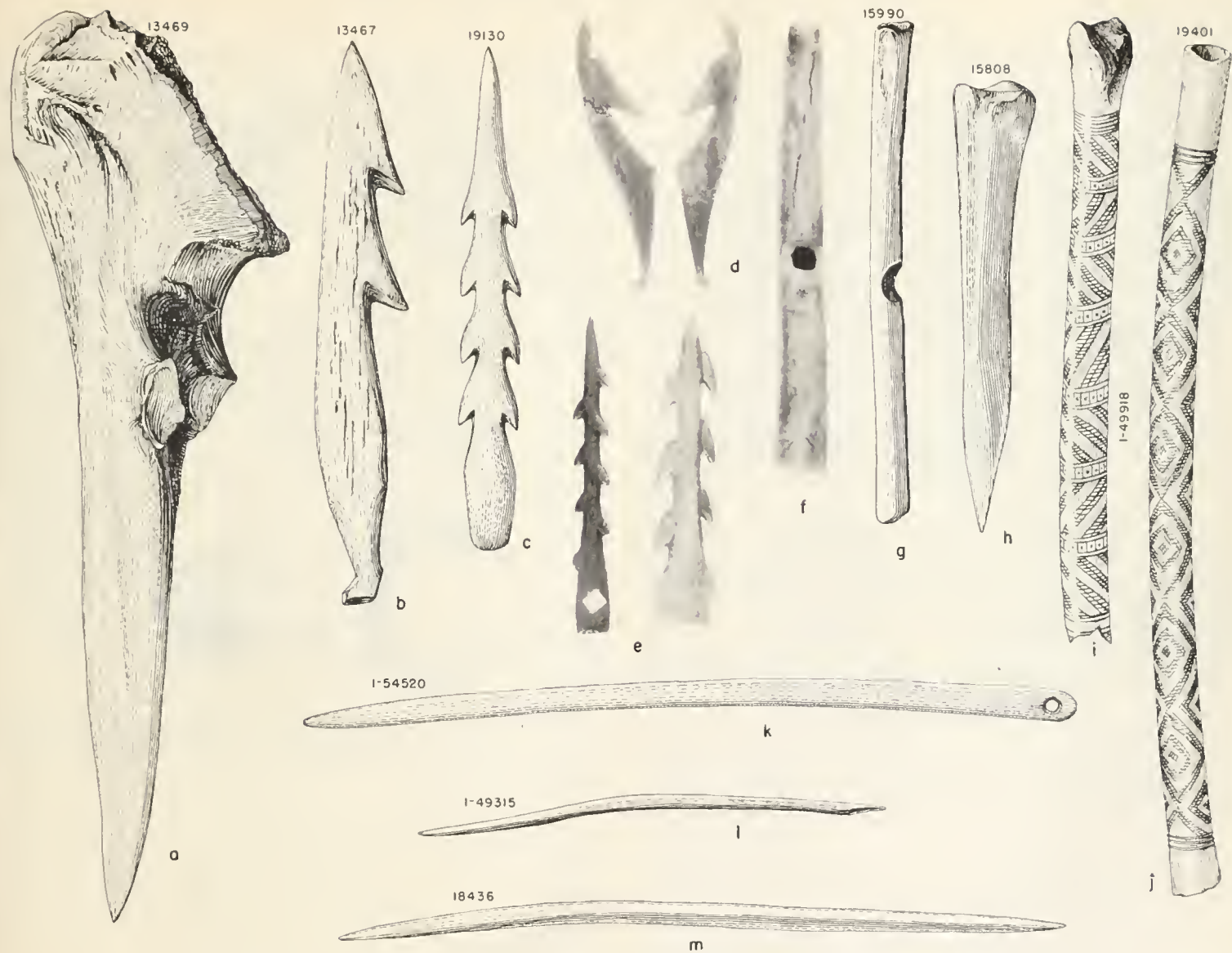


FIG. 15. Objects of bone and antler from prehistoric village sites in the San Francisco Bay area (slightly less than natural size).

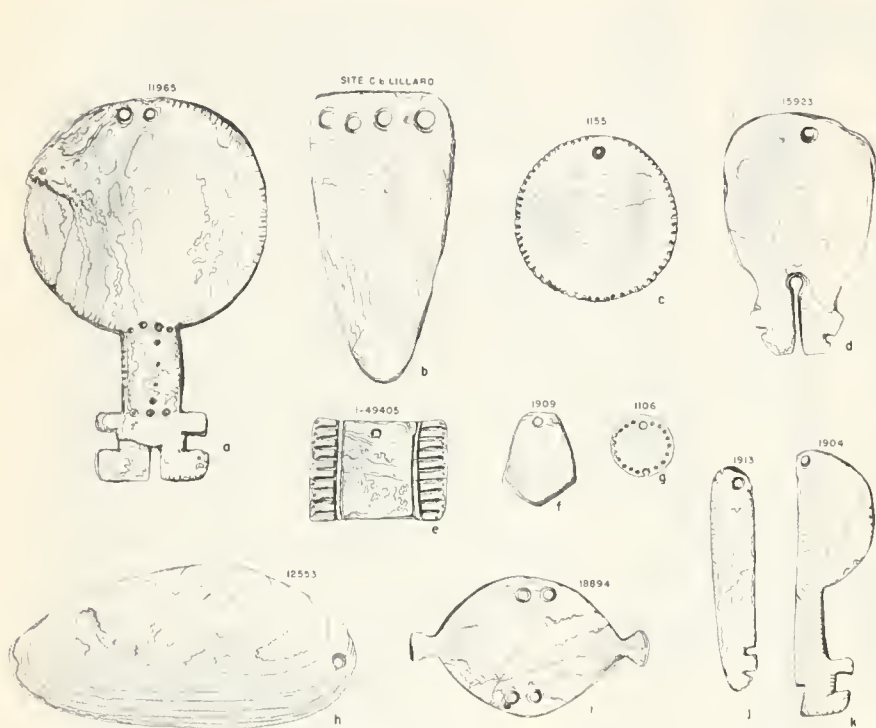


FIG. 16. Ornaments of abalone shell from various San Francisco Bay area Indian village sites (slightly less than half natural size).

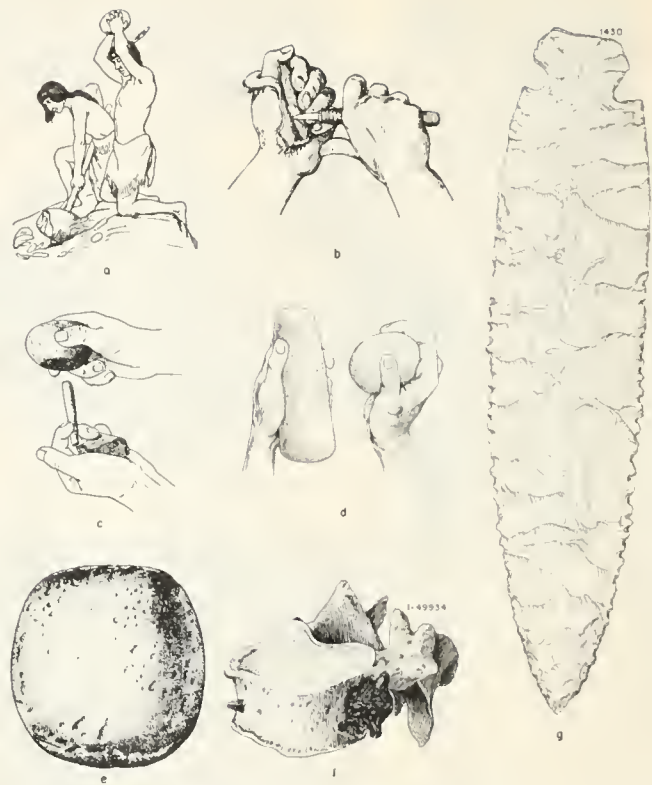


FIG. 17. Methods of working stone. Human vertebra with obsidian projectile point imbedded. Large flint blade. (Slightly less than half natural size.)

## ADOBE HOUSES IN THE SAN FRANCISCO BAY REGION

By J. N. BOWMAN \*

The word adobe, derived from Egyptian through the Arabic and Spanish languages, is used in California as a noun and as an adjective. As a noun it means the fine-grained black soil which when wet becomes very sticky; it names the sun-dried brick made from this and other soils, and also the building constructed of the sun-dried brick. From the advent of Europeans in California to the present the soil has been used as a building material. In Spanish and Mexican California, adobe bricks were made of soil, binder if needed, and water. During the early American period this process was continued; and during the last quarter of a century experimenting has made improvements in the provincial system, so that at present adobe brick manufacturers are producing a greatly improved building material.

Adobe bricks in provincial California were made from the soil near the site of the building to be erected; the soil may have been adobe, clay, loam, or sandy or gravelly earths. Most of the adobe soil possessed sufficient adhesiveness to hold together when dried, but the other soils required a binder. The binder in the bricks of the early buildings consisted of weeds, or tules, or any other vegetation at hand; later, after grains had been introduced and cultivated, the straw of wheat and barley or wild oats was used; so too was the refuse from the kitchen garbage can. The late Prof. G. W. Hendry, who worked on the identification of reliques found in dissolved adobe bricks, always hoped to discover the brick containing the kitchen refuse, because of the seeds and other plant and domestic reliques that found their way into the garbage.

The making of California adobe bricks was a simple process inherited from the early Spanish settlers as developed and practiced in Mexico and Spain. From existing documentary evidence the probable processes may be reconstructed somewhat as follows. A convenient level spot was selected near the proposed building site and near the water supply from a spring or creek. The ground was spaded up and sometimes slightly excavated in order to hold water. When the loose earth was saturated with water, bare-legged servants, usually Indians, tramped the wet earth and the binder into a well-mixed consistency suitable for carrying to and placing in the brick moulds. On a level area nearby were the brick forms. These moulds were made from boards, hand hewn in the early days, but later sawed; held together in the first settlements, with rawhide thongs, and later with wooden pegs—or with nails after they had been introduced into the province. The dimensions of the forms were usually divisions of the *vara* or yard: about  $\frac{2}{3}$  in length and  $\frac{1}{3}$  in width, or about 22 by 11 inches. This size mould made the typical California adobe brick weighing 20 to

40 pounds—convenient to carry and easy to handle in the construction of the house. Some smaller forms were made for special-purpose bricks; those to be burned in the mission kilns were about 8 by 10 inches. The thickness of the brick was the depth of the mould—2 to 5 inches, on the average  $3\frac{1}{2}$  inches; most bricks for the kilns were about 2 inches thick.

After the forms had been placed in convenient rows and the earth well mixed with binder, the "mud" was carried by hand or in baskets to the forms, tamped down with hands or feet onto the level ground and against the sides and ends of the moulds, and leveled by hand to the top of the forms. Occasionally an Indian would leave an impression of his hand or foot on the surface of a freshly packed brick, or a literate workman would print his name and the date on the surface; sometimes, too, a domestic or wild animal would leave a footprint on the adobe before it had dried.

The bricks were allowed to dry in the sun; as soon as the tops were fairly dry, they were turned over. Then, when the underside was dry, they were taken from the forms and set on edge so that the drying process would be uniform and there would be no cracking. Finally the bricks were stacked in convenient rows to await their use in construction.

A small one-room house required about 1,000 bricks; the typical two-room dwelling needed perhaps 2,500 bricks for its walls and partitions, and as replacements for broken or defective bricks. For very large buildings like the mission churches, priests' houses and mills the number of bricks needed ran into the thousands. On ranchos where a number of buildings were to be erected a "brick yard" was established, like that of Jose de Jesus Vallejo, brother of the General, in the small ravine at Niles across the highway and north of the present nursery. He used the bricks in his houses and mill.

The soil in the bay region, when mixed with binder, was quite good for making adobe bricks—except in the area around the Presidio of San Francisco. As early as the 1780's the commandante reported to Monterey that the soil available was very poor for making the bricks needed in the frequent repair and reconstruction of the presidio walls and garrison houses.

Adobe bricks which were to be burned in kilns were not handicapped by soil conditions as were the sun-dried bricks. The burning of bricks and roof tiles was confined to the missions. The kiln at Mission San Luis Rey is the best preserved, and the one recently unearthed at Mission Carmel is a smaller but equally good example of the padres' workmanship. No mission kiln has been discovered within the bay counties, but evidently one existed at Mission Dolores, because burned

\* Historian, Central Records Depository.





FIG. 1. Mariano Guadalupe Vallejo adobe near Petaluma, built about 1836. Photo by Theur, Inc., courtesy of *San Francisco Chronicle*.

bricks were used for the floor of one part of the church, for the building of the battery in Fort Point and Point San Jose, and for the walls of the *pozo* or well at Polin Spring in the presidio grounds. The *pozo*, which is still partly intact, is now covered up; it is located just below the spring at the edge of the newly constructed road below the old dam at the head of MacArthur Avenue, about 110 feet west of the well marker erroneously placed in the middle of the creek bed. Professor Louderback of the University of California kindly analyzed one of the bricks from the *pozo*, and found that it had been made from local soil.

At the missions, burned bricks were used in flooring parts of the church, and in constructing columns of the church front and corridors.

Foundations of the better houses were built of large rocks held together with adobe mortar. This foundation raised the adobe brick walls above the level of the surrounding ground, protecting them from ground moisture and rain, and thus from melting. On the foundations the adobe bricks were laid with the lengths and widths alternating, forming a wall the length of the bricks, or about 2 feet thick. The partitions in which the bricks were laid lengthwise only, were about a foot thick. The bricks were held together with adobe mortar. The next layer of bricks in the walls again alternated the lengths and widths in its course, and also alternated the widths and lengths with those of the lower course. When the walls and partitions had reached the required height, they were plastered over with adobe mud to form a smooth surface. On the outside of the house, this smooth surface served as a further protection against the dissolving action of rain. In the better class of adobes such as churches, priests' houses, and the com-



FIG. 2. Blue Wing Hotel, Sonoma, built during the period 1836-50, as it was in 1930. Reputed to be the first large hotel building erected in California north of San Francisco. Photo courtesy of *Pacific Gas and Electric Company*.

mandante's residence, the walls were whitewashed with a whiting made of burned seashells. Such is the description of the San Francisco Presidio church and *comandancia* as given by Vancouver in 1792.

Another method of adobe construction may be called the "poured method"; only one such construction, however, has been found in the bay counties—an adobe on rancho Pulgas probably built in the 1840's. A neighbor described it as "built of earth which was placed in a box and pounded having water thrown on it, and when a part was completed the box was removed to another part of the building. It was roofed with *tabletas*, small pieces of red boards. The house was about 3 varas [or about 16.5 feet] square. . . . It fell down in the year."

The roofs of the churches and other buildings were formed of timbers held together in the early years with rawhide thongs tied tightly. As these thongs dried, they held the units still more firmly together. The original roof of Mission Dolores church was constructed in this manner. In later years, wooden pegs were used, and still later hand-wrought nails. On this foundation the roof tiles were laid.

Roof tiles were made of adobe formed in the same manner as bricks; but while plastic they were given their curved and tapering shapes by folding over a form. Tradition has it that some of the tiles were shaped over the thighs of the workers—and that this shaping process was best performed by the Indian maidens whose anatomy was best suited by nature for the task! After burning in the kilns the tiles were ready for the roof. The overhanging roofs and the corridors gave further protection for the walls against rain. On most of the ranchos the roofs were of tules bound together or loose, placed over a roof

foundation of poles and brush covered with adobe mud. These, naturally, were not rain-proof.

In the first houses, even in the churches, the windows were only openings in the walls. Later, white animal skins thin enough to allow some light to enter were used to cover the openings. On the ranchos and in the pueblos the windows were at first left open, but later they were barred with vertical wood poles placed a few inches apart. Windows of the Peralta adobe in San Jose were barred in this way. Tradition tells that petty thieves thrust long poles through the windows between the bars, to spear and pull out desirable articles from the interior. Later the bars were replaced with iron rods and later still with glass.

Most of the doors, like the windows, were left as openings. When some protection was needed against the intrusion of domestic and other animals, a pole frame was made, covered with cowhide, and set against or hinged to the door frame. Frequently this door was divided into an upper and lower half. Alfred Robinson described such a door at the Pulgas rancho house in the early 1830's.

The floors of the houses were made of pounded earth and were raised somewhat above the surrounding ground. These floors were uneven, hardened by constant tramping, and smoothed by wear.

No provision was made for heating the houses in provincial California. The material used and the thickness of the walls made the adobes cool in summer and warm in winter. Some heating was secured when the cooking was done in one corner of the room, but when the kitchen and the bakeoven were separate from the house, warmth was obtained by donning more coats and cloaks—as Simpson learned when he dined with the General and Mrs. Vallejo at Sonoma in 1841. Indoor fireplaces were introduced into California by General Vallejo's brother-in-law, the American George C. Yount, in Napa County, in the middle 1830's. The provincial Mexicans, however, did not adopt them. The fireplace in one corner of the restored Mission Purisima Concepcion is a restoration of one installed long after the end of the mission period.

The missionaries were the greatest builders of adobe houses. They built adobes at all three of the Santa Clara Mission sites. At Missions Santa Clara, San Jose, and Dolores, buildings were erected around one or two patios; while at San Rafael and Sonoma, two sides of the square were enclosed by walls. At most of the missions the tannery was erected at some distance from the main buildings, and the jail was farthest away of all. In addition to these buildings, the missions also had adobes for their neophytes on the mission ranchos. Early examples are to be seen at Dolores, at San Pedro, and near Rockaway; a later example is located at San Mateo, and a still later one at San Pablo in Contra Costa County.

The Presidio of San Francisco had the typical presidio structures, only the fourth wall enclosing the square was not constructed entirely of adobe. Against or near the inner sides of the walls, the church, the officers' houses, warehouses, and troop quarters were built. On Pulgas Rancho, the *rancho nacional* for San Francisco Presidio, adobes for the caretakers of presidio stock were also built.

On the ranchos of the bay counties the number and the location of the adobes varied. At most ranchos there was only one adobe at the homestead, but on others one or more buildings were erected within a few feet or at some distance from the first dwelling. As the sons and daughters of the owners married, they built their adobes nearby or on more distant parts of the ranchos. Between 1820 and 1842 adobes were erected by the Bernal family on rancho Santa Rita, the Higueras on rancho Milpitas, the Younts on rancho Caymas, the Martinez children on rancho Pinole, and the Peralta sons on rancho San Antonio.

The number of adobe structures in the bay counties (exclusive of Sacramento, San Joaquin, and Yolo Counties) was 832, counting the houses, corrals, additional wings, lean-tos, fences, and the uncertain number of rooms in the long structures built for the mission neophytes. When restricted to structures of walls and roofs, the number is 696, of which the mission buildings account for 183. At Santa Clara Mission, 64 known houses were erected at the three sites; at Mission San Jose 40 were built; at Mission Dolores 31; at San Rafael and Sonoma 24 each. The Presidio of San Francisco had about a dozen houses and an unknown number of separate soldier quarters and shops built at different times within and against the garrison walls. Also, adobe was used in the fortifications on Fort Point and Fort Mason, as was burned brick. The total number of all types of adobes built in each of nine bay counties is relatively as follows: Marin 59; Sonoma 114; Napa 37; Solano 27; Contra Costa 57; Alameda 115; Santa Clara 311; San Mateo 25; and San Francisco 87.

Of the 696 adobe houses only 88 were standing wholly or in part in 1942; since that date some are known to have fallen or to have been razed, and no doubt others have disappeared. The five missions have six adobes still standing: Santa Clara and Sonoma have two each, and Dolores and Mission San Jose one each. The Presidio had only one. Pueblo San Jose has three, pueblo Sonoma eleven, pueblo Santa Clara two. There are 16 adobes on the ranchos of Santa Clara County; 15 in Sonoma County; 12 in Contra Costa County; 8 in Alameda County; 6 in Napa County; 4 in Solano County; and 2 each in San Mateo and Marin Counties.

Most of the 696 adobes were erected between 1777-78 and the end of the Mexican period; a few were erected during the 1880's. The oldest now standing is Mission Dolores, which dates from the period 1782-91; the Officers' Club on the Presidio at San Francisco was

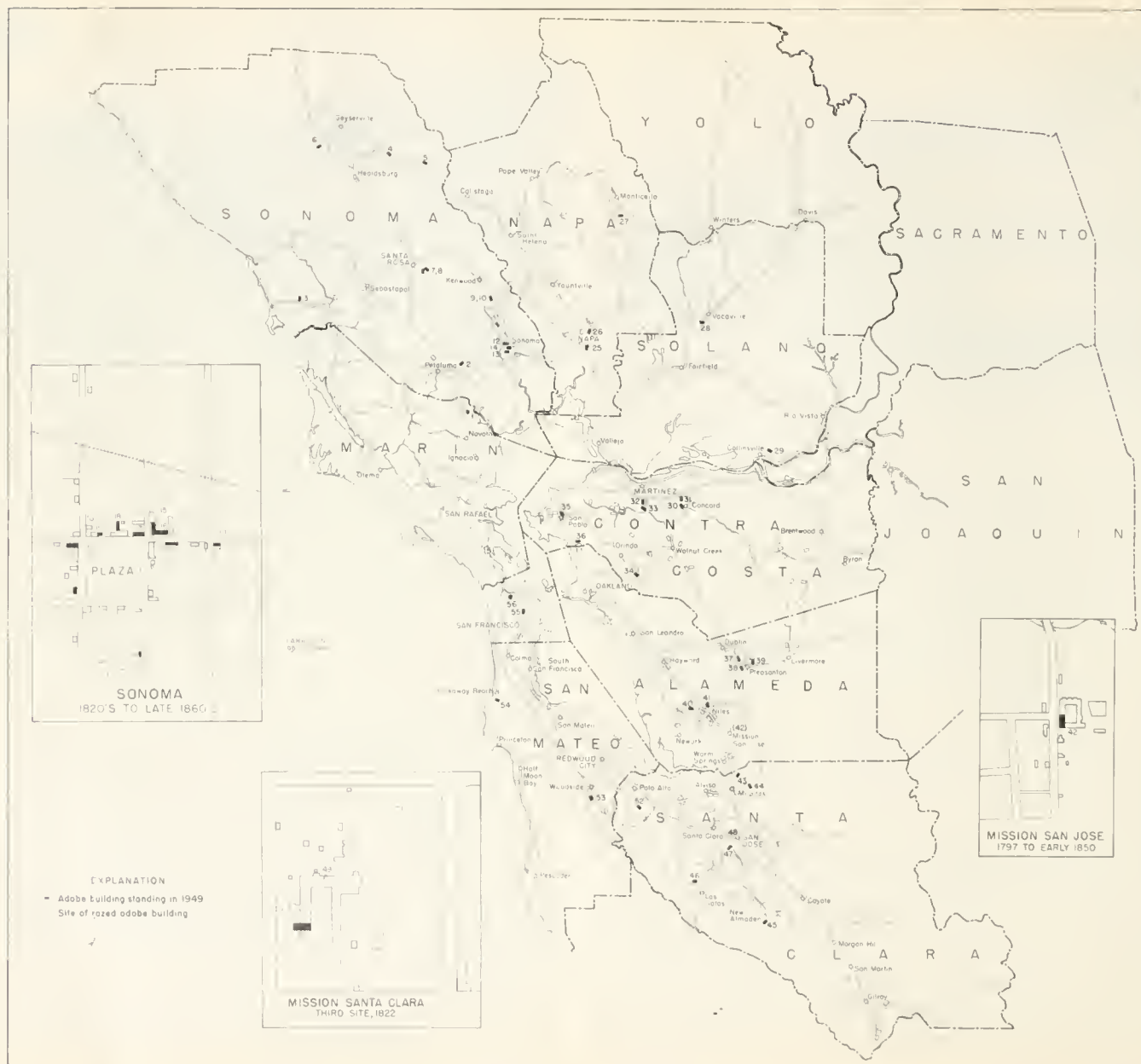


FIG. 3. Index map showing location of old adobes in nine of the bay counties.



FIG. 4 — Priests' house at Mission San José, completed about 1810; building is all that remains of the old mission. *Photo courtesy of San Francisco Chronicle.*

erected during the 1810's or 1820's; the Peralta dwelling in San Jose was built about 1808; and the Higuera house on rancho Milpitas was erected in 1828.

In the following paragraphs are listed some of the more prominent provincial adobe structures which were standing in 1942. Many of the dates of construction given are only relative; where the date is preceded by the word "about" it is accurate within the limits of one year before or after the figure given. Numbers in parentheses following the names of the dwellings apply to the map, figure 3.

In Marin County one of the two adobes standing is the *Camilo-Black* dwelling (1), now used as a residence by Mrs. Burdell. It was built about 1840 on rancho Olompali, 3.7 miles north of Novato.

In Sonoma County 15 adobes still stand, wholly or in part. Among them is the *General Vallejo Fort* (2), erected in 1836-39 on rancho Petaluma. This is the largest of all adobes in the nine bay counties, even with half of the building fallen. It was 178 by 173 feet. About a mile northwest of Bodega are the ruins of the *Stephan Smith* dwelling

(3), close to his store, tannery, distillery, and the first stream saw-mill in California. The ruins are now fully covered with myrtle, which is a characteristic of many adobe ruins. The *First Alexander* adobe (4), built in 1845-46 on part of rancho Sotoyome, stands a quarter of a mile east of the Alexander Valley highway, half a mile south of the Alexander school. The *Berryessa-Knight* adobe (5) was built in 1843 on rancho Mallacomes and stands some 75 feet east of the Knight's Valley highway, about 7.5 miles northwest of Calistoga. Northwest of Healdsburg and about 4 miles southwest of Geyserville stand the two *Peña* adobes (6), built in 1841 and 1844 on rancho Tzábaco. The *Carrillo* and "*Salvador*" adobes (7, 8) on rancho Cabeza de Santa Rosa stand on the south side of Santa Rosa Creek about 2 miles east of the courthouse; they were built about 1839 and 1840 respectively. The *Justi* dwelling and winery-stable (9, 10), built in the late 1840's and early 1850's on part of rancho Agua Caliente, stand on the west side of the old Sonoma-Santa Rosa road 2.8 miles south of Kenwood. The "*Fighting Joe*" *Hooker* adobe barn (11) stands 4 miles north of



FIG. 5. José de Jesus Vallejo adobe on grounds of California Nursery Company at Niles. Adobe was built about 1850. *Photo by Mary Rae Hill.*



FIG. 6. Foundation of Vallejo flour mill, located just east of the Highway 17 underpass at Niles. Building was completed in 1856. *Photo by Mary Rae Hill.*



FIG. 7. Higuera adobe on Curtner Ranch, two miles northeast of Milpitas. House was built in 1823. *Photo by Mary Rae Hill.*



FIG. 8. Museum building at New Almaden, Santa Clara County, dating from the late 1840's. *Photo by Mary Rae Hill.*

Sonoma near the bank of the creek; it was erected in 1852 on Hooker's part of rancho Agua Caliente. On outlots 506, 508, and 516 of pueblo Sonoma stand adobes built in the early 1850's.

In pueblo Sonoma 11 adobes still stand. Facing the plaza are the *Mission Church* (15) built about 1841 and restored later; the *Priests' House* (16) erected about 1825 and also later restored; the *Second Barracks* (17) built in 1835-36; the *Indian House* (18) nearby, erected by General Vallejo about 1836; the *Vallejo-Reeger* dwelling (19) built by the General's brother, Salvador, in 1850, and now used as the Swiss Hotel; the *El Dorado Hotel* (20), built by Salvador Vallejo in 1845-46; and the *Leese-Fitch* adobe built in 1842 and later owned by the widow of Henry D. Fitch. The Leese-Fitch adobe was used by Leese as a store, and by General Percifer Smith as his headquarters; and it no doubt housed at least part of the Spanish-Mexican archives during their transfer from Monterey to Benicia, and later to San Francisco. Opposite the Priests' House stand three adobes—the *Blue Wing Tavern* (22) built between 1836 and 1850; the *John G. Ray* adobe (23) erected west of The Tavern, probably in 1847; and the *Scott* adobe (24), erected about 1846 on the west side of East First Street about 108 feet north of Patten. The Scott adobe is also locally known as the Green adobe. Both men claimed the land, but in 1847 the investigation of the activities of alcalde Nash by Governor Mason's agent, Jacob R. Snyder, decided the claim in favor of Scott.

In Napa County, six adobes still stand. Among them is the *Second Juarez* dwelling (25) now used as a restaurant at the junction of the railroad tracks and the highway a mile east of Napa; it was built in 1847 or 1848 on rancho Tulucay. The *Vallejo-Alberts* dwelling (26) or Longwood, standing at the Trancas (Soda) Creek bridge north of Napa, was erected in the middle 1840's by Salvador Vallejo on rancho Yajome. The *Mack* adobe (27) stands about 600 feet south of Putah Creek at the end of a ranch lane about 3 miles south of Monticello; it was probably built in the early 1860's by an unknown builder on rancho Putas.

In Solano County six of the provincial adobes are still standing. Among them are the *Juan Felipe-Demitorio Piño* dwellings (28) on the east side of the highway 2 miles south of Vacaville, built on rancho Los Putos in 1842; and the *Montezuma* dwelling (29) built in 1847 on rancho Ulpines Sobrante. This latter stands 1.3 miles east of the school house, which is half a mile north of Collingsville.

Contra Costa County had 12 adobes standing in 1942, among which were the *Salvio Pacheco* (30) and *Ferdinand Pacheco* (31) adobes in and near Concord. These were built on rancho Monte del Diablo about 1847 and 1845 respectively. The *Vicente Martinez* (32) and *Abitino Attamirano* (33) adobes, the first built in 1849 near the mouth of Franklin Canyon, and the latter built about the same time

3 miles south of Martinez, on rancho Pinole. The *Moraya* adobe (34) stands in the rear of the frame ranch house on the south side of the Orinda-St. Mary's highway 3.9 miles east of Orinda; it was erected on rancho Laguna de los Palos Colorados about 1841. At the corner of Church Street and San Pablo Avenue in San Pablo stands the *Gabrielita-Alvarado* dwelling (35) on rancho San Pablo. It was built for the grantee's widow in 1842-1843 by her son Francisco; in it Ex-Governor Alvarado took up his residence in 1848. The present El Rancho Restaurant in El Cerrito houses what remains of the three adobes (36) built by *Victor Castro* in the late 1830's and late 1840's, when he established his own home on rancho San Pablo.

In Alameda County eight adobes still stand. Among them is the *First Pacheco* dwelling (37), now the dairymen's club house of the Meadowlark Dairy. It stands 2.8 miles south of Dublin on the east side of the highway, and was built in 1844 or 1845. About a mile farther south on the west side of the same road stands a frame house which encloses the two *Agustin Bernal* adobes (38) built within 5 feet of each other about 1847 on rancho Valle de San Jose. In Pleasanton on the south side of Bay Street 525 feet east of Main stands the *Kottinger Stable* (39) built in the early 1850's on part of the Bernal rancho. In the Niles Nursey stands the *Jose de Jesus Vallejo* adobe (40) erected about 1850, and at the highway underpass in Niles are the foundations of the *Vallejo Mill* (41) erected in 1856. In Mission San Jose stands the *Priests' House* (42) built probably in the 1810's.

In Santa Clara County 16 adobes are standing. Among them is the *Higuera* dwelling (43) on the Curtner ranch east of the highway about 2 miles north of Milpitas; the house was built in 1828; and others nearby, now in ruins, were erected in the following decade on rancho Tulareitos. South of Arroyo de los Coches and on the east side of the Piedmont road stands the *Jose M. Alviso* dwelling (44), built in the middle 1830's on rancho Milpitas. It is now used by Joseph Cuez. In New Almaden are a store, two office buildings and three dwellings of adobe (45), built in the late 1840's on land granted to the mine. North of Los Gatos on the east bank of San Tomas Aquinas Creek on the Quito road half a mile north of Austin stands the *Hernandez-Peralta* adobe (46) built about 1839 on rancho Rinconada de los Gatos. It is now the residence of A. J. Raisch. At 770 Lincoln Street just outside the city limits of San Jose are the adobes of *Roberto* and *Roberto-Suñot-Splivalo* (47), built within a few feet of each other on rancho Coches in the late 1830's and early 1840's. These have now been made into one building within the frame house.

In Pueblo San Jose, 130 adobes have been found, 107 of which have been located on present lots and blocks; but only three of them remain standing. One is the *Peralta* adobe (48) at 184 San Augustine Street, erected about 1808—the second oldest standing adobe in the



FIG. 9. Frame house covering two old adobes at 770 Lincoln Street, San Jose. Original adobes built in the late 1830's and early 1840's. Photo by Mary Rae Hill.

line bay counties. The late A. P. Giannini of the Bank of America spent several years of his childhood in the frame house on the front of this lot.

In Santa Clara, a part of the altar end of the *Mission Church* (49), built at the third site in 1822-25, is now visible behind glass in the sacristy, and at the corner of the patio is the *Store Room* (50) or stable in which the first classes of the University of Santa Clara were held. The store room was erected at the same time as the church. Across the street from the campus is the *Tannery* (51), built in 1849. On rancho Purísima Concepción south of the Arastradero road 1.5 miles west of the San Francisco-San Jose highway stands the *Juana Briones* adobe (52), built by her in 1844, and now occupied by Dr. Edith Cox Eaton.

In San Mateo County only two adobes are still standing. The *Charles Brown* adobe (53), built probably in 1842 on part of rancho Cañada de Raimundo, stands on the east side of the Searsville-Woodside highway less than 3 miles north of its junction with the Menlo

Park-Portola road. About a mile south of Rockaway at the mouth of San Pedro Valley stands the *Sanchez* adobe (54) erected on rancho San Pedro about 1837. Legend places the date of construction in the preceding century, and restoration in 1817.

In San Francisco County, only two adobes are standing: the *Mission Dolores Church* (55) built in 1782-91; and the *Officers' Club* (56) in the presidio, built probably in the 1810's or 1820's, the lone survivor of the garrison buildings.

So far as can be learned no study has been made of the adobe houses erected since the beginning of the century; however, adobe brick are now being manufactured in Contra Costa County and elsewhere.

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## OLD LIME KILNS NEAR OLEMA

By ADAN E. TREGANZA \*

Aside from the debated location of Francis Drake's landing and the Mission San Rafael Archangel building, few places of historic interest in Marin County have attracted as much attention as have the old lime kilns near Olema. Much of this interest can be attributed to two facts—that for many years the original builders of the kilns have remained unknown, and that the setting of the kilns has an air of antiquity. Most impressive is the presence of two large Douglas fir trees growing directly out of the architectural structure of the kilns. Both trees, obviously, started their growth after the kilns were abandoned. The lack of true knowledge concerning the age of these trees has led to speculations that the builders of the kilns were the Russians established at Fort Ross in 1812, or the Spanish padres who erected the Mission of San Rafael in 1817. With the passing years, the cool, moist climate of the Marin coast has caused the stone structure to become so covered with moss and lichens that it assumes a natural position in the landscape.

The lime kilns are located on the east bank of Olema Creek about 100 yards west of State Highway 1. Because of the topography and the vegetational covering, neither the kilns nor the limestone outcrop can be seen from the highway. The present owner of the property is Mr. Sam Smoot of Petaluma.

Mr. Bliss Brown deserves credit for discovering the historical document establishing the time of construction and the identity of the original builders of the Olema Creek lime kilns. Though his description of architectural features may be subject to several additional notes and some revision, the date of July 13, 1850, presented by him as the original time of building, goes unchallenged.

Speculations that the Russians, established at Fort Ross in 1812, and at Bodega Bay somewhat earlier, could have built and operated the kilns, find no basis in historical fact. From all indications it would appear that the construction of the kilns was a costly and fairly long-term project such as would have been undertaken either by a group of people intending to establish a large settlement or by some group of individuals intending to exploit the limestone deposit for a ready and profitable market. Neither of these situations provides a suitable frame for the picture of Russian penetration into upper California. First of all, the Russians, with the aid of Aleut Indians, were moving southward to obtain sea-mammal skins, and to establish bases in warmer latitudes where they could grow vegetable produce to ship back to their settlements in southern Alaska. Secondly, Russian architecture employed a highly involved notched-wood construction tech-

nique, of which an excellent example still remains in the ruins of the old block house at the northeast corner of the compound at Fort Ross. Lime was not used. A ready market for the sale of lime seems improbable, as the nearest purchasers would have been the Spanish settlers on San Francisco Bay, and at that time relationship between the two parties was anything but favorable. Also, the buildings of the mission period consisted in large part of adobe brick set in a mud mortar. Had the Spanish required lime in any great quantity, one would expect to find kilns in a chain from Baja California to San Francisco. Actually, only a few exist. When lime was required by the Fathers at Mission Carmel, for instance, they burned in a kiln abalone shells obtained from the Indian shell mounds.

The land upon which the Olema kilns are situated was originally granted to James R. Berry by the Mexican Government on March 17, 1836; at that time there was no mention of any limestone or kilns. The property must later have changed hands, for the first historical document that bears reference to the lime kilns is dated July 13, 1850. This document established the true identity of the builders of the kilns, thus eliminating much of the mystery surrounding them—especially any implication of an early Russian or Spanish origin. The document consists of a lease between Rafael Garcia, owner, and James A. Shorb, county judge in 1850, and William F. Mercer, a clerk in the judge's court. The lease was to run for a period of 10 years and the significant part reads as follows: "Rafael Garcia, as party of the first part and owner of the land, and James A. Shorb and William F. Mercer parties of the second part. . . ." The lease was to cover ". . . all that tract or parcel of land known as the ranch to the party of the first part and called or named *Punta lastera de Malo*, for all the limeing and timber and wooded purposes." The lessees were to have the privilege of building lime kilns; of quarrying and using limestone; of using wood for burning the kilns; and the entire privilege of the rancho. In exchange for these privileges, the parties of the second part were to give one-third of all the lime burned in the "*kiln or kilns that they may erect or cause to be erected.*" At this point it seems quite clear that had any other kilns been present, notation of them would certainly have been made in this rather carefully worded document. It is further mentioned that ". . . the party of the first part is to furnish oxen, carts, and Indians to haul all the lime burnt in the kiln or kilns to the Embarcadero and assist in loading or putting the lime in the vessels. Also the party of the first part may receive his one-third at the kiln or Embarcadero." According to Mr. Brown, the Embarcadero mentioned was probably the one at

\* Assistant Professor of Anthropology, San Francisco State College.



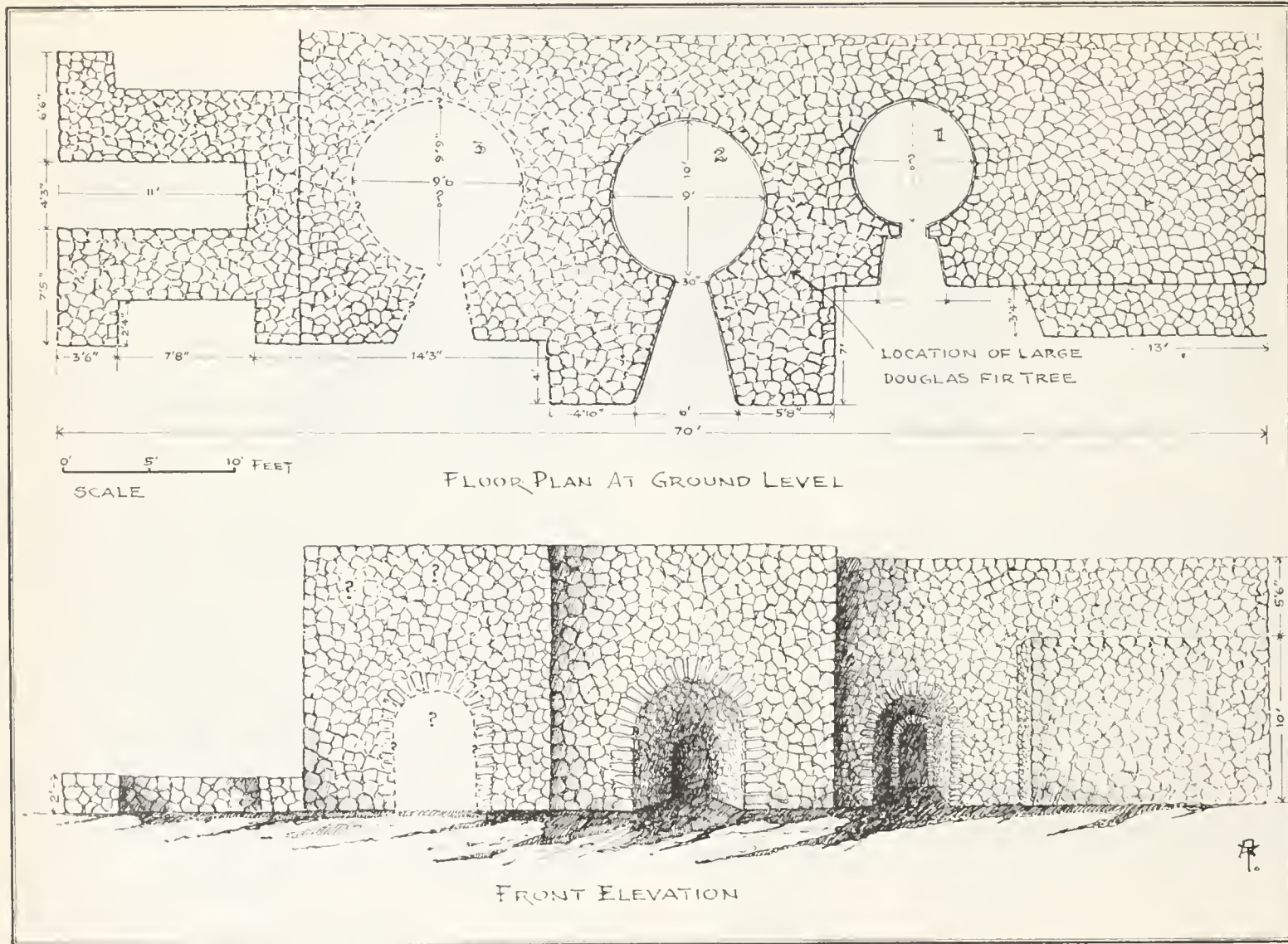


FIG. 1. General ground plan and elevation of the Ojema Creek kiln.

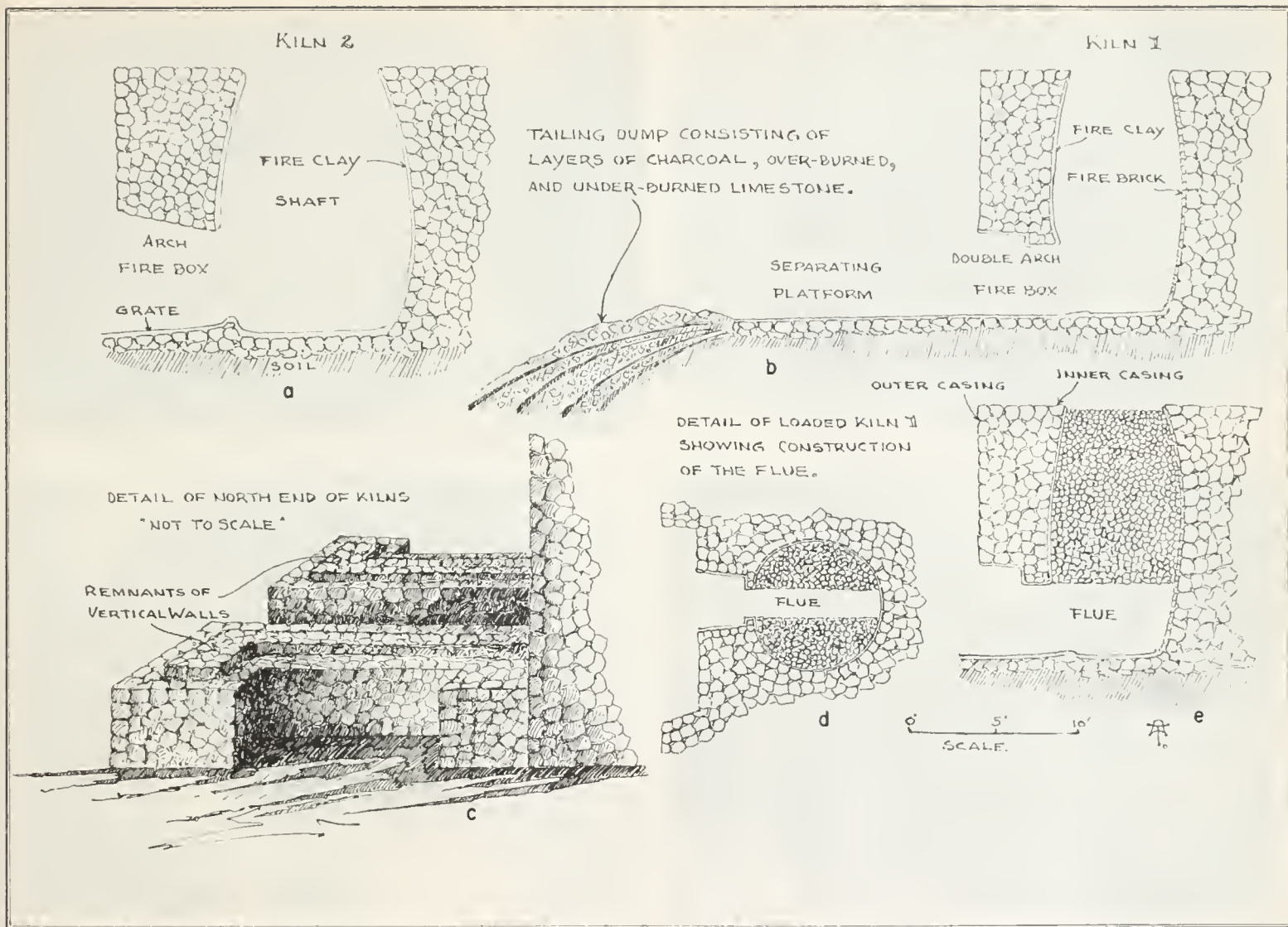


FIG. 2. a, Profile of kiln 2, showing harrel shape and heavy fire-clay lining in both back and front of kiln. Kiln 2 has only a single arch in fire box, but has retaining shelf at back of arch, and sloping floor in fire box. b, Profile of kiln 1, interior casing composed of large blocks of limestone cut to follow exact contour of burning shaft so a consistent coating of fire clay or fire brick can be applied. Backing material between inner and outer casings consists of irregular chunks of limestone set in mud and a small amount of mortar. Brick lining runs about halfway around inner casing, covering rear of kiln. Front of shaft is lined with about two inches of coarse tempered fire clay applied like plaster. This difference indicates a higher temperature at the back, necessitating use of brick. c, Detail showing structure at north end of kilns, probably used for storing burned lime. d, e, Profile and top view of kiln 1, showing manner in which shaft was hand-packed to produce a flue leading directly from fire box into rear of shaft. As unloading was done through fire box, it was necessary to cease firing and to cool kilns.



FIG. 3. Photographs showing kiln 2. *a*, Inside of kiln, showing inner casing and fire arch; mason work has been carefully done. *b*, *c*, Outer casing and fire arch. Stone masonry on outside casing proved resistant to weathering, but inside chunky "fill" is crumbled and slumped. *d*, Front view of fire arch and grate; floor (grate) is composed of 8-inch layer of rock set in mortar or fire clay. *Photos by J. Quast.*

Bolinas Lagoon, a point from which lumber was being shipped at that time. He suggests that the landing may have been the one located at Inverness Park, as this was but a short distance from the Garcia home. However, the Bolinas Lagoon was closer to San Francisco.

As indicated by all the evidence from historical records and excavation, the lime kilns were operated for a very short period. On March 15, 1852, the land west of the kilns was leased by Gregorio Briones to George R. Morris to cut wood and timber. In this lease the kilns were mentioned, as they constituted one of the boundary markers; the lease also stated that the kilns were being operated by a Spaniard, who may have been employed by Shorb and Mercer. The description, however, did not suggest any large-scale operation. On September 25, 1856, Garcia sold the tract of land containing the kilns to Daniel and Nelson Olds. This sale was made 4 years before the lease to Shorb and Mercer was to have expired, yet there is no mention in the deed of any transference of the lease. From all indications, it would appear that the financial venture by Shorb and Mercer was a failure. Material evidence also militates against the idea of any large-scale operation for any length of time. By trenching the dumps in front of the kilns and by counting the sequence of layers of charcoal-ash and over-burned limestone, it has been determined that no one kiln has been fired more than four times, and that there have probably been no more than 12 firings for all the kilns. When abandoned, the smallest of the kilns (no. 1) was loaded but had not been fired. The amount of material removed from the face of the quarry is of no great significance. Taking into account the large amount of limestone used in the actual construction of the kilns, it is evident that very little stone was quarried and prepared for firing. Thus, both the source of material and the reject from firing indicate that there was no large-scale operation.

The greatest obstacle in dating the kilns has been the presence of the Douglas fir trees. One of these trees, 6 feet 5 inches in circumference, has grown directly out of the floor of kiln 3. A larger tree, 11 feet 4 inches in circumference and 40 inches in average diameter, has grown up between the outer retaining wall (easing) and the central kiln. In 1935 the Marin County Agricultural Commissioner attempted to determine the age of the larger tree by taking a core boring and counting the annual growth rings. Unfortunately, the increment auger could take only an 8-inch sample, thus leaving about 12 inches to the center of the tree in which the number of rings had to be estimated. Inasmuch as rings are very compact and narrow near the outside of a tree, but increase in width as the center is approached, any estimate as to the number of rings contained in the unsampled inner 12 inches would be subject to considerable error.

In 1949 the author was able to obtain a much larger increment auger. With it two samples were taken—a complete one from the small

tree, and one within 2½ inches of the center of the large tree. The one from the big tree was taken on the same level and just to the side of the 1935 test. The samples are now in the Museum of Anthropology, University of California. They were examined by Dr. Coekrell, dendrologist at the University of California; he estimated the age of the tree to be 70 to 80 years. Two distinct methods were used to estimate the number of rings on the unrecovered 2½ inches. In the first method, the number of rings contained on the last inner one inch of the sample were counted and multiplied by 2.5; the result, added to the known 59 rings, gave 70 years as the age of the tree. In the second method, the inner 2½ inches of the small tree was substituted for the 2½ inches not obtained from the big tree. Since the two trees grew under almost the same environmental conditions, their growth patterns should be approximately the same. Through this method an age of 69 years was obtained. Since the tree was sampled about 4 feet above the ground level, the loss of about 10 rings could be assumed. Taking into consideration possible errors, a safe estimate of the age of the large tree would be 70 to 80 years. According to Dr. Coekrell, the growth rate of the tree was not unusual, considering that there was sufficient water, little competition, and certainly no calcium deficiency.

The trees, spectacular as they appear, can henceforth be eliminated as a confusing factor in determining the age of the lime kilns. As nearly as can be ascertained, the kilns were last in operation in 1852, some 97 years ago. Allowing the large tree its maximum age (80 years), there remains a period of 17 years between the time the kilns could have been abandoned and the time the seedling fir took root. It therefore seems most certain that the lime kilns along Olema Creek date from 1850.

Maps made in 1862 show the kilns on the east side of Olema Creek, and a house and road on the west side of the creek. The house is reported to have burned down, but about 50 yards down the creek from the kilns the remains of the stone fireplace may still be seen. Sections of the road remain, but they are badly cut up by earth slides and obscured by vegetational growth.

Excavation in and around the base of the kilns did not produce a single cultural object of any consequence. However, the rubbish dump associated with the house was located and partially excavated. From this dump was recovered a great quantity of broken porcelain, glass, iron objects, square nails, and the stem of a clay tobacco pipe. All the material recovered appeared to be characteristic of the post-1850's. This would be in accordance with the known historic date of the kilns, assuming the occupants of the house were also the operators of the kilns. Directly across the creek from the kilns the hillside adjacent to the water has an unnatural appearance, suggesting possibly that some sort of structure might once have occupied the area; however, test pitting failed to produce any cultural material.

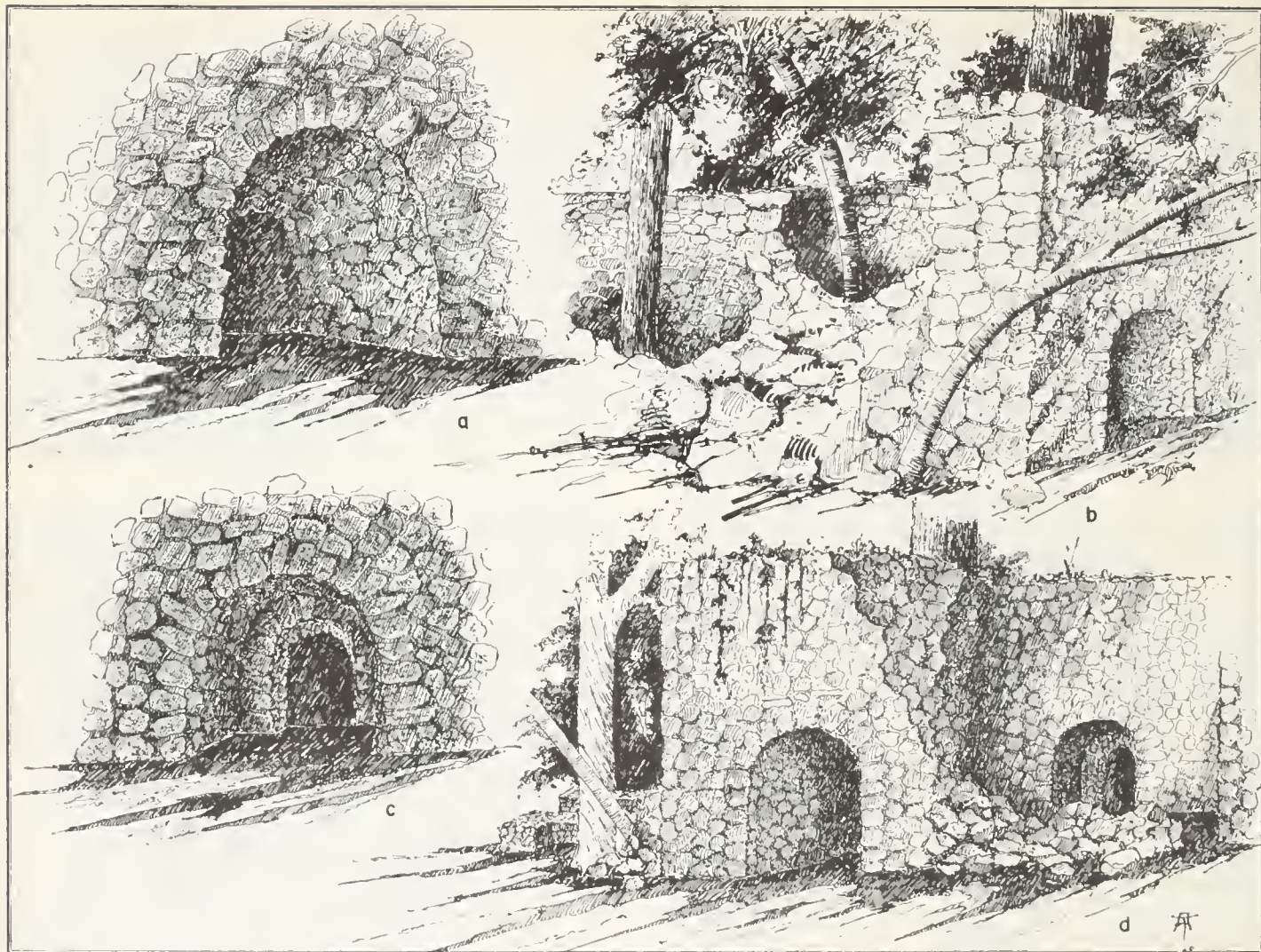


FIG. 4. *a*, Fire box of kiln 2. Single arch is  $7\frac{1}{2}$  feet high and 7 feet deep. Sides and top slope in, so that arch where it joins kiln is  $2\frac{1}{2}$  feet wide and  $4\frac{1}{2}$  feet high. *b*, Sketch showing small Douglas fir growing out of kiln 3 (left), and large Douglas fir (only trunk is shown) growing between kilns 1 and 2. *c*, Detail of fire box of kiln 1, showing double arch. Outer arch is 6 feet high, with passage 3 feet deep. Inner arch is  $4\frac{1}{2}$  feet high; passage, which is 2 feet deep, presumably served as retainer for burned lime out of the fire box. *d*, Sketch of kilns 1 and 2, showing also the undetermined structure at the north (left of picture).



FIG. 5. Photograph taken inside kiln 3, showing small Douglas fir growing in kiln. Stone mason work of inner casing has been carefully done. *Photo by J. Quast.*

At present the greater part of the kilns still stands intact, though through natural agencies and vandalism by people seeking moss-covered garden stone, some of the more important features have been destroyed. Someone has torn down and hauled away the vertical walls of an undetermined structure at the north end of the kilns. Also missing is the entire front casing and fire arch from kiln 3. The large Douglas fir growing out of the top of the wall in front of kiln 2 has so weakened the structure as to place it in immediate danger of total destruction. Since 1913 the roots of this tree have pushed out an entire section of the front retaining wall and have partially destroyed the inner part of the fire box in kiln 2.

Though the gross features of the kilns are rustic, it is nevertheless apparent that the builder was an experienced stone-mason well versed in the building of kilns suitable for burning limestone. Judging from the consistency throughout the structural detail, the kilns were erected as a well-planned unit under the direction of one person. Considerable time and labor must have been expended on the construction.

The structure consists of three barrel-shaped kilns surrounded by angular casings. The angular offsets on the front facade are the result of building around the contour of the hill, and for structural support. On the north end joining kiln 3 is a rectangular structure of uncertain use, which probably served as a storage bin for burned lime. It is a passageway 4 feet 3 inches wide, 11 feet long and 32 inches deep, which extends back to the outer casing of the northernmost kiln. The sides of this structure are built up with stone and lined with lime mortar. At one time there were straight vertical walls rising along both sides of the passage.

The three kilns are made basically on the same plan, though they differ considerably in their dimensions and vary in minor architectural detail. Some idea of the sequence of construction can be obtained on the basis of the type of mortar used. It is reasonable to assume that no lime mortar was available until the first kiln was constructed and fired. This assumption is borne out by examination of kiln 1, the smallest of the three, wherein the fire box and casing were laid up entirely in a clay matrix. This clay, where it has been in contact with the heat, has been partially metamorphosed into a poorly fired, dull red brick; however, it has proved itself a good bonding material. Kilns 2 and 3, and the structure at the north end, were all laid up in a combination of this same clay and a lime mortar, the latter presumably being derived from the first firing of the small kiln.

Following traditional form, the quarry is located above the top of the kilns. This provided easy access for loading the shafts. Examination of the quarry face indicated no drilling, or use of powder; instead, a stripping technique following the dip and strike of the fracture zones along a near-vertical face was apparently used. The talus debris gives every indication of having been reduced to a fairly uniform size by means of a sledge hammer. The quarry is in a fine-grained dark-gray limestone lens in the Franciscan formation. Some of the specimens on the talus slope below the quarry face contain impurities, but the material in the loaded kiln was fairly uniform and of relatively pure grade.

The practice of burning limestone to obtain lime is an extremely ancient one. It was not until very early in the twentieth century that any radical or new improvements were introduced into the industry. With the exception of the method used to remove burned lime from the shaft, the Olema Creek lime kilns were remarkably like kilns operating in 1913 in the eastern United States.

A stipulation in the Mercer and Shorb lease called for the lime to be transported to an Embarcadero by means of ox carts and Indian labor. At the waterfront it was to be loaded on vessels and shipped, presumably to the port of San Francisco. That lime from the Olema kilns ever reached San Francisco or any other destination is, however,

unlikely, for only a brief period of operation is indicated, which probably resulted in considerable financial loss to the original builders and operators.

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FIG. 6. Front of kiln 2. *Photo by Mary Rae Hill.*

PART II  
HISTORY OF THE LANDSCAPE

**Editorial Note:**

PART TWO deals with the origin and development of San Francisco Bay and the surface features of the twelve counties surrounding it. This subject is known to geologists as *geomorphology*, or the evolution of the landscape as determined through the study of the activities and accomplishments of the various geologic agents which have made the rocks, moved and disrupted them, carved and covered them, and left them as we find them exposed on the surface today. This subject represents the latest of geologic histories; whereas the earlier stages in geologic history and formation of rocks are more fully described in the parts of the book that follow. It is hoped that PART TWO will give an interpretative picture of the earth's surface of this region, serving to answer the many questions that arise in the minds of the inquiring public.

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## GEOLOGIC HISTORY OF SAN FRANCISCO BAY

BY GEORGE D. LOUDERBACK \*

San Francisco Bay, recognized as one of the most beautiful harbors in the world, owes this beauty largely to its natural setting. It lies in a long valley bounded east and west by high hill lands; above its surface rise a number of islands; from its western shores project a series of headlands and peninsulas separated by small bays headed by valleys that lead to canyons in the higher hills; for about 40 miles its east shore is bordered by a sloping plain, broken here and there near the shore line by isolated hills or hill ridges, the plain rising to the canyon-sculptured steep slopes of the main range to the east. The bay partakes of some of the attractive features of a mountain lake, although its surface is at sea level and it is connected with the ocean by a picturesque strait with the scenic characteristics of a river canyon.

The bay, the valley in which it lies, and the hills that border this valley are all comparatively recent features of the landscape. Although many of the known events in the geological history of the region extend back through a rather long stretch of geological time, it would seem appropriate in giving an outline history of the geological development of San Francisco Bay and its general setting, to go back only so far as the most recent epoch in which these characteristic features did not exist; that is, to the Pliocene epoch.

Many difficulties have been encountered in attempting to determine some of the significant items of geologic history, especially in the bay area and the lower valley slopes toward the bay, because there the bedrock, the early valley deposits, and the early topographic features and structures are largely or entirely covered by sediments, water, or younger alluvial deposits. Desirable evidence can only be obtained by excavation or boring. Although numerous wells have been put down in certain areas, many are shallow and do not penetrate the superficial formations; others, though deeper, have unfortunately produced neither adequate records nor samples. Borings through the bay bottom have been made for engineering purposes, and some of these have yielded important information in regard to geologic history; others have yielded no permanent records, or records and samples too imperfect to permit further study. Another difficulty in interpreting the geologic history is the fact that many of the later deposits occur in separate areas so that their time relations cannot be determined by tracing their continuity or their relative superposition. They might possibly be correlated if a sufficient number of remains of past life could be found in them. But characteristic fossils have been found only in spotted distribution, and many of the areas as yet have yielded nothing distinctive.

The result is that even now, after a number of years of study by geologists and paleontologists, a statement of the geologic history of the bay region must be looked upon as incomplete, and some of the relations and dating uncertain—the results of the best tentative guessing. An encouraging fact, however, is that every few years some new boring or excavation yields additional information, or a new find of fossils is made, or other field evidence is obtained, adding to, confirming, or modifying previous inferences. Such progress gives promise that our knowledge has not reached its limit and that we can look forward to the definite, even if gradual, development of a more complete and accurate understanding of the historic sequence in the future.

Measurements of radioactive minerals and rocks to find the approximate age of the geologic formations of the earth's crust indicate that the earliest determinable deposits are some 2,000 million years old. The early part of the Pliocene epoch, with which this historic sketch will start, has been estimated as about 10 to 12 million years ago. In other words, the events to be recounted herein occurred within the last one-half of one percent of the earth's history. The development of the bay itself may not have taken more than the last one-hundredth of that small fraction.

*The Region East of the Bay During the Pliocene Epoch.* The landscape of the San Francisco Bay region was quite different during the Pliocene epoch from what it is today; in fact, its appearance at that time gave no hint of the topography that was to develop. During most of the Pliocene epoch the present bay lands were part of the highlands which drained to the east; the Berkeley Hills did not exist, and their area and the area of the present rolling hill lands to the east were largely occupied by a broad lowland. In fact, during the later part of the preceding epoch (the Mioocene) part of this eastern area was below sea level and was occupied by an arm of the sea which connected with the Pacific Ocean south of the present bay region, and extended up the west side of the then central valley which lay between the Coast Ranges region and the Sierra Nevada.

At many localities between the present Berkeley Hills and the San Joaquin Valley, the deposits of this early bay have been tilted up by earth movements and so eroded as to be exposed to view. They carry fossil remains of marine animals of shallow-water type. In the latitude of Berkeley, the extreme western limit of this ancient bay was probably not far west of the present western face of the Berkeley Hills. There its shore or near-shore deposits are exposed in two comparatively narrow bands of variable thickness about 4 miles east of the eastern shore of the present San Francisco Bay. To the north, deposits of the ancient

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FIG. 1. An exposure of Pinole tuff on the Bailey Ranch between Bailey Road and Kirker Pass, Contra Costa County. The rock is composed of pumice fragments set in a matrix of volcanic ash.



FIG. 2. Pinole tuff exposed in a railroad cut opposite Wilson Point, one mile west of Pinole, Contra Costa County. Rock is composed predominantly of fine-grained volcanic ash.

bay are well exposed on the east shore of San Pablo Bay, and remnants have also been found north of Carquinez Strait and Suisun Bay.

Toward the end of the Miocene (according to invertebrate paleontologists) or early in the Pliocene (according to vertebrate paleontologists) a progressive replacement of the bay conditions of deposition by land conditions of deposition began. The bay gradually became more and more restricted, and finally disappeared; and, as seen in the west face of the Berkeley Hills, the thin lowest belt of the ancient bay's western fringe of sediments was covered by alluvium. Somewhat later bay conditions were reestablished for a while; but soon again the marine strata (assigned to the Neroly formation) were covered by land-laid deposits and there were no more marine incursions. Some miles to the east, marine conditions lasted longer, for marine strata grade through brackish-water deposits into fresh-water deposits. Still farther east, in the area southwest of Mount Diablo, marine conditions appear to have lasted the longest, for 1000 feet of marine beds (Alamo formation) were deposited above the Neroly beds during the lower Pliocene, before alluvial conditions were finally established.

Judging from the vertebrate fossils found in the deposits, the alluvial plain persisted throughout the lower Pliocene and through

much if not all of the middle Pliocene. During this time the earth's crust in the region was undergoing slow deformation from compressional forces acting from southwest to northeast, which tended to produce a trough-like depression extending roughly in a northwest direction and deepening eastward for a number of miles from the present bay area. The movement was slow enough so that the alluvial deposits spread by the streams kept pace with the sinking and in the course of time built up a mass of sediments with a maximum thickness of possibly 5000 feet. Apparently while the trough was deepening the west border lands were slowly rising, for there is no evidence to the west of material overlap by the later deposits of the sequence, as commonly occurs in basin filling.

In the midst of this development (in the lower Pliocene), volcanic activity broke out in the border belt between the areas of elevation and depression. This resulted in the 1500-foot series of lava flows and associated deposits of volcanic ash and breccia (Moraga formation) which now characterizes the summit region of the Berkeley Hills. The series may be seen along Grizzly Peak Boulevard and in the high road cuts along the highway east of the Broadway low-level tunnel. Both Grizzly Peak and Bald Peak, and the ridges of which they are the culminating

peaks, stand out above the general level because of the resistant lavas of which they are composed.

It was formerly believed that the succession of Pliocene fresh-water deposits was ushered in by a series of volcanic explosions which produced what is known as the Pinole tuff. With this idea of its age, there was always a question as to why the tuff was not found in the Berkeley Hills at the base of the fresh water (Orinda formation) section, only 10 to 12 miles from the thickest exposure. South of Mount Diablo, however, the tuff is found not at the base of the section, but many feet above the base; also vertebrate fossils obtained from the tuffs between Oleum and Rodeo, and at two localities near Pinole, are middle Pliocene in age. On the basis of this evidence, the Pinole tuff and the beginning of fresh-water sedimentation in the San Pablo region are considered to be later than any of the Pliocene deposits found in the Berkeley Hills, the youngest of which (Siesta formation) is lower Pliocene.

The Pinole tuff, where best developed, is a sequence of alternating beds of volcanic ash, breccia, and ashy sediments. The ash is composed of small bits, shards, and globules of volcanic glass, and carries numerous pieces of pumice and fragments of volcanic rock. Along the eastern shore of San Pablo Bay it overlies the youngest Tertiary marine strata (Neroly formation), and everywhere its intercalated

sediments are alluvial. Its thickest section, between Rodeo and Oleum, is about 900 feet, and carries lava fragments up to several feet in longest dimension, and volcanic bombs up to 3 feet in diameter. To the east it decreases in thickness; it has been traced intermittently for about 25 miles to a point south of Pittsburg, where its observed thickness is only 15 feet. To the southeast it has been traced for more than 30 miles, gradually decreasing in thickness to about 10 feet.

Attempts to find the center of eruption of the Pinole tuff have not been successful. Formerly it was believed that the Pinole corresponded to the Sonoma tuffs of Sonoma and Napa Counties, and originated in that region. More recent studies have shown that the Pinole tuff has a composition different from the Sonoma tuff, and that it was formed at an earlier date. As the exposure on the east shore of San Pablo Bay displays by far the greatest thickness of Pinole tuff, and as it also carries the largest included lava fragments, the maximum size of which decreases with distance from that occurrence, it may be concluded that the locality is close to the center of eruption, which may well lie under the waters of San Pablo Bay. As the tuff carries numerous fragments of lavas of various types, the eruption vent may be expected to be associated with such lavas, which may occupy a fair-sized area. Such lavas are not found about the shores of San Pablo Bay, but in that bay there appears to be sufficient room for them to be concealed. San



FIG. 3. Detail of Pinole tuff as seen in sea cliff half a mile southwest of Oleum, Contra Costa County. Note the large pumice fragments. *Photo by O. E. Bowen.*



FIG. 4. Steep-dipping lower Pliocene lake bed sediments exposed along the north side of Broadway Tunnel Road on the east side of Siesta Valley midway between the tunnel and Orinda. *Photo by O. E. Bowen.*



FIG. 5. Steeply tilted lower Pliocene lavas on Grizzly Peak Boulevard half a mile north of the Fish Ranch Road intersection. Photo by O. E. Bowen.

Pablo Bay is a roughly circular body, about  $11\frac{1}{2}$  miles long by  $10\frac{1}{2}$  miles wide—an area large enough to hold the whole of the Berkeley Hills lava fields. Whether this conclusion as to the location of the center of eruption is correct or not, it is clear that here is a good example of the concealment of evidence, which might settle the question definitely, by bay waters and sediment.

The nonmarine deposits thus far discussed have yielded fossils of various types and at a number of localities. In general, the mammalian fossils have been the most helpful in determining the relative age of the enclosing layers. Some idea of the mammalian inhabitants of the ancient alluvial plain may be given by listing the common English names of the general types: rabbits, beavers, ground sloths, dogs, horses, rhinoceroses, mastodons, peccaries, camels, and prong-horns.

*Marine Pliocene Embayments of the West Bay Region.* During the lower Pliocene, a trough-like depression (or depressions), elongated roughly northwestward, began to develop west of the present bay. The sinking ground was flooded by the sea, and an embayment was produced, in which marine sediments accumulated. The depression developed progressively but slowly enough so that the deposits

were formed under shallow-water conditions; yet in time they were built up to a noteworthy thickness. The Pliocene marine deposits found west of the present bay have been named the Purisima and Merced formations.

The Purisima formation, which reaches a thickness of more than 9000 feet, includes the oldest strata of the local marine Pliocene sequence. At present the deposits extend from the vicinity of Halfmoon Bay to the Santa Cruz Mountains. They can be traced to the southeast along the flanks of Butano Ridge to within a mile of San Lorenzo River, and some disconnected patches, doubtfully referred to the Purisima, lie to the east some 2 or 3 miles from the south end of San Francisco Bay. They extend south from Halfmoon Bay along and near the coast past Pescadero almost to Año Nuevo Bay. Purisima sedimentation is generally believed to have begun in the lower Pliocene and continued through middle Pliocene.

The Merced formation is well exposed along the beach from near Lake Merced to Mussel Rock, and extends to the southeast diagonally across the San Francisco peninsula almost to San Mateo. More than 5000 feet of sediments have been measured in the beach section. The trough in which the Merced was deposited extended across an area now occupied by the sea off the Golden Gate, and similar deposits, carrying the same kinds of marine fossils, are exposed along Bolinas Lagoon and continue almost 4 miles north of the head of the lagoon. The Merced deposits are younger than the Purisima. In the beach section the lower beds (the larger part of the section) are apparently upper Pliocene, and the upper beds are generally assigned to the Pleistocene.

Conditions in the San Francisco Bay region in mid-Pliocene time were in striking contrast to those of the present. Two roughly parallel structural troughs were progressively developing: the one to the northeast was being filled with fresh-water sediments; the one to the southwest was occupied by sea water and was being filled with marine (Purisima) sediments. The land barrier between them occupied the location of the present trough-like depression that holds San Francisco Bay.

*Late Pliocene Intense Deformation.* The slow process of building up a sequence of sediments well over a mile thick in the structural troughs to the east and west of the present bay area was brought to an end in the late Pliocene by a series of earth movements. These made marked changes in the geological structure and ultimately resulted in a complete transformation of the landscape. The earth's crust of the region entered a period of accelerated compression in a southwest-northeast direction, by which the country from the sea to the Great Valley was gradually forced into a narrower belt. The layers of sediment were disturbed and crumpled into a series of folds whose axes were directed in the main about northwest-southeast. In a number of instances, under the influence of the great compression, groups

of strata broke, giving rise to faults along which masses of rock were thrust over or under other masses.

It is difficult to determine at specific localities how and to what extent the older rocks of the region have been affected by the late Pliocene movements, because they have also been subjected to earlier deformations. The Pliocene beds, however, which at the start of the Pliocene movements lay at or near the horizontal, show clearly the character of the crustal disturbance (diastrophism). The strata of the eastern trough, depending on where they occur in the new folds, may now be found at any angle to the horizontal up to and including the vertical. Some of those which lie at angles less than vertical can be shown to have been overturned through the vertical in the course of the folding. Although large areas of the Pliocene beds are so covered with soil that their attitude may be difficult or impossible to determine by surface observation, there are many road cuts, steep canyon walls, and shore cliffs where the steep dips of the strata can be recognized at a glance. For example, near the east portal of the Broadway low-level tunnel, along the cut of the south approach to the Fish Ranch road, vertical sandstone and clay layers are well shown, and down the canyon toward Orinda high-dipping volcanic rocks are prominent. Along the shore of San Pablo Bay between Rodeo and Oleum, vertical Pinole tuff and other high-dipping beds are exposed.

Apparently the folding took place after the middle Pliocene—possibly even after the beginning of the upper Pliocene, for the youngest mammalian fossils so far found in the strongly folded sediments and the marine fossils from the upper Purisima formation, are middle Pliocene in age.

No evidence has yet been found as to the heights above sea level attained by the folds during this period of compression. Throughout the process of folding and faulting the affected area was continuously subject to erosion. This erosion continued after the acute folding was completed and removed great quantities of material, especially of the younger, less resistant formations. Much of the area to the east of the present bay was reduced to moderate or low relief, and therefore probably ultimately stood at only moderate elevations above sea level.

The drainage system of the streams which eroded the developing folds east of the present bay is not definitely known. Nor is it known whether part of the eroded material reached the sea. Some, if not all of it, must have been deposited in adjacent parts of the Great Valley.

*The Initiation of Great Valley Drainage Through the Bay Region.*  
It is not definitely known when the drainage from the Great Valley began to reach the sea across the coastal region in the vicinity of San Francisco. In the upper Miocene and, according to vertebrate paleontologists, up into the lower Pliocene, a marine embayment separated the present bay region from the interior country. Its sediments can

now be found along the hills west of the San Joaquin Valley, continuing north to the west of the Sacramento Valley as far as the Vacaville Hills. They are also found farther west to the Berkeley Hills and the shore of San Pablo Bay. This ancient embayment had its connection with the sea to the south of the present bay region, and there is no evidence or indication of any such connection to the north or west.

As marine conditions gave way to alluvial conditions the developing structural trough east of the present bay deepened and lengthened; so the fresh-water deposits not only built up on the earlier marine sediments but overlapped them, and extended over older formations beyond the limits of the ancient bay.

Although this transition is now concealed by the waters and sediments of San Pablo Bay, there is ample evidence that it exists. Strongly folded marine beds (Neroly formation), as well as middle Pliocene fresh-water sediments, are well exposed on the eastern shore of the bay and disappear under the waters, trending northwest. To the northwest of San Pablo Bay no corresponding marine beds have been found, but a strongly folded belt of brackish-water sediments overlain by fresh-water beds (Petaluma formation) extends in directional continuity beyond Petaluma. The lower part of the Petaluma formation carries brackish-water sediments, and in them were found two invertebrate forms also found in the uppermost portion of the San Pablo (Neroly) formation on the eastern shore of San Pablo Bay and on Carquinez Strait. The upper Petaluma formation consists of freshwater beds in which late middle Pliocene horse teeth have been found. The Petaluma formation has been estimated to be about 4000 feet thick, of which the lower Petaluma makes up the lower 500 to 600 feet. Below the Petaluma formation, deep wells have penetrated almost 4000 feet of lavas, volcanic breccias, and tuffs (Tolay formation), without reaching the bottom of the series. These may well be lower Pliocene, and so correspond to the Moraga formation, which represents the period of volcanic activity in the Berkeley Hills.

Nowhere along this structural trough with its thousands of feet of sediment, which lay east of the present San Francisco Bay (in the restricted sense) and continued across the present San Pablo Bay and on beyond Petaluma, has any indication been found that the sediments were modified, or the belt's continuity broken, or its western boundary breached by a major stream crossing it transversely from the Great Valley to the sea. Nowhere else has evidence been found suggesting that such a drainage system existed from upper Miocene to the time of the late Pliocene diastrophism.

During the late Pliocene crustal deformation the Coast Ranges as a whole were compressed, folded, and faulted. These disturbances finally closed the seaways which had existed to the south of the bay

region. This would have been an opportune time to develop an outlet for the interior drainage to the sea in the region where it now exists, and it is possible that this may have taken place. If so, it must have occurred across some fortuitous low in the system of folds.

Just east of the Carquinez Strait there is a remarkable west-trending downfold of the strata which has been recognized in the older rocks (Upper Cretaceous) in the course of subsurface explorations. Surface studies show that the younger strata (Tertiary) dip into this structural depression from both sides: on the north from the Potrero Hills; on the south from the foothills that run from behind Port Chicago to Antioch and beyond. Within this basin lies Suisun Bay, which terminates at Carquinez Strait, and through which the river waters now pass on their way to San Francisco Bay and the sea. This remarkable east-west structural feature is unique along the whole length of the western border of the Great Valley, and narrows the Coast Ranges belt to less than half of its normal width.

Development of the west-trending structure may have influenced the production of a transverse low in the folds immediately to the west. It was probably instrumental in determining where the outlet to the sea would be, but there is no independent evidence at present to indicate that the drainage break-through took place at that time. It may have occurred somewhat later. There was evidently a well-developed river in existence in Pleistocene time.

*The Valley of San Francisco Bay.* The first indication of the development of the valley of San Francisco Bay—that is, the whole basin in the midst of which the present bay lies, and not merely the part occupied by bay waters—appears after the late Pliocene period of acute folding and associated faulting. The earliest evidence is found in deposits that lie in the southern part of the bay valley south of the Golden Gate. None of these older deposits have yet been found in the northern part. This may indicate that the valley was formed like the older trough to the east and was extended toward the north in its later development. It is probable that the trough in which the marine Merced formation was deposited was initiated about the same time.

The most noteworthy aspects of the modification of the landscape at this time were the results of changes in relative elevation. The lands to the east of the present bay were elevated to start the development of the hills that now form the east border of the bay valley. The lands immediately west of these rising hills lagged behind or were depressed to form the basin.

The valley of San Francisco Bay has been recognized for decades as a structural valley, that is, one produced primarily by earth deformation. It has been explained as caused by the tilting of great earth blocks along fault zones, the eastern depressed edge of the San Francisco-Marin block lying against the uplifted Berkeley Hills block.



FIG. 6. Lower Pleistocene beds southeast of Irvington, Alameda County. Top (white) layer is clay. Dip 20 degrees. Fossil bones of land animals have been found in all strata shown in picture. *Associated Press Photo.*

Some geologists hold that the Hayward fault is the boundary plane separating the rising from the sinking area; but the Hayward fault does not fulfill the first requirement of a rising fault-block boundary: over most of its course it is not located where such boundary is to be expected, and for about 12 miles it lies from 1 to 2 miles east of the base even of the visible bedrock slope of the hills, the still lower part of which is covered by alluvium. The southern part of the bay valley has been considered as bounded on the west by the Montara block, depressed along the San Bruno fault. It is difficult to fit the distribution of land masses and topographic form into any definite adjustment of major blocks. The bay valley in its course crosses obliquely

the supposed boundary faults on both sides of the bay, and transgresses the adjoining blocks. It passes at various angles over or by all recognized medium to large faults in its way, whether old or young, and similarly cuts obliquely across the structural trends of both older and younger rocks. Only for limited distances does it follow one or the other. Definite bounding faults that correspond to the requirements have not been recognized, although it is possible that such may lie under alluvium or bay deposits.

The bay valley may be most simply explained by considering it a result of warping: in some parts the slopes being formed as in normal open folding, in some parts affected by distributed shearing. The outline of the valley may locally be coincident with preexisting structure, and it may also show local fault displacements here and there.

The early history of the bay valley is imperfectly known. A number of areas in the southern part and in the southern extension of Santa Clara Valley have been mapped as underlain by older alluvium. Such areas occur along the foothills at the west edge of the valley from west of Palo Alto to Los Gatos. At a higher altitude, the older alluvium occurs as a narrow belt along the course of the San Andreas fault, where it has been protected from removal by erosion by having been dropped down as a slice along the fault zone. This belt is traceable to the north as far as the road crossing at Crystal Springs Lake. In these areas the deposits have been named the Santa Clara formation and assigned a Plio-Pleistocene age (uppermost Pliocene and lower Pleistocene); they are considered the equivalent of the Paso Robles formation which is farther south in the Coast Ranges. Fossil evidence for the age consists of a few fresh-water mollusks and a number of fossil plants. The flora is considered to be late upper Pliocene, or possibly early Pleistocene. The Santa Clara deposits appear to be at least in part contemporaneous with the Merced, and it is possible that the drainage with which they were associated reached the Merced embayment.

Southeast of Irvington, on the east side of the bay, a deposit of older alluvium has been cut and its east portion elevated along a fault. Subsequent erosion has exposed gravels which have been excavated for commercial use. In the course of this excavation excellent mammalian fossils have been brought to light. A group of boys known as the Boy Paleontologists of Hayward, under the direction of Mr. Wesley Gordon, have been indefatigable in collecting and have become expert in preparing fossil specimens from these Irvington deposits. With their aid has been gathered by far the best collection of vertebrate fossils yet found in any part of the region. If there had been a few more such amateur groups distributed about the bay region, we would undoubtedly have a much more definite knowledge of its history than we have today. Fossils from the Irvington beds are lower Pleistocene in age. The mammals collected include ground sloths, dire

wolves, foxes, coyotes, mammoths, horses, peccaries, camels, deer, and pronghorns.

*Mid-Pleistocene Crustal Compression.* In the midst of the Pleistocene epoch the region again experienced deformation by crustal compression. This diastrophism was very widespread in the general Coast Ranges region, and in some areas, particularly in southern California, was more intense than the late Pliocene folding. In the San Francisco Bay region it was less intense than the earlier episode. The added effects which it had on formations already deformed by the earlier disturbance are difficult to appraise; it is therefore best judged by its action on those deposits that were laid down after the late Pliocene deformation.

At least some of the sediments referred to the Santa Clara formation were deformed at that time; their layers lie at angles up to 50° to the horizontal, and underlie unconformably the comparatively flat layers of later alluvium. The Irvington beds are distinctly folded and the strata dip as much as 20°.

North of the bay area a depression transverse to the general trend of the axes of folding was formed at the time of the late Pliocene folding, or not long thereafter, allowing the sea to extend from the coast to the vicinity of Santa Rosa and Petaluma. In this embayment sediments were deposited that carry characteristic Merced fossils. The strata lie unconformably over the upturned and eroded edges of the Petaluma beds which were strongly folded by the late Pliocene compression. These Merced strata were in turn folded at the time of the mid-Pleistocene disturbance and are now found at angles of 10° to 15° in the folds. The Sonoma volcanics, which cover much of the country from the Santa Rosa-Petaluma region to the Sacramento Valley, and which were contemporary with the northern Merced, at least in part, were folded at the same time, and show that the effects of the mid-Pleistocene diastrophism extended from the coast to the Great Valley.

The Merced formation of the San Francisco-Bolinas trough was presumably deformed at that time. This brought to an end the period of Merced deposition. The resultant structure on the San Francisco peninsula was determined in part by movement on the San Bruno fault, the fault which has been instrumental in the production of the striking southwest scarp of San Bruno Mountain.

*Later Pleistocene Compression.* Folding which is judged to be younger than that just described has been noted in two formations. Where observed it is distinctly gentler than that produced by the earlier Pleistocene movements.

(1) A belt of older alluvium, which extends along the front of the hills in Oakland for about 6 miles (San Antonio formation), is a series of fans made up of detritus derived from the apparently newly formed steep front of the Berkeley Hills. The lower part of the San Antonio



formation contains pebbles derived only from the lower part of the hill slope; fragments derived from the higher parts of the slope first appear in the upper part of the formation, indicating the progressive development of the streams. Recent studies have determined that this formation has been compressed into open folds with approximately north-south axes, and core borings indicate a dip of  $8^\circ$  on the eastern flank of one such fold, as measured on a bed of fine clay pierced by a number of borings.

(2) The best exposed section of the Merced formation is along the cliffs from Mussel Rock to Lake Merced. Paleontologists have generally considered the northern (upper) part to belong to a later epoch (Pleistocene) than the southern part (upper Pliocene). Peculiarly enough, at the part of the section where the change should take place, a large landslide has made observation impossible. The deposits south of the slide have yielded abundant marine fossils about 63 percent of whose species have been determined as now living, while deposits to the north have 100 percent now living. The strata to the south dip at rather high angles, mostly  $30^\circ$ - $60^\circ$ , and strike northwest; those to the north strike about north-south and dip  $5^\circ$ - $10^\circ$  east. Both the structural change and the faunal change suggest an unconformity, in other words, that the upper Merced is a different formation. Accepting this interpretation, the lower Merced (upper Pliocene and possibly in part lower Pleistocene) was probably deformed at the time of the earlier Pleistocene disturbance, the upper Merced deposited afterward and folded in the upper Pleistocene deformation.

Evidence will be given later that both of the above formations are probably lower upper Pleistocene.

*Elevation of the Berkeley Hills and Other Areas.* The elevation of the Berkeley Hills, carrying on their summit region strongly folded deposits of Pliocene age, with respect to the land immediately to their west, has been noted as one of the outstanding features of the development of the valley of San Francisco Bay. The dating of the increments of this movement cannot at present be precisely stated. Recognized lower Pleistocene alluvial deposits have been found only in the southern part of the area (Irvington deposits). Along the central portion (Oakland region), the first alluvial deposits giving evidence of a range front sufficiently high and steep to develop streams capable of producing extensive gravelly cones were those of the San Antonio formation. This would suggest that the striking range front in this area was initiated at or following the time of the early mid-Pleistocene disturbance. Farther north (in the Rodeo region) the earliest such alluvial deposits so far recognized are upper Pleistocene. No evidence has yet been obtained as to whether they were contemporaneous with or later than the San Antonio, that is, whether their formation was before or after the upper Pleistocene disturbance.

Starting with the outlining of the bay valley, or perhaps with the mid-Pleistocene disturbance, the whole body of present hill lands, from the immediate bay region to the Great Valley, was slowly uplifted—slowly enough so that the main river (combined Sacramento and San Joaquin) could maintain its course from the Great Valley across the uprising land. The cutting action of this river produced Carquinez canyon (now Carquinez Strait) which ultimately reached a depth of 800 to 900 feet. Similar action to the west of the bay valley, possibly at the same time, cut Golden Gate canyon (now Golden Gate strait) to a depth of more than 700 feet. East of San Francisco Bay this phase of elevation and more recent canyon cutting appear to have taken place chiefly in the upper Pleistocene, probably mostly in the earlier part of the upper Pleistocene. Some evidence of differential uplift may be interpreted as indicating movement in Recent time, and such action may not yet have ended.

*Upper Pleistocene Deposits.* Although the bay valley was narrowed somewhat by the action of the mid-Pleistocene compressions, it still remained a broad topographic trough. Appropriately situated areas of older alluvium were planed or terraced by streams, and a new group of alluvial cones began to develop, in part from the erosion of the older alluvium, but in the main by continued erosion of the bordering hill lands. Remains of the land animals of the time have been found at a number of localities in these younger alluvial deposits, and some of the characteristic types distinctive of the Pleistocene (Glacial) epoch are now extinct and not found in Recent deposits. The forms most commonly found are mammoths, bison, and horses.

Remains of one or more types of Pleistocene animals have been obtained from deposits at such widely distributed localities as near Fleischaacker pool in San Francisco; near Mussel Rock and near Millbrae in San Mateo County; in a San Francisco-Oakland Bay Bridge excavation east of Yerba Buena Island (bison, 180 feet below sea level); and at Treasure Island (mammoth, 45 feet below sea level). East bay localities include San Lorenzo Creek, Hayward; at least two localities in Oakland, one being in the excavated approach to the Posey Tube (mammoth, 80 feet below sea level); several localities in Berkeley, one being off the Berkeley wharf (mammoth dredged from below sea level); several localities on the eastern border of San Pablo Bay; and one near Benicia on Carquinez Strait.

A number of extinct Pleistocene mammals have been obtained from the younger alluvial deposits previously thought to be Recent (Temescal formation, younger alluvium). As such fossils have been found on both sides of the bay within a few feet of the top of the younger alluvial deposits, it is evident that the bulk of this younger (or later) alluvium is Pleistocene, and that the Recent part is but a small fraction.

*River System of the Upper Pleistocene.* Borings have been made into the bottom of the upper bay and Carquinez Strait along lines for proposed bridges or possible locations for a salt-water barrier. In connection with such borings little attention was paid to the conditions of origin or the age of the material penetrated, the object being primarily to determine the physical character of the layers penetrated. While, therefore, little for the historic record can be derived from the data, certain information is available concerning the buried bedrock topography and the depth of bay deposits.

In Carquinez Strait the deepest reported boring to bedrock was 167 feet below sea level. A number of streams tributary to the bay, such as Napa Creek, Petaluma Creek, and streams from the Marin side of San Francisco Bay, entered the main valley through valleys or canyons over ground that is 150 to 200 feet below the present sea level. Boring profiles indicate that these valleys were of open V-shaped form. Streams operated on a bedrock floor, and had not reached the stage where by meandering they would produce flat-floored valleys. In other words, the streams were still eroding, or down-cutting, when their activity was stopped by changed conditions which gave rise to filling rather than cutting.

A series of borings across San Pablo Strait, which separates San Pablo Bay from San Francisco Bay (in the restricted sense), did not include a sufficient number of holes to bedrock to develop a bedrock profile. In a distance of 7500 feet only two borings reached bedrock, the deepest at 240 feet below sea level. The actual lowest point of the bedrock floor is probably deeper.

The combined Sacramento and San Joaquin Rivers reached the ocean through the Golden Gate canyon. To date no borings to bedrock, except on the shallow sides, have been made between San Pablo Strait and the sea, so that the course of the river cannot be definitely traced nor the profile of the river bed determined. The Golden Gate is by far the deepest part of the bay. The deepest sounding reported by the Coast and Geodetic Survey is 381 feet below sea level. The strong tidal currents prevent the deposition of mud and sand on the bottom. In the course of a study of the bottom deposits of the bay in 1912-13, the only samples obtained from the deep part of the Golden Gate, along and immediately west of the line of the Golden Gate Bridge, were rock fragments dragged by a dredge from the bottom surface. The largest was a fragment of gabbro 18 inches long and 61 pounds in weight. Gabbro has not as yet been found on either shore, but elsewhere it is associated with serpentine, a large mass of which enters the Golden Gate from the Fort Point area. All the other rock types dredged up—Franciscan sandstone, chert, and serpentine—are found on the one or the other side of the Golden Gate, and are last seen on the surface passing down beneath the water. It is concluded

that the deepest portions of the Golden Gate are floored by bedrock and represent approximately the bedrock bottom of the river that flowed through the canyon in pre-bay time.

The main bay valley did not have the simplicity of the Carquinez and Golden Gate canyons or the valleys of the tributary streams, which are valleys of stream erosion. It was traversed by hill ridges more or less diagonal to its trend, such as the Potrero San Pablo west of Richmond and the Coyote Hills near Newark; and above its surface here and there arose such hills as Angel and Aleatraz Islands, Red Rock, El Cerrito (Albany Hill), and San Mateo Point. All of these stood 200 to 300 feet higher above the bottom of the valley than they do above the bay surface today. Besides these hills and ridges, the upper parts of which are now visible, borings have shown that there are lower hills and ridges whose tops are below sea level; a number of them are partly or entirely buried in bay sediments. All of these hills and ridges known are composed of Franciscan sediments and igneous rocks.

According to the figures obtained from borings, the main river was not a sluggish stream. It had an average gradient, at the end of its bedrock eroding period, of 8 or 9 feet to the mile, from where Carquinez and Napa canyons joined the bay valley, to Golden Gate canyon.

Data concerning the stream that traversed the southern part of the bay valley are very limited. Bedrock is found in the lower gorge of Coyote Creek (southeast of San Jose) at 80 feet above sea level. As this location is about 60 miles from the deep part of the Golden Gate the general average gradient would be about 7.7 feet per mile. Judged from the deep boring (369 feet) to bedrock east of Hunters Point, the gradient of the last 12 miles could not be much more than 1 foot per mile. Coyote Creek had, of course, important additions of water, from San Antonio, Guadalupe, Alameda, and other streams, on its way to Golden Gate canyon. However, the river from the north carried a much larger volume of water and under normal conditions of erosion should have had a lower gradient than the southern tributary. The fact that the actual conditions were the reverse is another indication that the bay valley originated primarily by crustal deformation rather than by erosion. The explanation of the steeper gradient to the north probably lies in involvement of that area to some extent in the Pleistocene deformation already described.

North of the Golden Gate the cross profile of the bay valley is unsymmetrical with respect to the bay or the old river. There is a marked difference in the two sides. On the west the steep slopes of the mountainous mass of Marin County, culminating in Mount Tamalpais, extended down to the bottom of the bay valley and the Pleistocene tributary streams entered the valley along canyons. Their loads of sediment were apparently contributed directly to the main river.

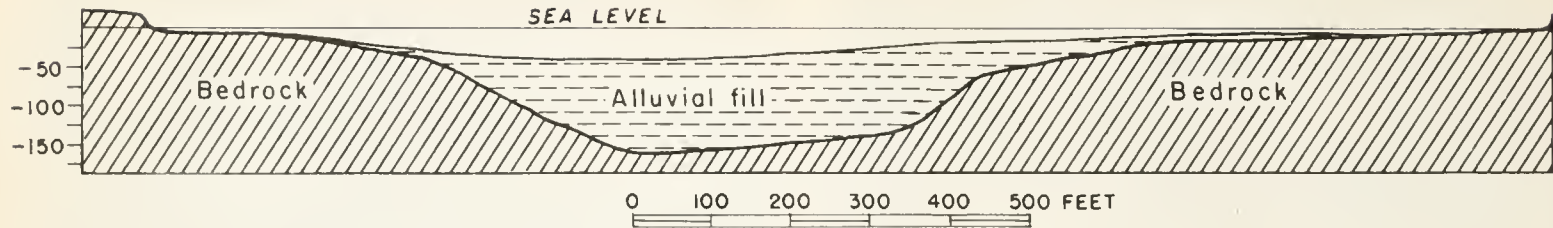


FIG. 7. Section showing bedrock profile across Mare Island strait and its relation to bay deposit fill and mean low water.

At present the bay waters enter these canyons, forming indentations or small bays, and the interstream ridges extend out into the bay as points or peninsulas.

On the east side of the bay valley the hills have correspondingly steep slopes, but these become less steep at elevations of 200 to 350 feet above present sea level. On the gentler slopes, streams draining the upper parts of the hills have built a series of alluvial cones which coalesce to form a broad sloping plain on which the east bay cities have been built. This condition, which extends the whole length of the east side of the bay valley, made possible the preservation of evidence from which the history of the valley and its early inhabitants was deciphered.

The southern part of the bay valley is more symmetrical, and similar lowered slopes on the west side have given rise to alluvial cones, an alluvial plain, and city occupancy as on the east side.

*The Advent of the Bay.* The next stage in the transformation of the landscape was the progressive flooding of the lower levels of the valley and canyon regions; the development of San Francisco Bay and associated water bodies. The valley of San Francisco Bay became a typical drowned valley; salt water invaded the region and ocean tides became effective throughout the flooded areas.

Drowned valleys can be produced by depression or subsidence of the land, and for many years it was believed that a belt of local subsidence was responsible for the production of the bay. However, no independent evidence of a subsidence so timed and oriented as to produce the distribution and characteristics of the actual flooding has been observed; and for some time previous to the advent of the bay critical parts of the river system were evidently operating under the influence of rising ground, especially in the north bay and along Carquinez canyon.

In more recent years it has been recognized that an entirely different agency was competent to account for the production of the bay; that is, the rise of the ocean level as a result of the melting of the

great ice sheets of the glacial period. Such an explanation is consistent with other evidence of the geological recency of the bay's development.

The acceptance of the glacial control theory simplifies previous ideas as to the later earth movements in the area. The eastern hill lands were elevated in Pleistocene time, and the valley area experienced a relative, if not an absolute, depression. Under the depression theory of bay origin, a belt from the ocean to the Great Valley must have subsided, the maximum subsidence following a peculiar curved course and reversing the movement of the uplifting masses. But after the bay was well established, eastern lands were still going up. For on the eastern shore of San Pablo Bay an oyster bed laid down in the bay has been raised well above the present sea level. Similar deposits, now above sea level, containing shells of species at present living in the bay, occur on Carquinez Strait. The Merritt sand, which underlies part of Oakland and Alameda, probably had a similar origin; it is a marine sediment which lies in front of a sea cliff cut into the San Antonio alluvium at a time when the area was lower than at present.

It is evident that the flooding that produced the bay was not limited to relatively depressed areas but, where topographically possible, spread across the uplifting areas, and through the Carquinez gorge, to reach into the lower elevations of the Great Valley (a relatively depressed area) and produce Suisun Bay. The elevation of the eastern hill lands was a long and slow process. That it acted in stages with periods of rest between is indicated by the remnants of stream terraces found in Carquinez canyon and adjoining areas. Two of these are below present sea level. The lowest, 120 feet below sea level, suggests that the last increment of pre-bay elevation must have started well along in the Pleistocene, and that the resultant stream down-cutting was interrupted by the rising bay waters. The rise of sea level that produced the bay was a much shorter and on the average more rapid process than that which elevated the hill lands, even though it was only about a quarter of an inch a year.



FIG. 8. Late Quaternary oyster bed raised well above present bay level showing unconformable contact with north-dipping upper Miocene marine beds. Sea cliff just south of Lone Tree Point opposite Rodeo, Contra Costa County. *Photo by O. E. Bowen.*



FIG. 9. Raised oyster bed on Lone Tree Point showing detail of the shell bed. *Photo by C. W. Chesterman.*

*Amount of Rise of the Sea Level.* If at the beginning of flooding the river mouth was at the west end of the Golden Gate—and at present there is no evidence to the contrary—and if the deepest part of the Golden Gate is on bedrock, the deepest sounding reported by the Coast and Geodetic Survey, 382 feet, may be used as an approximate measure of the change of water level since that time.

A river flowing into the sea, if at base level, would have the bottom of its bedrock channel below low tide level to an amount dependent on the effective depth of the stream. For the river in the Golden Gate this might have been 20 or 30 feet. If 381 feet is taken as the bottom of the channel, the change in water level would have to be reduced by such an amount, say to 350 or 360 feet. If the deepest sounding was on a stretch locally scoured below the even gradient, the figure for the change would be still further reduced. On the other hand, 381 feet may not represent the channel bottom, and may not be the deepest possible sounding. These details are mentioned to indicate that the figure 381 should not be taken as an accurate figure for the change in water level, but as an approximation; the actual figure may differ by 20 or 30 feet or more.



FIG. 10. Ellis Landing shell mound near Richmond, the highest part surmounted by a shed, as seen at high tide.

Several scientists have attempted to arrive at a figure for the rise of sea level resulting from the melting of the ice sheets by estimating the volume of ice that disappeared. This requires a determination of the areas and thicknesses of the departed ice sheets. Much is known about these quantities but the data are incomplete and some of the estimates, especially of thickness, uncertain. It is surprising, with these uncertainties, that three outstanding studies have led to results, expressed in rise of sea level, ranging only from 75 or 85 to 103 meters.

Local studies along European coasts have shown that sea level during the last glaciation stood at approximately 100 meters (about 330 feet) below its present elevation. One study was made of conditions over a large area considered to have maintained its stability since the Pleistocene—the so-called Sunda Land, now covered by the shallow Java Sea and the South China Sea. Old river courses were traced on hydrographic maps, and it was found that before the post-glacial flooding they passed into the sea at what is now approximately the 100-meter depth contour.

It appears likely, therefore, that the rise of sea level resulting from melting of the ice sheets of the last glaciation (Wisconsin) accounts for the flooding that produced San Francisco Bay. Because of the numerical uncertainties, local crustal movement affecting the Golden Gate and adjacent parts of the bay region during that time cannot be excluded; if such occurred since the beginning of last sea-level rise, which was probably initiated 15,000 to 25,000 years ago, its effects must represent only a small fraction of the result. The small apparent discrepancy is within the limit of error of the estimates and measurements.

*Effects of Earlier Glaciations.* It is known that during the glacial period there was a succession of stages of ice-sheet development separated by intervals of recession. During the great interglacial interval in mid-Pleistocene time, when less glacial ice existed than at present, it might be expected that the sea level would have risen higher than it is today. The bay deposits now found above sea level on the east side of the bay might have been formed under such a high stand of the sea. However, nothing corresponding to these deposits has been found anywhere on the west side of the bay at any level. Their above-sea-level position has therefore been accepted in the present account as the result of the continuation of the elevation of the area east of the bay after the bay had been well established.

The great interglacial interval has been estimated as existing from 400,000 to 240,000 years ago. This would probably bring it into the time of the mid-Pleistocene crustal disturbance of the California coastal region. It seems likely that these earth movements prevented the preservation in recognizable form of evidence of the earlier glacial effects on sea level.

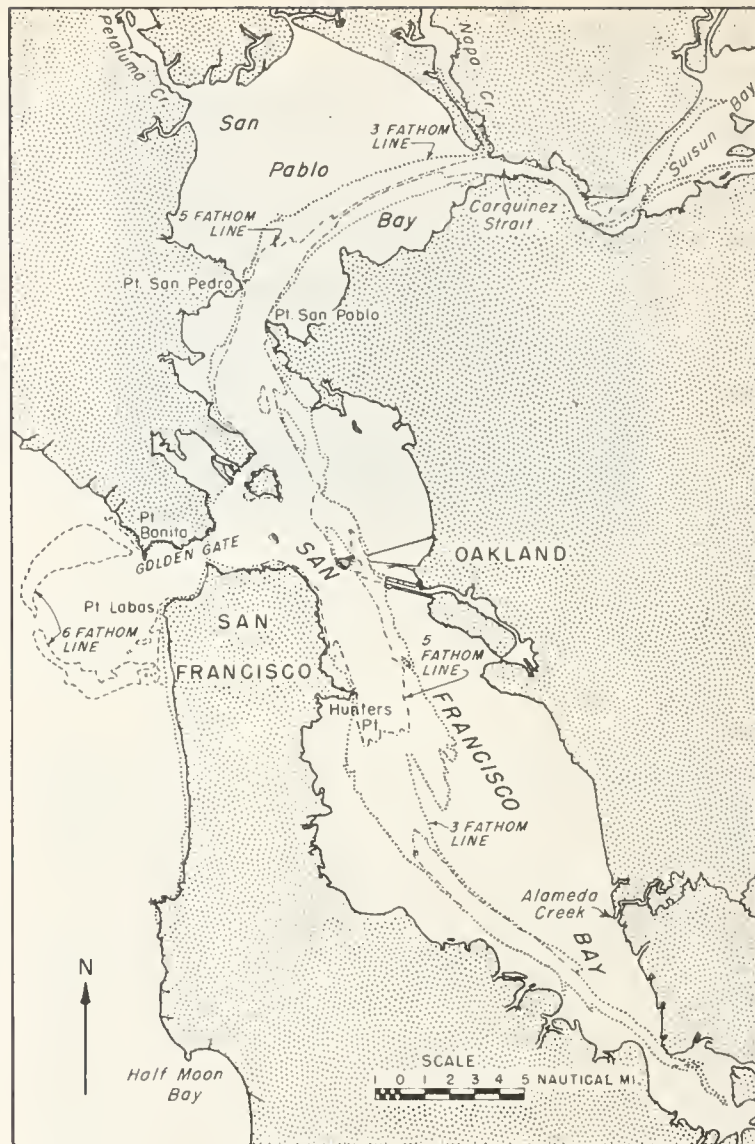


FIG. 11. San Francisco Bay showing 3-fathom and 5-fathom lines, and the 6-fathom line off the Golden Gate.

*Man in the Bay's History.* Along the shores of San Francisco Bay, and in their vicinity, the existence of many shell mounds testified to the human occupation of the region for a long time previous to the coming of European man. Many of these mounds have been partially or completely destroyed in the course of the settlement and development of the region by new inhabitants, but in 1908 a survey under the auspices of the University of California found 425 such shell heaps. Many human skeletons were obtained from the mounds, together with numerous tools and implements and decorative objects. Altogether there was much learned about the characteristics, food habits, and activities of the early inhabitants. Of particular interest to the present story is the fact that at least 10 of the mounds extended below sea level, and such partially submerged mounds were found on both sides of the bay. While most of these were in the central bay region (near Richmond and Berkeley on the east side, Tiburon on the west side), one or two were found at each end of the bay. Three of the mounds were tested for depth and showed a submergence of 3 to 18 feet.

The most information was obtained from the Ellis Landing mound near Richmond. It was probed and trenched, and a shaft was sunk to its bottom. Its base was oblong in contour, 460 feet in length, and 245 feet in average width. The height of the mound was about 30 feet, and the estimated volume of material built up by human agency was 1,260,000 cubic feet; 146 human skeletons were obtained during the excavation and it was estimated that the entire mound probably contained in the neighborhood of 3,000. Two burials were encountered near the bottom of the shaft.

This mound was built on a base of firm gravel and at the time of the investigation (1908) high tide rose 18 feet above the base. Silt had also deposited about the mound to a depth of 11 to 16 feet. It is quite evident that when the natives first occupied this site they did not locate it where the waves at high tide would splash on them, nor would they have stayed there if the waters at high tide washed their mound while it was low. They may originally have been 10 or more feet above high tide. This would mean that since their first occupancy the bay waters have risen perhaps 25 or 30 feet. A rough calculation of the duration of the mound's occupancy, estimated on the basis of the number of inhabitants, the daily accretions, and the total volume of the mass, gave 3,500 years. This admittedly cannot be accepted as a close figure, but it may indicate roughly the order of magnitude.

*Recent Bay Borings.* During recent studies by the California Toll Bridge Authority of the California State Department of Public Works, made in connection with two proposed bay crossings, new information has been obtained on the succession of formations deposited on the bay floor. These formations are described in detail by Trask

and Rolston.\* Briefly the succession, top to bottom is: bay mud, 0-100 feet thick; Merritt sand, 0-60 feet; Posey formation, 0-50 feet; San Antonio formation, 15-120 feet; Alameda formation, 0-200 feet; and Franciscan formation (basement). All of these are separated by erosional intervals (unconformities).

The Alameda formation was originally recognized as a shaly clay underlying the alluvial deposits in the Oakland-Alameda-Berkeley region. The recent borings show that it extends across the bay and on the west side lies against the bedrock slope at 130 to 180 feet below sea level and is overlain by later bay deposits. In a boring along the line of the southern crossing and about 5,000 feet from the west bay shore a layer of volcanic ash was sampled at a depth of 280 feet in the lowest of the five recognized members of the Alameda formation. I am indebted to Dr. Trask for a sample of the ash which he obtained for me through the kindness of Mr. N. C. Raab of the Division of San Francisco Bay Toll Crossings. It is of particular interest because it seems to be identical with an ash layer that occurs in the upper Merced marine beds about seven miles across the San Francisco peninsula from the bore hole. Both are very fine-grained clean, white, fresh ash made up chiefly (over 95%) of fragments of clear glass and pumice. The most abundant light mineral is an acid soda-lime feldspar and the characteristic colored mineral is hornblende (pleochroic colors green and pale brown). These are the only occurrences of volcanic ash found to date in the bay deposits or in adjoining Pleistocene deposits. The source of the material is not known. The Sonoma tuffs to the north of the bay show some similar ash layers, but these consistently have a development of pyroxene dominant over hornblende. No augite was observed in the local ash beds. In the absence of evidence to the contrary their essential identity is accepted as evidence of the contemporary deposition of upper Merced and Alameda.

The San Antonio and the Posey formations of the bay occupy the same interval between the Alameda formation and the Merritt sand that the San Antonio formation alone does on the land east of the bay, and the two bay formations together are believed to correspond to the land San Antonio. The separation of the bay deposits into two formations was based on the recognition of an erosional interval between them. This erosional interval is best explained as the result of a temporary change in the relative position of sea level, and such change would probably have no effect on the deposition of the now exposed parts of the San Antonio alluvial cones.

The most important erosion interval in the bay deposits was that following Posey deposition. The streams flowing westward from the hills back of Oakland cut valleys in the older sediments which are 80 to 100 feet below sea level along the present Oakland and Alameda

\* Trask, Parker D., and Rolston, Jack W., Engineering geology of San Francisco Bay: Geol. Soc. America Bull., vol. 62, no. 9, pp. 1082-1083, 1951.

water fronts. They drained into a master valley coming from the south that continued northward across the submerged rock ridge that joins Yerba Buena Island with San Francisco, and onward to the west of the island. Where last tested by boring it lay more than 150 feet below sea level.

This valley cutting was followed by the deposition of the Merritt sand. This formation with its well-sorted sand, in part showing evidence of wind-blown origin, and its well sorted silt similar to loess, is suggestive of the influence of glacial conditions. Such conditions would hardly have been expected in this locality so far from the ice sheets. The Merritt filled the previously cut valleys and covered the Posey formation as a general blanket.

Following deposition of the Merritt the valleys were re-excavated in part to the same depth as before. Their drainage in the Oakland-Alameda region escaped along the same line passing to the west of Yerba Buena Island. The low sea level at this time apparently was the result of the last glacial advance.

The final withdrawal of the ice sheets, whose disappearance is generally accepted as terminating the Pleistocene epoch, led to the gradual rise of the sea level to its present elevation, in the course of which the bay muds were deposited.

*Glacial Stages.* In the construction of the San Francisco-Oakland Bay Bridge, during the excavation for pier E-3, which is about 1,500 feet east of Yerba Buena Island, part of a jaw of a bison carrying several teeth was found at a depth of about 180 feet, close to a two-foot layer of decayed vegetation. The depth and the vegetation layer are evidence that the occurrence is near the base of the San Antonio formation. This find together with a mammoth tooth found in another bridge excavation (E-5) about 1,000 feet further east, determine the San Antonio formation as upper Pleistocene. As the San Antonio and the correlative of the Alameda (upper Merced) follow the major mid-Pleistocene compression and precede the upper Pleistocene deformation, these bay formations, preceding the main lowering of the sea level in the midst of bay deposition, are considered lower upper Pleistocene. In other words, the whole known history of the Bay of San Francisco is within the upper Pleistocene and Recent. On this basis it is concluded that the first development of the bay was the result of the rise of sea level during the third, that is, the last (Ultimate) interglacial, and so may have been 150,000 or more years ago. The marked lowerings of the sea level in post-Posey and post-Merritt time would then represent stages of the last glaciation, the Wisconsin, with an interstage retreat of the ice between them.

The development of the bay was a slow process. In the early stages the streams must have retained their identities, followed the lines of their earlier channels, and been flanked by tidal marshes.

Most of their load of sediment was carried to the sea. More than half the time from the beginning of last sea-level rise to the present (possibly 8,000 to 12,000 years) must have passed before the advancing sea water traversed Carquinez canyon to reach the edge of the present Suisun Bay. With increasing depth the bay system became a great settling basin for the retention of detritus carried by the tributary streams, although still some of the transported material (an unknown fraction) reached the ocean.

The coming of the white man led to the most rapid build-up of sediments in the bay's history. This resulted from his activities that added to the silt and sand content of the inflowing streams. The most noteworthy of these activities was the early widespread hydraulic mining; but substantial contributions also have resulted from farming, road and trail building, deforestation, denudation of grass lands by overgrazing, etc. From a study of successive hydrographic charts, the following rough figures were reached:

*Sediment added to bay system from all sources,  
1849-1914*

Body of water	Dates of surveys	Volume of deposits (cu. yds.) between survey dates	Estimated volumes (cu. yds.) 1849-1914
Suisun Bay .....	1867-1886 .....	64,000,000	200,000,000
Carquinez Strait.....	1861-1890 .....	40,000,000	50,000,000
San Pablo Bay .....	1857-1897 .....	366,000,000	570,000,000
San Francisco Bay.....	1856-1896 .....	196,000,000	326,000,000
Total.....	.....	.....	1,146,000,000

Among drowned valleys San Francisco Bay is peculiar in that its connection with the ocean is through a comparatively narrow east-west channel that opens into the middle of the long north-south body of the bay. Within the bay the main tidal effects on sedimentation are in the form of hydraulic currents. With rising tide the main current enters the bay through the Golden Gate and branches to the north and to the south, maintaining channels in both directions. With outgoing tides the waters unite again in the main channel of the Golden Gate.

Fresh water enters the bay in part by small local streams draining the immediately adjacent Coast Ranges, but in the main from the combined Sacramento and San Joaquin Rivers, the waters of which enter the bay near its north end through Carquinez Strait. The major part of the silt entering the bay comes in at the northern end, and much of it is deposited there. However, such deposits are abundant in the southern arm of the bay; part of these are derived from river silts that entered at the north. The spreading of the flood waters as they migrate down the bay, and the wind currents, often carry some of

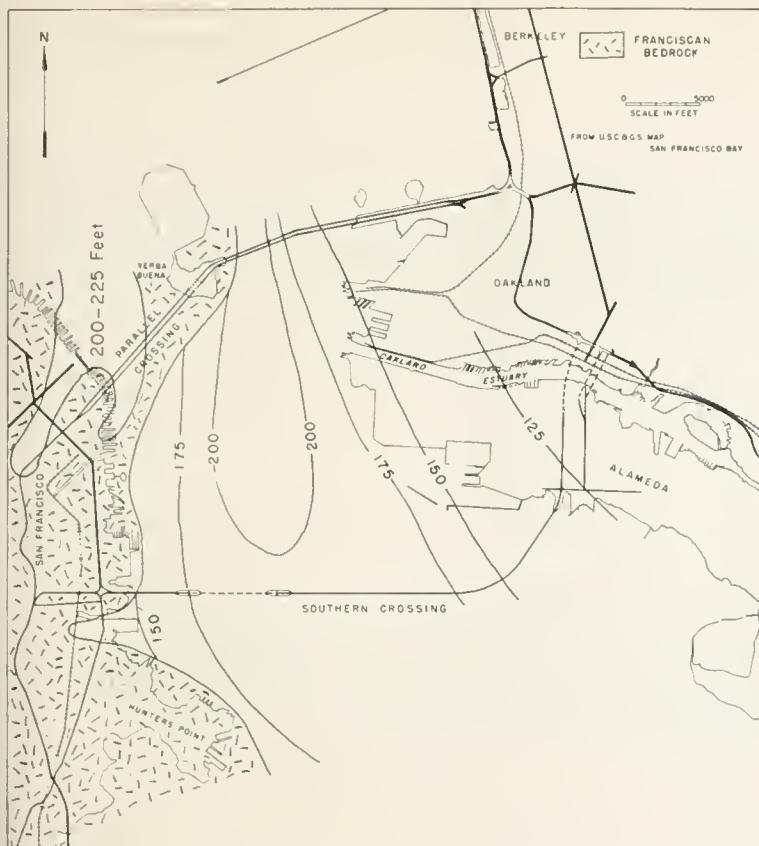


FIG. 12. Contours on the top of the Alameda formation showing the drainage prior to deposition of the San Antonio formation. Principal channel at that time was east of Yerba Buena Island instead of west of the island as it is at present. After P. D. Trask and J. W. Rolston, in *Bull. Geol. Soc. America*, vol. 62, no. 9, September 1951.

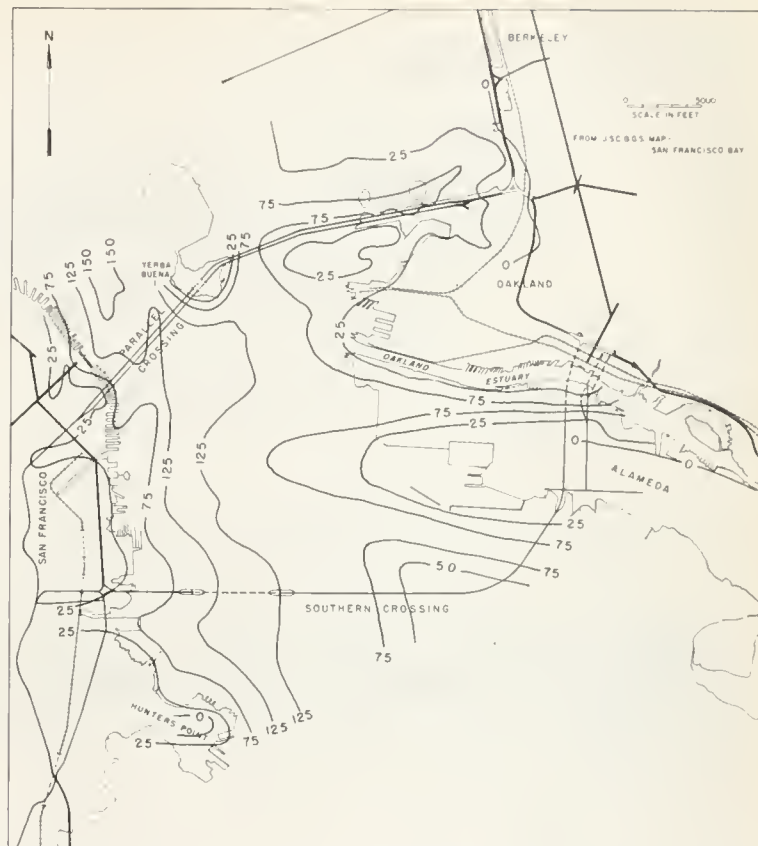


FIG. 13. Contours on the base of the Bay Mud, the uppermost deposit in San Francisco Bay, showing the drainage pattern as it was prior to this most recent episode of deposition. The principal channel is west of Yerba Buena Island as it is today. After P. D. Trask and J. W. Rolston, in *Bull. Geol. Soc. America*, vol. 62, no. 9, September 1951.

the mud-laden waters south of the normal exit point. However, the tide is the most important distributing agent. Silt-laden water during ebb passes through the Golden Gate to the ocean. With the turn of the tide the body of water in the Golden Gate is moved back, dividing, as it enters the bay proper, part of it being carried into the south arm of the bay, and this is repeated with every tidal return. During the slow movement of the water, including the period of practically no movement, about high tide limit, some of the suspended fines are deposited.

*Depths of Water.* According to calculations published in 1914, which may be taken as approximately correct at the present time, about 70 percent of the area of the bay has a depth of less than 3 fathoms\* and 80 percent has a depth of less than 5 fathoms. The tidal flow has developed and maintains a system of channels, a sort of submarine stream system, in which are found more rapid currents and the greatest depths. The deepest of all is the main trunk channel, the Golden

\* Figures given here in fathoms (1 fathom is 6 feet) are depths below mean lower low water; depths given in feet in this paper are below mean sea level.



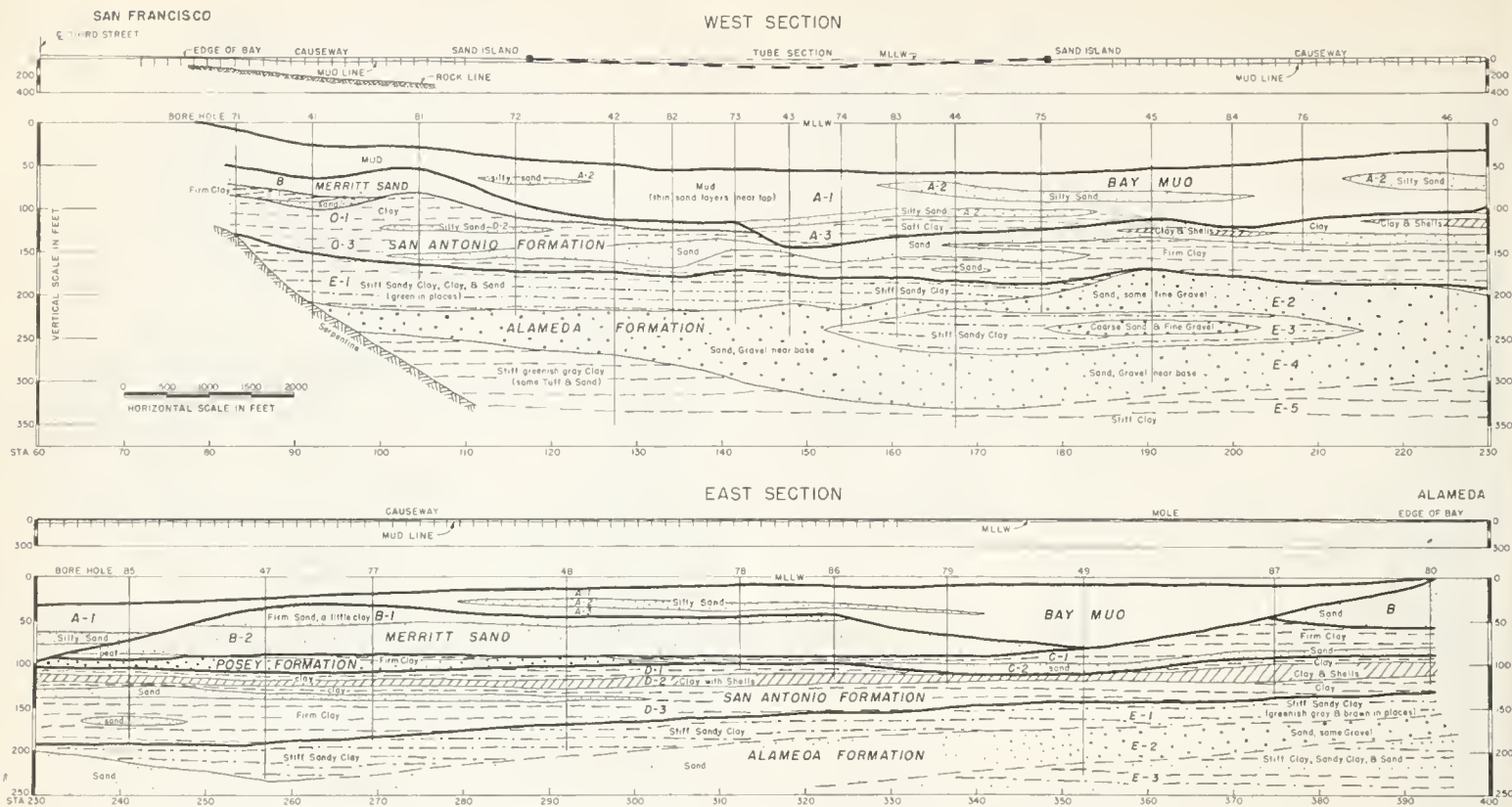


FIG. 14. Cross section along the proposed line of the southern crossing (see Fig. 13) between San Francisco and Alameda, based on drill-hole data. Heavy lines represent boundaries of the principal formations; lighter bounding lines represent changes in lithology. After P. D. Trask and J. W. Rolston in *Bull. Geol. Soc. America*, vol. 62, no. 9, September 1951.

Gate, in which the greatest recorded measurement is 63 fathoms. The main branch channel to the north, Raccoon Strait, reaches a depth of 36 fathoms.

*Distribution of Sediments by Size of Grain.* There are two main types of distribution of bay sediments by prevailing grain size: (1) that in which grain size decreases with depth of water and distance from certain elements of the shore line, and (2) that in which coarseness increases with depth of water.

The first type of distribution corresponds to the normal distribution of sediment on an exposed rocky sea coast, that is, coarsest material along the shore terrace at the base of wave-cut cliffs (gravel, etc.), grading through gradually decreasing sand sizes to muds.

At intervals along the bay shore occur projecting rocky points or headlands. Each is more or less (depending on exposure) affected by wave cutting and is bordered by a sea cliff at the base of which is gravel or gravelly sand. Passing outward toward deep water, and laterally trailing away from the cliff in both directions along the shore, the shallow water and beach deposits become progressively more sandy, and finally muddy. Considering the bay as a whole, while this type of deposit is repeated at about 20 localities, it represents but a small fraction of the bay deposits.

The second type of distribution is characteristic of by far the larger area of the bay. The greater extent of shore line is occupied by muds which merge into the muds of the outer and lateral zones of wave-rock reaction influence. Proceeding from these muds into deeper water, the proportion of clay and silt in the sediments decreases and the proportion of sand increases. With greater depths the sands carry more of the coarser grain sizes, and in the more noteworthy depths gravel is found where there is a local source for that type of material. This type of distribution is determined by the tidal currents which are weakest about the edges of the bay and become progressively stronger as the channels become deeper. It is, of course, the concentrated flow of the tidal currents that has produced and maintains the depth of the channels.

The amount of fines that gets into the Golden Gate must be large, but the amount deposited is almost nothing, only some sand that gets trapped between larger fragments. Part of the fines that reach the Golden Gate is carried back into the bay during the rise of the tide. Some of this is deposited in quieter places, but much of it is swept out to sea.

The south main branch channel, as much as 27 fathoms in depth, is occupied largely by sands. The north main branch, which has measured depths up to 36 fathoms, has yielded samples carrying much gravel.

*Maximum Thickness of Bay Deposits.* The thickest masses of bay sediments so far penetrated by borings have been found in the

central bay area east of San Francisco, from the line of the San Francisco-Oakland Bay Bridge east of Yerba Buena Island south and southwestward to near Hunters Point. To date, the deepest bedrock surface reached by boring on the west side of the bay south of Yerba Buena Island is 369 feet below sea level. The water there is about 69 feet deep, so the thickness of sediment is 300 feet. As two borings to the northeast and southeast of this deepest one are 314 and 326 feet respectively, the suggestion is that the bottom shallows to the east and the deepest boring is along the channel of the pre-bay north-flowing stream.

On the east side of the bay the bedrock drops down to the east and southeast of Yerba Buena Island. The deepest bedrock surface reported in a boring is under the western part of Alameda at 444 feet below sea level. It is not known how far east this down-slope extends. Apparently here the bedrock surface is 60 feet or more below what has been taken as the deepest bedrock surface in the Golden Gate. This relation must be the result of crustal deformation which presumably took place in pre-Alameda time or at some early date in what has been called Alameda formation in the bay sediments. In this deepest hole, and in other holes in this eastern region where bedrock has been reported as over 320 feet in depth, as far as known, no geological study was made on a formational basis. It is therefore possible that the relative depression in the bedrock may be occupied by some older formation, which may or may not be a bay deposit, and may be separated from the true Alameda formation by a structural unconformity. This suggestion is made here because the first definite evidence of the position of the river from the south in this area, on the top of the Alameda formation, places it near the east shore of Yerba Buena Island. The recent work on bay borings makes it evident that the change was made some time during San Antonio-Posey deposition. At the beginning of San Antonio deposition, as shown on the contour map of the top of the Alameda formation, the channel was about 2000 feet east of Yerba Buena Island at a depth of 200 feet below present sea level. When the lowering of the sea came at the end of Posey deposition, the drainage crossed the buried ridge connecting Yerba Buena Island and Rincon Hill and flowed west of the island. It could hardly have done that if the main tidal channel had not already been established along that route.

*Buried Topography and Shifts in Tidal Channels.* Considering the fact that the San Francisco Bay basin was valley land before the encroachment of marine waters turned it into a bay, and that the streams, including the combined Sacramento and San Joaquin Rivers, flowed along its floor, it might reasonably be inferred that the present main channels are inherited from the dry land period, held in place by the more rapidly moving currents which in the early stages

of the bay would naturally have been in the deepest troughs. When therefore it is found that the deep north branch channel heading up to where the combined Sacramento and San Joaquin Rivers enter the basin is the narrow Raccoon Strait northwest of Angel Island, it would seem reasonable to conclude that that was the course of the pre-bay river. A special geological explanation would then seem necessary to make clear why the main river took that course rather than down what appears to be the main valley to the east of Angel Island.

There is as yet no evidence regarding the history of that channel but recently some definite evidence has been obtained regarding the main south branch channel, which lies between San Francisco and Yerba Buena Island; this evidence suggests that Raccoon Strait does not represent the course of the original main river.

Borings for the San Francisco Bay Bridge have shown that to the east of Yerba Buena Island bedrock lies at a depth of more than 300 feet, whereas to the southwest of the island it is at a depth of less than 200 feet. There is, in fact, a low ridge with rolling summit topography that connects the island with Rincon Hill on the San Francisco peninsula. The present deeper south main branch channel crosses this ridge, which, except for its high summits (Yerba Buena Island and Rincon Hill) is entirely buried in bay sediment and does not show on the hydrographic chart. In pre-bay time, Yerba Buena Island was separated on its west from the present San Francisco area by a northward-draining tributary valley with its floor about 100 feet below the saddle in the ridge over which the present tidal channel lies. This valley, going upstream, turned to the southwest between Rincon Hill and Telegraph Hill in San Francisco (approximately along the line of Market Street) and drained the branch valleys coming down from the surrounding hills. In the progressive flooding of the bay valley system, the ridge joining Yerba Buena Island and Rincon Hill would not have been covered by water over its saddles until the water was about 230 feet above the floor of the Golden Gate, and at that time the original valley floor east of the island would have been more than 150 feet below the bay water surface.

At the present time the connecting bedrock ridge carries on its top a maximum of 100 feet of bay sediment. The greatest depth of water directly west of Yerba Buena Island is 143 feet, but this is near the island, and above the old valley drainage line there is about 80 feet of water over 120 feet of bay sediment. Directly east of the island the greatest depth of water is 96 feet, at a location near the island where the bedrock is about 290 feet below the water surface.

It is evident that the position of the deep south branch channel has at some time changed from east to west of Yerba Buena Island. Why it was made is not certain, but it may be because the new course is the shorter and more direct route, and because the direct movement

of the water is not interfered with or complicated by secondary reactions of the waters from the north and south arms of the bay, as occurs in the broader body of water to the east. A similar change may have developed the deep north main branch channel in Raccoon Strait.

*Future of the Bay.* It is difficult to predict the future of San Francisco Bay. Man is engaged in many activities that will affect that future. Many large dams have been and are being built on its tributary streams which, during their lifetime, will retain sediment that otherwise, in part, would add to the filling of the bay. On the other hand, many improvements of water fronts and the reclamation of marshes work toward restricting or narrowing the area of the bay. A plan under consideration would divide the bay by great embankments into three parts and make fresh-water lakes of the northern and southern areas. This would result in the production of two settling basins that would retain most of the incoming sediment, reducing materially the amount that now reaches the sea. The remaining bay would occupy a comparatively small area, and the tidal prism would be greatly reduced, lessening the effectiveness of the tidal currents to maintain channel depths.

As to the effects of nature beyond the control of man, there is also considerable doubt. We do not know whether we are in the midst of a moderate interglacial interval and a new glacial stage will follow and thus again lower the sea level, or whether deglaciation will continue until the present glacial ice all disappears, resulting in a sea-level rise of perhaps another 130 to 170 feet. Crustal movements are likely to produce still further effects, but are unpredictable. Whatever the trend, the modification of the landscape will, as in the past, progress so slowly that no one in the course of a lifetime will be aware of any marked change, even if such change is measurable.

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FIG. 15. Bedrock contours, Yerba Buena Island to San Francisco. Figures represent depth in feet to bedrock below mean sea level. Based on the Hoover-Young San Francisco Bay Bridge Commission Report, pls. 7 and 8.

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## DEVELOPMENT OF THE LANDSCAPE OF THE SAN FRANCISCO BAY COUNTIES \*

BY ARTHUR DAVID HOWARD †

*The Modern Landscape.* The bay region as here defined extends from the Pacific Ocean to the foothills of the Sierra Nevada, embracing the full width of the Coast Ranges and the Great Valley of California. The Coast Ranges form a continuous barrier between the valley and the sea except in the bay region. Here a broad irregular gap in the mountain barrier, now flooded by the waters of San Francisco Bay, affords outlet for the drainage from the east.

The Coast Ranges consist of a number of nearly parallel ranges confined to a belt averaging about 50 miles in width. The belt itself trends about N. 30° W., approximately parallel to the coast, but the individual ranges within the belt trend more nearly northwest and are diagonally truncated by the coast line. Thus on one side they end abruptly along the sea, and on the other they terminate with gentler declivity along the edge of the alluvial plain of the Great Valley.

Most of the ridges are between 2000 and 4000 feet high, but a few summits are above 5000 feet. The flat-topped crests of many of the ranges represent remnants of a once extensive, gently undulating erosion surface. Higher ridges stand as residual prominences above the hilltop remnants of this old level, and locally bear remnants of an even higher and earlier surface. Below the remnants of the principal upland surface, youthful canyons have been carved.

The variety of topographic expression found in the different parts of the Coast Ranges has been attributed primarily to the variety of types of uplift to which the ranges have been subjected, and secondarily to differential erosion of diverse rocks and to the many types of rock structures involved. In some cases, erosion and deposition have greatly obscured the original forms produced by the earth movements. Some of the ranges have been raised in horizontal position, some have been tilted, and others have simply been arched upward. True horsts (uplifted blocks bounded by faults) and simple warped blocks are the least common; tilt blocks are the most common. The majority of ranges are more complex, having been formed by combinations of movements. The fault pattern itself has strongly influenced the topography. Where the bounding faults are parallel and straight the ranges tend to be uniform in width and rectilinear. Where the limiting faults converge, diverge, and branch, the breadth of the mountain blocks varies. Faulting has directly or indirectly played the dominant role in the fashioning of the present landscape. Because of this, there is

a lack of correspondence between topography and geology, in contrast to the situation in other ranges of the world such as the Appalachian Mountains of eastern United States and the Jura Mountains of western Europe.

The valleys of the Coast Ranges are as varied in origin as the mountains which confine them. Some, such as the Santa Clara Valley, are down-dropped or down-tilted blocks. Others, like the Livermore basin and the basin of San Francisco Bay are irregular downwarps complicated by faulting and modified by erosion and filling. Some of the valleys north of San Pablo follow synclines. These have been carved either by streams which came into being on original folds or by streams that originated along belts of weak rock after an earlier peneplanation. Other valleys were clearly carved along fault zones, and still others have had complex histories involving periods of filling and re-excavation as well as deformation.

Large areas in the Coast Ranges have a fault-trellis drainage pattern in which the principal valleys have been eroded along fault lines. These valleys, although parallel for long distances, commonly diverge, and a dendritic or tree-like pattern develops in the broad inter-fault areas. This type of fault-trellis pattern is particularly well displayed in the San Mateo quadrangle.

North of San Francisco Bay the Coast Ranges consist of four parallel ranges, named from east to west the Yolo, Napa, Sonoma, and Marin. The intervening valleys in the same order are the Berryessa, Napa, and Petaluma. None of the valleys compare in size with the Santa Clara Valley south of San Francisco Bay. Petaluma Valley, in the neighborhood of the low watershed near Santa Rosa in Sonoma County, is 4 to 5 miles wide, but narrows appreciably within 12 miles to the north. About 50 miles north of the bay, the above-mentioned ranges, except the Sonoma, merge into a single, sprawling dissected upland, the Mendocino plateau. Of the valleys mentioned, only the Petaluma and its extension along the valley of the Russian River continue that far north. The Mendocino plateau is a rugged belt 10 to 20 miles wide extending from the Marin Range north to Cape Mendocino. The plateau is submaturely dissected and rises from 1600 feet on the west to 2100 feet on the east, where it is surmounted by higher residual summits forming the Mendocino Range. The uniform altitude of the ridge crests north of San Francisco Bay, and the scattered level summits, suggest an ancient peneplain. Whether or not a still higher surface is preserved on the monadnock-like ridges is not certain.

South of San Francisco Bay the Coast Ranges are separated by Santa Clara Valley into an eastern group, collectively known as the

\* The following outline of the evolution of the bay region landscape is based on the studies of workers too numerous to mention individually. Some of the more important publications consulted are included in the appended bibliography. The present writer's only contribution lies in the attempt to synthesize the many isolated and diverse ideas of others.

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Diablo Range, and a more or less homogeneous mountain mass to the west, the Santa Cruz Range. Santa Clara Valley is about 100 miles long and reaches a width of about 15 miles in the north where it is flooded by the southern part of San Francisco Bay. About 75 miles of the valley are included in the bay region. The greater part of the valley drains north by way of Coyote Creek into San Francisco Bay. The southern part, separated from the northern only by a large alluvial fan on the broad valley floor, drains southward by Llagas Creek into Pajaro River and Monterey Bay.

The Berkeley Hills, which overlook San Francisco Bay from the east, are a low but prominent range some 15 miles long and 10 miles wide, with an even crest and a steep, dissected western scarp. They are considered by some to be independent of the Diablo Range, the northern terminus of which, dominated by Mount Diablo, 3849 feet high, is considered to lie east of San Ramon Valley. South of Livermore basin the Diablo Range is known locally as the Mount Hamilton Range, a sprawling mass some 30 miles wide with peaks over 4000 feet high. Mount Hamilton, the site of Lick Observatory, is 4209 feet high, but is exceeded by still another crest.

The Diablo Range, that is, all of the Coast Ranges east of Santa Clara Valley, is divided into several smaller northwest-trending ridges by a number of prominent valleys, largely controlled by faults. Among these are Sunol and Calaveras Valleys. The western margin of Livermore basin itself is determined by a major fault.

The Santa Cruz Range extends south about 85 miles from the Golden Gate to Pajaro River. The range is narrowest and lowest in the San Francisco peninsula, increasing in altitude and breadth to the south. The highest peak has an altitude of about 3800 feet. The range narrows again to only 6 miles at its southern termination. The low northern portion, consisting of San Bruno Mountain and the hills of San Francisco, is cut off from the main southern mass by the trough-like depression of Merced Valley, which trends obliquely across the range from San Francisco Bay to the sea. The highest point on the floor of Merced Valley is less than 200 feet above sea level.

Northwest-trending valleys are present in the Santa Cruz Mountains, but are not so striking as those in the Diablo Range east of Santa Clara Valley. The San Andreas rift cuts the Santa Cruz Range throughout its extent. This active fault, which meets the sea just south of Merced Valley, is marked by a series of aligned valleys occupied in part by San Andreas and Crystal Springs Lakes.

The crests of many of the Coast Ranges south of San Francisco Bay are broad rolling uplands, but interspersed among these are still higher crests. The general aspect is less plateau-like than in the Coast Ranges north of the bay. Remnants of two erosion levels are present in the Santa Cruz Range; one is preserved on the summit of Buri-Buri and other ridges, at an altitude of about 600 feet; the other is

preserved on Sawyer Ridge and other crests between 1100 and 1200 feet. Whether these represent a single surface offset by faulting or two distinct surfaces has not been determined. Steep-sided youthful valleys trench each surface. Elsewhere in the Coast Ranges, at least one mature upland surface in addition to the youthful valleys is visible, but monadnock ridges may preserve a still older surface.

On the west, the Coast Ranges generally rise abruptly from the sea. Inasmuch as the coast line cuts obliquely across the ranges, the coast may correspond to a line of structural deformation, but this is by no means certain. Similar relationships prevail along the eastern boundary of the Coast Ranges at the border of the Great Valley. Throughout much of the extent of the Coast Ranges the seaward slope is notched by a series of raised wave-cut terraces, the highest of which are more than 1500 feet above the sea. The lower ones are the best preserved, in places being a mile or two wide. The terraces are poorly preserved in the immediate vicinity of San Francisco Bay. Stream terraces in the valleys of the Coast Ranges are lower and less pronounced than the marine terraces along the coast. This is believed to indicate tilting of the Coast Ranges, the greatest uplift being along the coast. The continental shelf in the bay region is 25 to 50 miles wide. A deep submarine canyon cuts across the shelf opposite the mouth of Pajaro River at Monterey Bay, but no comparable canyon appears off the Golden Gate. This has led to speculation that the drainage of the Great Valley may once have had an outlet into Monterey Bay.

Recent submergence of the coastal region is indicated by the presence of San Francisco Bay and numerous drowned valleys for some distance to the north and south. A more recent emergence, following the drowning of the bay area, is indicated by a fresh marine terrace around the shores of San Pablo Bay.

The second great landscape division within the bay region is the Great Valley. The larger part of the Great Valley is a low, generally featureless plain lying within a few hundred feet of sea level and reaching its lowest elevations in the vicinity of San Francisco Bay. Here large areas are actually below sea level, the sea being excluded by dikes and natural levees. The highest elevations are found along the valley margins where alluvial or dissected pediment slopes rise against the confining mountains. The valley is drained by California's two principal rivers, the Sacramento and the San Joaquin, which join just before entering the eastern extremity of San Francisco Bay. Throughout their courses in the bay region these rivers have gradients measured in only inches per mile. The natural levees combine with the alluvial slopes to enclose basins, some of which are occupied by flood waters or by swamps. The most important tributaries of the Sacramento and San Joaquin Rivers come from the Sierra Nevada to the east. The streams from the Coast Ranges are generally small and either

disappear on reaching the valley floor or lose themselves among the sloughs bordering the rivers.

The Sacramento and San Joaquin Rivers are choked with sediment in their lower courses and deposit excessively. The braided courses are nearly everywhere bordered by swamplands. The great quantity of debris washed down from the high southern Sierra Nevada has shunted the San Joaquin over toward the west side of its valley. The fans built into the valley by the large streams from the Sierra are far more extensive but flatter than those built by the smaller torrential streams from the Coast Ranges. The contrast in size of the opposed mountain masses is less marked in the case of the Sacramento Valley, particularly north of the bay region, and the main stream is more centrally located.

The Great Valley is largely a depositional plain underlain by sediment washed down from the confining mountains. The slopes of the depositional landforms are so slight that the valley floor appears essentially flat. Here and there, however, parts of the floor have been raised by folding and faulting and in these areas a rolling topography produced by erosion offers contrast to the otherwise monotonous landscape. The Montezuma Hills, east of Suisun Bay, have been eroded from such an uplift.

The valley includes five natural subdivisions—the red lands, the low plains, the river lands, the flood basins, and the island country. The red lands, so-called because of the characteristic reddish or reddish-brown soil, form belts of gently undulating to hilly topography along both margins of the valley. The accordance of level of the hill tops, and the numerous broad flat-topped divides, are remnants of a once-extensive level plain that descended toward the axis of the valley. This belt of dissected topography, with maximum relief of about 200 feet, stands above the flat central portions of the Great Valley, but lies below the level of the dissected volcanic plain forming the Sierran foothills. The red lands are more extensive on the east side of the Great Valley than on the west. Those within the area of the bay region have been designated the dissected Arroyo Seco pediment, and reach a width of 15 miles. The slope of the restored surface of the Arroyo Seco pediment is steeper than that of the low plains below. For part of its extent the pediment is separated from the foothills of the Sierra by a belt of low country over which the pediment originally extended. The volcanic plain, east of this low country, is a westward-sloping surface underlain by fluvial sandstones and silts, as well as mudflows, all derived from volcanic rocks in the higher parts of the Sierra Nevada. This volcanic plain is part of the foothill region.

The low plains are coalesced alluvial fans descending from the inner edge of the belt of red lands to the axial lowlands of the valley. Locally the low plains extend headward as tongues into the valleys cut

below the Arroyo Seco pediment, and where the red lands have been removed by erosion the plains reach to the foothills. The plains are fashioned from debris eroded from the red lands and the foothills beyond; they form a belt 12 to 16 miles wide, and slope 5 to 8 feet per mile. The surface is remarkably smooth except where trenched by the shallow channels of some of the streams issuing from the mountains beyond. The principal river floodplains and channels traversing the plains are, with exceptions, entrenched 15 to 40 feet below the plain at the apices of the fans, but the channels die out westward. The floors of the channels are from 300 feet to a mile wide. The plain on the east side of the valley is known as the Victor alluvial plain; it is 12 to 16 miles wide.

The river lands form the natural levees along the many rivers of the region. These are relatively narrow sandy or silty fertile belts that rise 5 to 20 feet above the adjacent lowlands. The latter are swampy and often submerged beneath flood waters from which are deposited fine clays.

The flood basins are broad shallow troughs enclosed by the sloping surface of the low plains on one side and the river lands or natural levees on the other. The basins are dry for the greater part of the year, or for periods of years, but are subject to flood where not adequately protected by reclamation structures. Because deposition within them is primarily from standing water, their surfaces are almost horizontal plains. The American and Yolo basins, north and west of Sacramento respectively, are examples of such flood basins. The lower part of the Yolo basin is below sea level and is a tidal lagoon.

The island country along the lower courses of the Sacramento and San Joaquin Rivers near their junction, consists of tracts of land hemmed in by the natural levees of the various rivers, streams, and sloughs. Each island is in a basin, usually swampy at its center. The island country is roughly the area of the delta plain of the combined rivers, a plain which, prior to the construction of artificial levees, was a maze of tidal marshes. The artificial levees along the distributaries and sloughs now protect the lowlands, which are as much as 6 feet below sea level. The boundaries of the delta plain are vague and locally have been placed at the zero or sea-level contour.

*Evolution of the Landscape.* The geomorphic history (landscape evolution) of the bay region is exceedingly complex and not yet thoroughly understood. Much of the evidence necessary to correlate events in the bay region with those in the Sierra Nevada lies buried under the thick alluvial fill of the Great Valley. In the Coast Ranges themselves, each fault-bounded block is a distinct unit whose history may differ widely from that of its neighbors. The history of each range must therefore be worked out independently before its part in the regional picture can be evaluated.



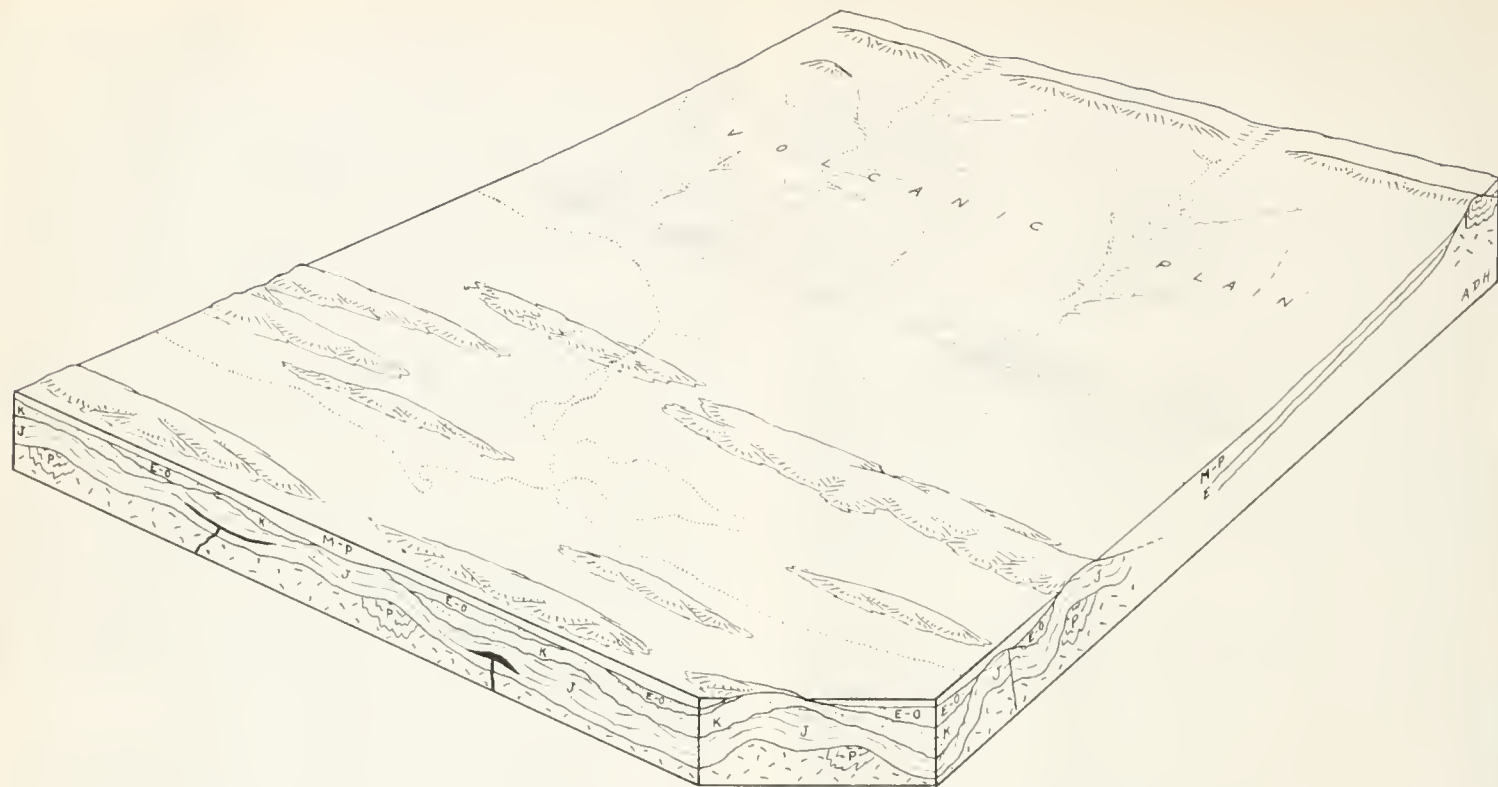


FIG. 1. Late Miocene-early Pliocene landscape. Only the lowermost foothills of the Sierra Nevada are shown. The Sierran crest lies well off to the upper right. The gradation plain, the result of erosion of the ancestral Miocene Coast Ranges and filling of the widespread Miocene seas, merges in the east with a gently sloping fluvialite plain composed largely of volcanic debris. The volcanic plain mantles an erosion surface beveling Eocene, Mesozoic, and Paleozoic sedimentary and metamorphic rocks in the foothill region, but is developed primarily on granite in the higher Sierra Nevada. The pre-volcanic erosion surface may correlate with the so-called Sierra peneplain farther south. The granitic igneous rock of the Coast Ranges area is of uncertain age; that in the Sierra Nevada is Jurassic. The letters signify the following: P, Paleozoic, including the Gabilan limestone and associated metamorphic rocks in the Coast Ranges, and the Calaveras formation in the Sierra Nevada; J, Jurassic, including Franciscan and Knoxville; K, Cretaceous, including Chico; E-O, Eocene and Oligocene, including Ione and white gold-bearing gravels in foothills, and Martinez, Tejon, and San Ramon in coastal region; M-P, Miocene and possibly early Pliocene, including Valley Springs and Mehrten volcanics in foothills, and Monterey, Wildent, San Pablo, and other formations in coastal region. The present shore line, the outline of San Francisco Bay, and the Sacramento and San Joaquin Rivers are indicated by dotted lines for purposes of scale and to assist in orientation.

In seeking an acceptable explanation of the broader characteristics of the present landscape it is unnecessary to consider detailed events prior to the late Miocene or early Pliocene, because these events are of secondary importance so far as the appearance of the present landscape is concerned. It is not meant, however, that pre-Miocene events have had no influence on the present landscape. On the contrary, the characteristics and relative positions imparted to the older rocks by folding and faulting prior to the late Miocene are responsible for much of the variety in topographic detail. Some for-

mations, for example, are eroded to a rugged topography, whereas others are sculptured into well-rounded hills. Extensive resistant formations form the higher crests of the broader mountain ranges, and smaller resistant bodies, including the products of ancient volcanic activity, add additional ruggedness. These, however, are in general subordinate characteristics; the gross forms, the ranges and larger valleys, the upland surfaces and the intermontane basins, are primarily the result of relatively recent events.

Throughout much of the interval from the Nevadan disturbance (late Jurassic) to the middle Miocene, a land mass lay some distance off the present coastline. Where the Coast Ranges now are, there was a coastal basin, periodically subject to relatively mild deformation by which it was divided into subordinate basins. The pattern of these subordinate basins changed to a greater or lesser extent with each episode of deformation. In these basins great thicknesses of sediment accumulated, either marine or continental, depending on the geography of the times; these sediments were derived largely from the immediately adjacent highlands. At the site of the present Sierra Nevada there was an ancestral range of mountains of folded rocks. These mountains, too, shed great quantities of waste over the western lowlands and into the seas which frequently inundated them. In Eocene time white gold-bearing quartz gravels were laid down in valleys eroded in the flanks of the ancestral Sierra, and the finer sediments washed from the gravels were carried out into the shallow sea beyond and deposited as the clays and sands of the Ione formation.

In the middle Miocene, after a time of widespread inundation, a pronounced mountain-building (orogenic) movement took place, at which time much of the structural framework of the present Coast Ranges is believed to have been established. Although the present topography of the Coast Ranges reflects to some extent the influence of the earlier periods of deformation, the general direction and localization of the ranges had their inception at this time. Later diastrophisms, culminating during the mid-Pleistocene, followed these major trends.

In the basins formed by the mid-Miocene deformation, later Miocene sediments were deposited—sediments derived from the newly risen axial ranges. The deposits include ash, coarse volcanic debris, lava flows, and intrusives, the products of widespread volcanic activity. Volcanic islands may have risen from the shallow Miocene seas. By late Miocene time the interbasin ridges were probably worn low and the basins filled, resulting in low relief. Such a surface, partly degradational and partly aggradational, may appropriately be referred to as a gradation surface, to distinguish it from a peneplain, a level lowland, which is primarily degradational. The so-called Sierra peneplain of Miocene time may be the equivalent of this surface. The Sierra "peneplain," remnants of which are well preserved on the present intercanon divides of the southern Sierra Nevada, is more properly described as a late mature surface surmounted by linear monadnock ridges of more resistant rock 2000 to 3000 feet high. The high-level broad valleys of the higher parts of the Sierra Nevada belong to this cycle of erosion. The Sierra "peneplain," in the latitude of the bay region, is mantled by volcanic debris, largely water-laid and derived from the summit regions of the Sierra of those days. The original slope of this plain is believed to have been about 90 feet

per mile. The volcanic debris includes mudflows and tuffs, and—as a final product of the volcanic episode—flows of latite and basalt which came down gravel-floored valleys carved in the volcanic plain. These lava flows were so much more resistant to erosion than the surrounding rocks that they were left standing as high table-like divides, protecting the stream gravels of the former valley bottoms. Such is the origin of Tuolumne Table Mountain near Sonora, east of the area covered in this report.

Figure 1 portrays in a generalized manner the major elements of the late Miocene or early Pliocene landscape in the bay region, extending east to the lowermost foothills of the Sierra Nevada. In the east was the even, gently sloping volcanic plain mantling the western slope of the northern Sierra Nevada. The crest of the Sierra was probably faulted up 3000 feet or so at the close of the Miocene, giving the range, for the first time, a fault-block appearance. The tilting steepened the original slope of the volcanic plain. The surface on which the volcanics rest in the lower slopes of the Sierra is underlain by large areas of the Ione formation. In the higher slopes, however, to the right of the diagram, the surface is underlain by Sierran granite and associated metamorphic rocks. This ancient buried surface is sometimes referred to as the Sierra peneplain, on which linear monadnocks protrude through the volcanic cover. In places the volcanic cover has been stripped by erosion. South of the area of this study, the volcanic cover is absent and the Sierran "peneplain" is exposed. The so-called "peneplain," however, was a far more irregular surface than the surface of the volcanic cover. In many places it was probably more rugged than the present topography.

To the west of the foothills, where the Great Valley and Coast Ranges now lie, was the late Miocene-early Pliocene gradation surface consisting of the eroded stumps of the axial ranges and the thick sedimentary fills of the adjacent basins. This gradation surface may have been somewhat younger than the buried Sierra "peneplain" because gradation may have continued here while volcanic deposition interrupted the cycle in the Sierra Nevada. The cycle was probably interrupted locally in the Coast Ranges as well, because lower Pliocene volcanics are reported in the Petaluma district.

Whether any remnants of the gradation plain are preserved today in the Coast Ranges is not clear. In any event, the late Miocene-early Pliocene landscape offers a satisfactory starting point for consideration of the subsequent evolution of the landscape.

The Miocene seas lingered into the Pliocene in many areas of the Coast Ranges. Thus, the early Pliocene seas occupied many of the chief Miocene basins of deposition, but also invaded new areas. The seas were shallow and the land masses low and well forested.

In the bay region a long rugged land mass, including the north end of the Santa Cruz Mountains, separated the interior continental

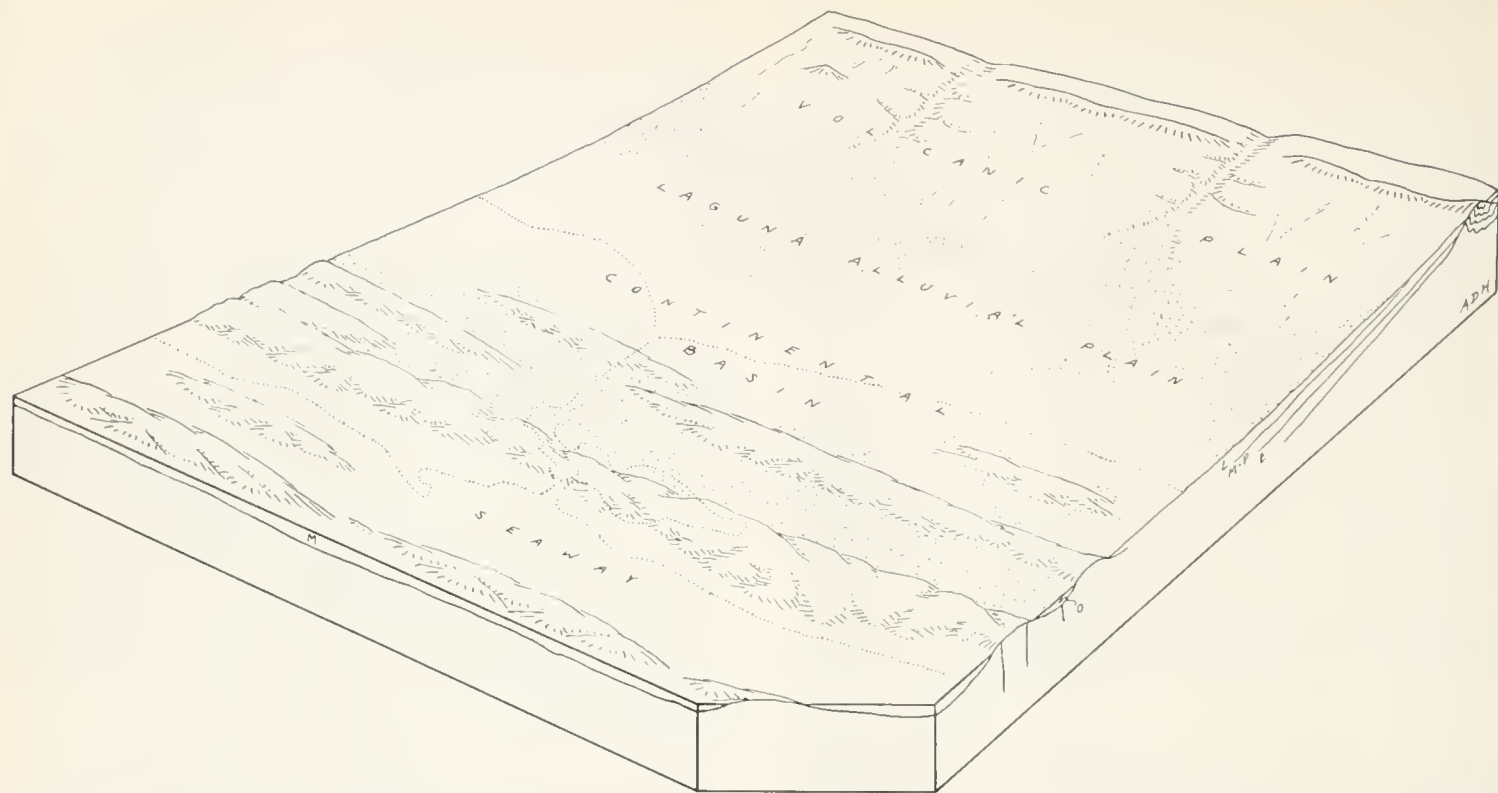


FIG. 2. Late Pliocene gradation plain, possibly correlative with the mountain-valley stage in the Sierra Nevada. The long, low coastal range is the Orinda-Merced axis, which excluded the sea from the interior during much of the Pliocene. E, Ione formation (Eocene); M-P, volcanics (Miocene to early Pliocene); M, Merced formation (Pliocene); O, Orinda formation (Pliocene); L, Laguna formation (Pliocene).

basins from the marine basins to the west. This land mass will be referred to as the Orinda-Merced axis. East of this axis lay the northern prong of the Diablo Range, a prominent land mass during the Pliocene and an important source of sediments. Far to the south, in the Coalinga area, the seas were able to penetrate to the interior, and here the marine Pliocene (Etchegoin) interfingers with continental deposits (Orinda equivalents). In the seaway to the west of the Orinda-Merced axis, the Wildeat, Merced, and correlative marine deposits were laid down.

The Sierra Nevada during early Pliocene time was a low land mass sloping gently westward to the Great Valley. As a result of the Miocene uplift and tilting, the rejuvenated streams dissected the mountain slopes and carried debris into the Great Valley where it was

spread out as a series of coalescing alluvial fans. The alluvial deposits, which thicken away from the Sierra Nevada, are known as the Laguna formation. This may have been the time of the "mountain valley eye" in the higher Sierra, during which mature valleys 1000 to 1500 feet deep were carved below the floors of the broad valleys of the late Miocene (?) Sierra "peneplain."

By late Pliocene time the axial ranges which were upheaved in the Miocene were reduced to their roots, and broad valleys such as the San Benito were filled, producing a second gradation surface. At increasing distances north of San Francisco Bay, filled valleys were less common and the gradation plain was more and more like a true peneplain.

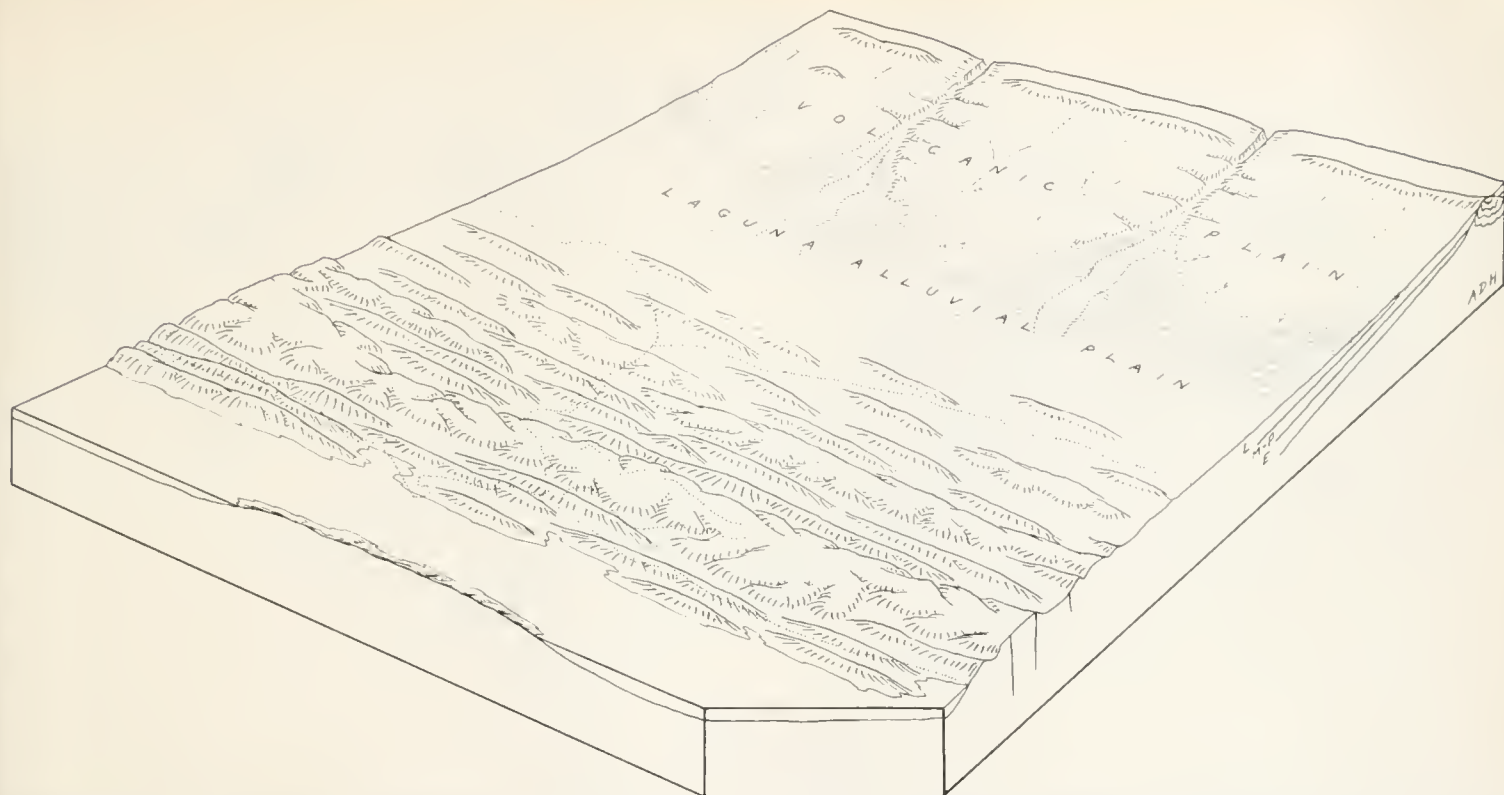


FIG. 3. End-Pliocene orogeny, possibly correlative with the beginning of the canyon cycle of erosion in the Sierra Nevada. Beginning of dissection of Laguna alluvial plain. E, Ione formation (Eocene); M-P, volcanics (Miocene to early Pliocene); L, Laguna formation (Pliocene).

The relative stability which characterized the Pliocene, and made possible the development of the Pliocene gradation plain, came to an abrupt end at the close of that epoch. At that time there began the penultimate phase of what, in the mid-Pleistocene, was to prove to be the most important mountain building (orogeny) since the late Jurassic disturbance.

In the end-Pliocene orogeny the entire Coast Ranges region was uplifted, and the sea receded from the interior, lingering only in coastal embayments. The younger sediments of the region were intensely folded; locally the strata were completely overturned. Both normal and thrust faulting were prevalent. In some areas, such as the Petaluma district, depressed, raised, and tilted fault blocks were created. In other areas, a reversal of movement took place along the older

faults; blocks which had formerly been down-dropped were now raised, and some which had earlier been raised were depressed.

Pressures were strong near the coast, weaker to the east. Complexities in the fold pattern resulted in part from presence of "islands" of unyielding crystalline rocks against which the folds of weaker sediments were crushed and deflected.

The late Pliocene gradation plain was preserved in the areas of older, more resistant rocks where these were not seriously warped or broken. Uplifted ranges were immediately attacked by erosion and coarse debris was deposited in the adjacent basins. These sediments were deposited not only in the late Pliocene but in the early Pleistocene as well.

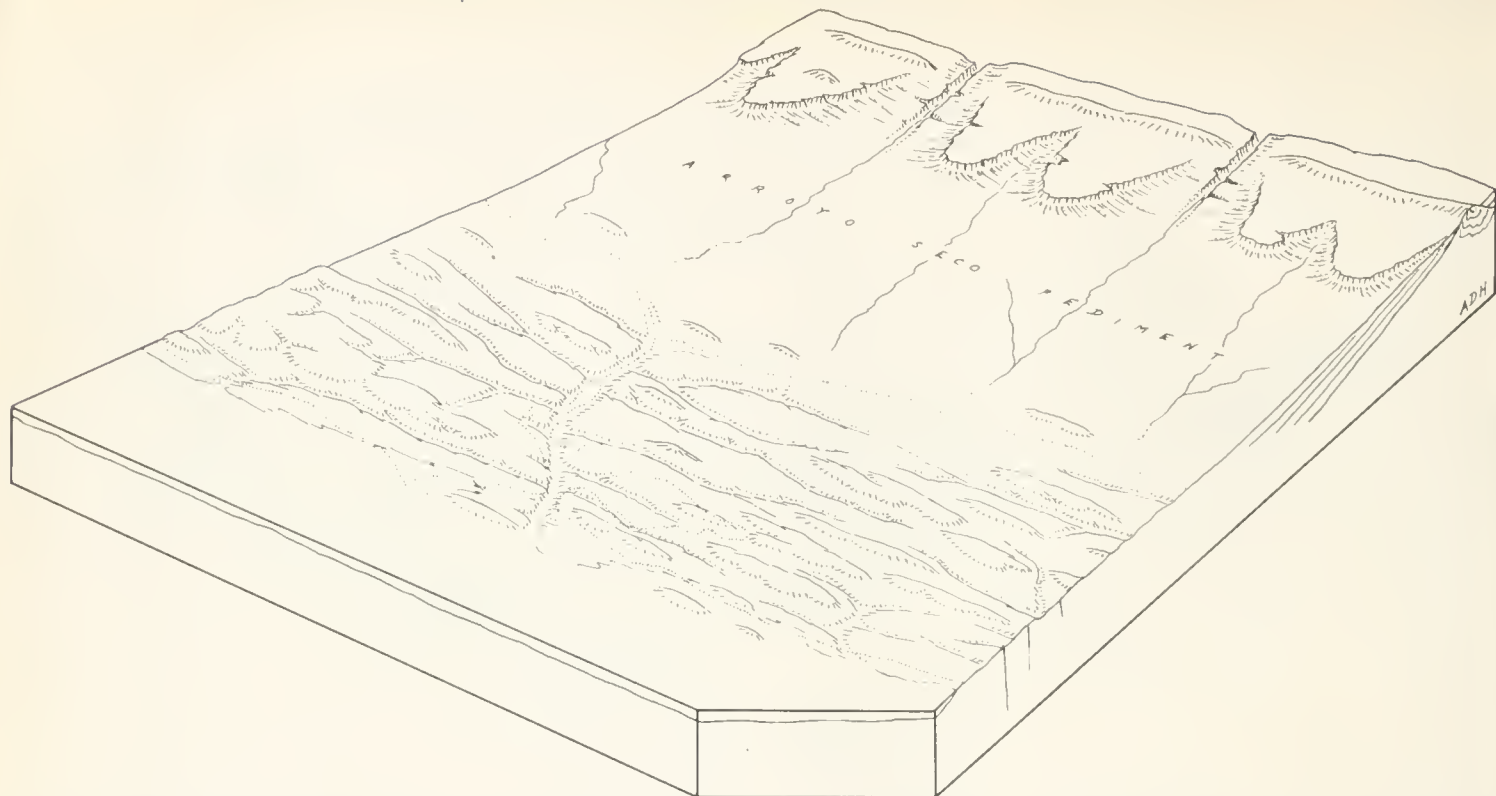


FIG. 4. Early to mid-Pleistocene gradation plain. Monadnock areas preserve remnants of late Pliocene gradation plain. Continuation of canyon cycle of erosion in Sierra Nevada. Development of the Arroyo Seco pediment and deposition of Arroyo Seco gravel across edges of older formations in foothills. Volcanic plain left at higher elevations. Course of Sacramento River established across coastal belt.

The structural history was much simpler east of the Coast Ranges. Continued downcutting by the streams from the Sierra Nevada, possibly influenced by additional uplift of the mountains and by subsidence of the Great Valley, caused trenching of the head of the Laguna alluvial plain. The streams began to erode laterally, in the early stages of development of what was eventually to become an extensive pediment. The products of erosion were presumably carried farther out into the Great Valley. The "canyon cycle" in the high Sierra may have begun at this time.

The wearing away of the coastal highlands upheaved by the end-Pliocene orogeny, the filling of the depressed areas created by that orogeny, and the development of the Arroyo Seco pediment in the foothills of the Sierra Nevada consumed the greater part of early Pleistocene time.

The folds in the weak Pliocene sediments of the Coast Ranges region were rapidly worn down to a level determined in part by undisturbed areas of the Pliocene gradation plain preserved on resistant rocks, and in part by the sedimentary fills of the depressed areas. The surface thus formed was expanded into the areas of resistant rock which had been elevated. Because the weak rocks are more prevalent south of San Francisco Bay, the early Pleistocene surface is more widely developed there. Thus, in the region of the Coast Ranges in the early Pleistocene, there was a widespread late mature topography, largely developed on weak sediments, and surmounted by more resistant masses preserving the Pliocene gradation plain. Remnants of the still older Miocene surface may have been preserved on monadnocks on the Pliocene plain. The drainage of the Great Valley escaped to the sea along much the same route that it follows today.

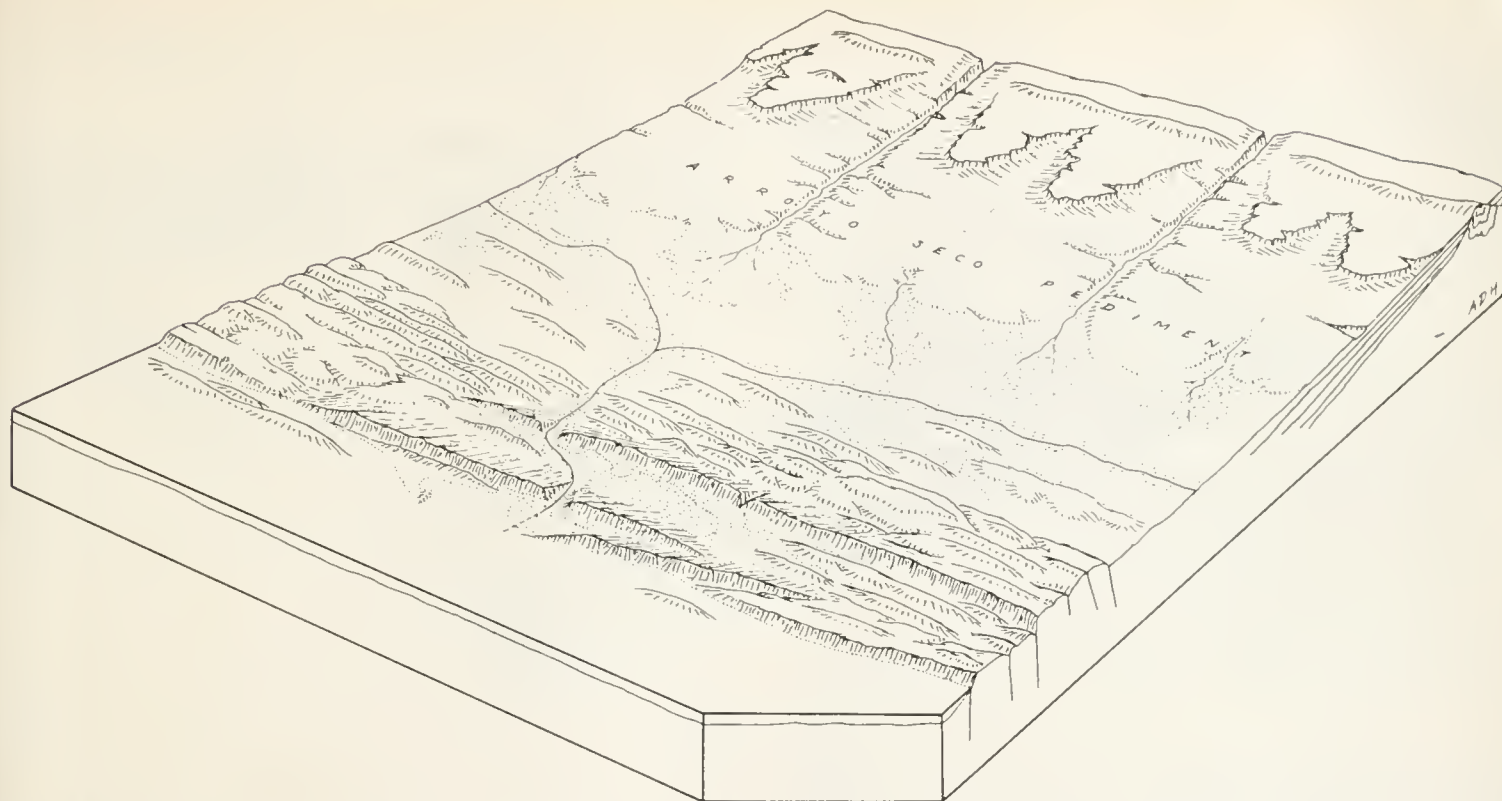


FIG. 5. Landscape produced by mid-Pleistocene orogeny, the most important orogeny since the Jurassic. Uplift of early to mid-Pleistocene gradation plain. Block faulting in bay area. Emergence of coastal terraces. Sacramento River antecedent across blocks. Maximum tilting of Sierra block. Beginning of dissection of Arroyo Seco pediment.

Along the eastern border of the Great Valley, continued lateral planation on the part of the Sierra streams resulted in the formation of the Arroyo Seco pediment over a belt probably 15 miles wide. The pediment, veneered by the Arroyo Seco gravel, bevels the Laguna and older formations. Back-wearing at the base of the more steeply sloping volcanic plain left the latter standing above the pediment surface.

In the Sierra Nevada, canyon cutting continued, possibly accelerated by additional tilting which was to reach its culmination in the mid-Pleistocene.

The orogenies which had weakly, but with increasing intensity, beset the bay region since Miocene time, culminated in the mid-Pleistocene in a major diastrophism which affected the Sierra Nevada as well.

The late Pliocene folds and faults of the Coast Ranges region were accentuated, new folds, locally overturned, were developed in the early Pleistocene sediments, and highland areas were re-elevated. Oversteepening caused by rapid uplifts resulted in landslides on a grand scale. The major configuration of the present coastline was imparted at this time.

In the immediate vicinity of San Francisco Bay, block faulting on a large scale took place, outlining the trough which was later to be inundated by the waters of the bay. Uplifts amounted to 1500 to 2000 feet or more. The Berkeley Hills block rose at this time forming a steep west-facing scarp. Across the valley, later to become the bay, the Marin block made its appearance, also forming a steep west-facing scarp, and a gentle slope to the east. The Sacramento River maintained

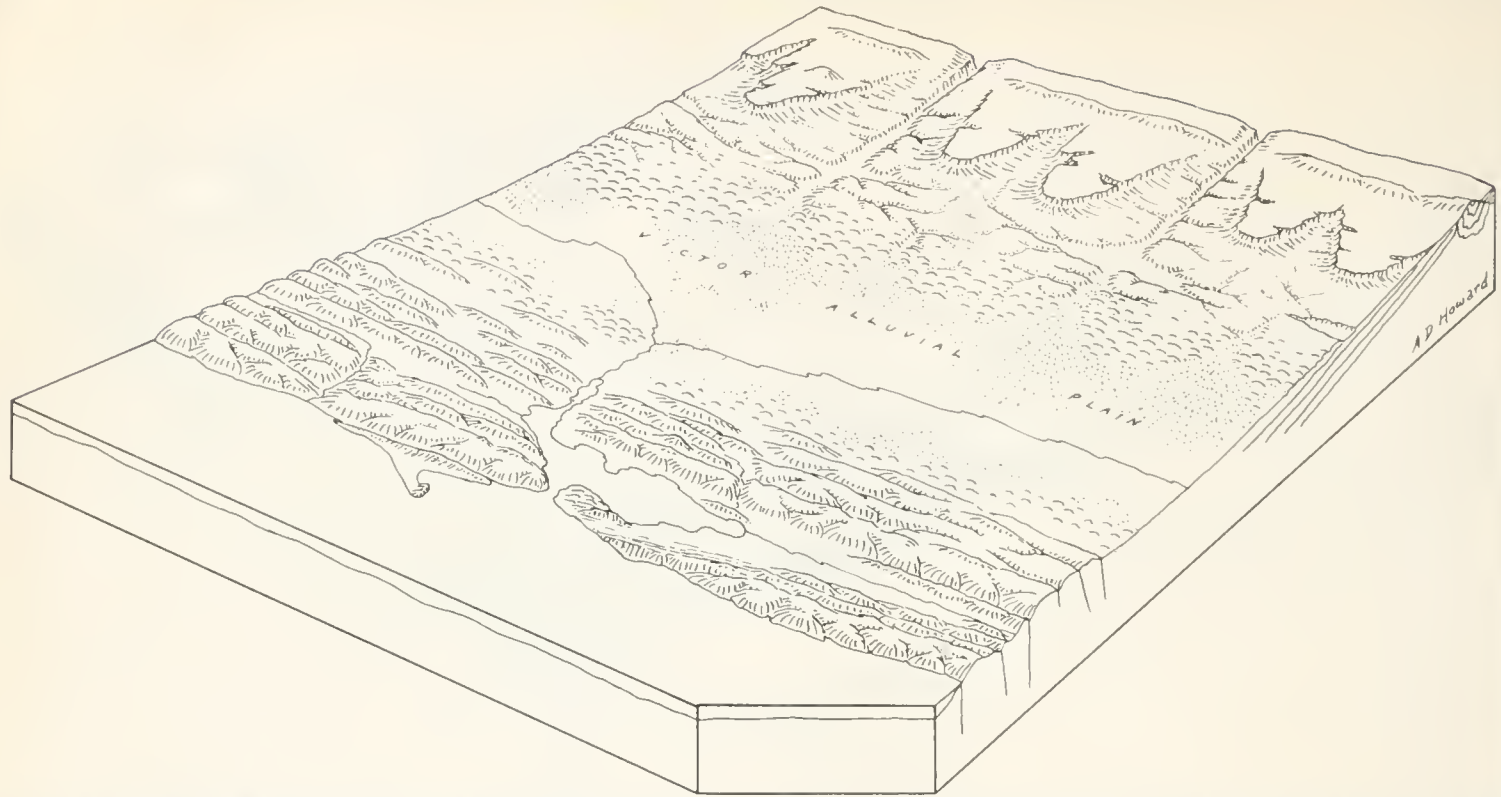


FIG. 6. The present landscape. Reduction of mid-Pleistocene folds and modification of fault blocks. Dissection of Arroyo Seco pediment and building of Victor alluvial plain. Subsidence to create San Francisco Bay. Warping of coastal terraces. Mild deformation along western border of Great Valley. Slight emergence.

its course to the sea across these rising blocks, as did the Russian River—which explains the anomalous lower course of the latter across the Coast Ranges. However, other westward-flowing streams south of Russian River were obstructed by the rising blocks and their former courses through the coastal mountains are now marked by wind gaps (valleys through which streams no longer flow). Among these are Lagoon Pass, Liberty Gap, and Elk Valley. Alameda Creek south of San Francisco Bay is believed to be antecedent across the Berkeley Hills block. South and west of the Marin block, and separated from it by the trough of Merced Valley, rose the Montara tilt block, also with a scarp to the west. The intermittent nature of the uplifts is indicated by the remarkable sequence of marine terraces which notch the seaward slopes of the coastal mountains up to elevations of 1500 feet or more. The higher terraces, however, are poorly preserved in

the vicinity of San Francisco Bay. The regional uplift of the Coast Ranges at this time is believed to have been greater along the coast than in the interior because no evidence of comparable high stands of the sea are found on the faces of the mountains inland.

The Santa Cruz and Mount Hamilton Ranges, and the southern extension of the Mendocino plateau, were uplifted without marked tilting, although subsidiary faulting within the ranges may have taken place.

The Sierra block was probably tilted up 6000 feet at this time, although part of this uplift may have occurred earlier in the Pleistocene. The tilt steepened the western slope by about 90 feet per mile, or about half the present inclination. The rejuvenation which resulted from this uplift accelerated the cutting of canyons in the Sierra Nevada and probably added another 1500 to 2000 feet to the depth of

the major canyons. And far down in the foothills, on the east side of the Great Valley the invigorated streams began to dissect the Arroyo Seco pediment and to carry the debris farther out into the Great Valley.

The sharp features produced by faulting during the mid-Pleistocene orogeny were rapidly eroded, and physiographic expression of the faulting was greatly subdued and obscured. The cycle of erosion induced by that orogeny has so far progressed only to late youth or, in some areas, to early maturity. The youthful valleys are in strong topographic contrast with the rolling uplands in many of the Coast Ranges.

Not all of the topographic features of the present landscape resulted from the mid-Pleistocene or earlier deformations and erosion cycles. The topographic features along the San Andreas rift, for example, probably developed since the mid-Pleistocene. The modern San Andreas fault coincides only locally with the ancestral Eocene fault. Elsewhere it cuts across mid-Pleistocene folds and faults, and even transects landslides developed along older fault scarps. Thus, the valleys developed along the trace of the modern fault are among the newer elements of the landscape. Where the new and the old faults coincide, however, the topographic features may be older.

Relatively recent deformation is also indicated by low folds along the western border of the Great Valley. Montezuma Hills east of Suisun Bay are mantled with Pleistocene sediments, and may be an example of such recent deformation. It is possible that the domal uplift of these hills shunted the Sacramento River into its present arcuate path around the southern edge of the hills.

Other evidence of recent deformation is furnished by warping of the coastal terraces. South of Halfmoon Bay a warping of 150 feet is indicated in a distance of 5 miles.

It may have been at this time of relatively mild deformation that subsidence took place in the vicinity of San Francisco to give rise to San Francisco Bay.\* The greatest submergence appears to have been along the west side of the bay, because the piedmont plain appears to have suffered the greatest inundation on that side. Furthermore, the subsidence must have been relatively local, because the transverse valleys of the Russian River, 50 miles to the north, and the Pajaro River, 50 miles to the south, are not drowned. Both Bolinas and Tomales Bays, north of the Golden Gate, are drowned portions of a broad valley carved along the San Andreas fault. Drake's Bay, near Point Reyes, was also formed at this time, and probably represents the drowned head of a valley system draining southward toward the

Golden Gate. The valley of Drake's Bay was eroded below a well-developed marine terrace.

It has been suggested that the subsidence continued down to the time of human occupation of the region, because the base of a large shellmound at Emeryville on the Oakland side of the bay is now more than 2 feet below sea level. Similar situations exist elsewhere in the area.

The last event in the geomorphic history of the coastal area was a slight emergence, possibly local in character, which elevated a low marine terrace on the shores of San Pablo Bay and in Bolinas Lagoon and Tomales Bay.

Minor features of the coastal landscape, of relatively recent origin, are the beaches, spits, and bars along the coast, and the sand dunes south of the Golden Gate. The main oceanic current is southward along the Pacific coast, but coastal irregularities result in countereddies, many of which transport sand northward. One of these is responsible for the northward drift of sand, derived chiefly from cliffed headlands well to the south of Golden Gate, which has resulted in the development of Ocean Beach at Golden Gate Park. The northward-drifting sand has formed bars across the mouths of many of the valleys which were flooded during the general subsidence that created San Francisco Bay. Merced Lake, in part now artificially contained, represents one of these valleys isolated from the sea. Many of the smaller land-locked bays have been completely filled and now present low, flat, often swampy areas back of the beach ridges. Many of the beach ridges are studded with sand dunes.

It has been suggested that the submarine bar off the Golden Gate is built of this same northward-drifting material, kept off shore, however, by the strong ebb tides running out of San Francisco Bay. Another view, however, is that the submerged feature is a former delta of Sacramento River deposited outside the Golden Gate before the subsidence that created San Francisco Bay. Finally, it is possible that part of the sediment of the submarine bar may have been sluiced from the Sierran foothills during the gold mining operations of the last century.

To the north of Golden Gate, the drifting sands were carried across the mouth of Bolinas Lagoon, nearly isolating it from the ocean. On the south side of Point Reyes peninsula, the various drowned headwaters of the drainage system represented by Drakes Bay and associated inlets, were also partly cut off from the sea by the growth of sand spits.

Before extensive settlement of the San Francisco peninsula the sands of Ocean Beach were swept continuously inland over the coastal slopes by the westerly winds, creating the extensive sand-dune topography of the area south of the Golden Gate.

\* Another possible explanation of the origin of San Francisco Bay is discussed in "The Geology of San Francisco Bay," by G. D. Louderback, another chapter of this bulletin, pp. 75-94.



The former course of the Sacramento River within the recent geologic past is a matter of speculation. It has been suggested that the river formerly flowed south along Santa Clara Valley to empty into the sea at Monterey Bay. Sea level is supposed to have stood lower so that the river could carve the now-submerged canyon which lies offshore. No such canyon occurs off the Golden Gate. The marked resemblance of certain freshwater fishes found in the Sacramento River to those found in the Pajaro River draining into Monterey Bay was, for a time, believed to strongly support this suggestion. It was subsequently shown, however, that the resemblance of the fish fauna could be explained without postulating a trunk stream through Santa Clara Valley. It was pointed out that Coyote Creek, on entering Santa Clara Valley from the mountains to the east, flows down the north flank of a large alluvial fan. During the building of this fan the stream must at times have spilled southward into Pajaro River affording a southern migration route for its fish population. Migration of freshwater fish from the Sacramento River into Coyote Creek could have taken place before San Francisco Bay came into existence, when no salt-water body separated the various fresh-water streams. As for the submerged canyon at Monterey Bay, its true significance cannot be evaluated until the possible presence of a sediment-filled submarine canyon off the Golden Gate has been investigated.

On the eastern side of the Great Valley, dissection of the Arroyo Seco pediment or red lands continued during the late Pleistocene, and its border was eroded to an undulating or hilly topography. A discontinuous northwest-trending lowland was opened out between the eastern margin of the dissected pediment and the higher-standing volcanic plain of the Sierran foothills. The trend of these lowlands may well have been influenced by the strike of the underlying formations. Other areas of red lands, possibly also pediment remnants, are less extensively developed on the Coast Ranges side of the Great Valley.

The products of erosion of the dissected pediment, plus the debris eroded from the Sierra Nevada by streams busily occupied in continued excavation of the Sierran canyons or in removing meltwater debris from mountain glaciers, were deposited as a series of coalescing fans beyond the western margin of the pediment. These deposits are known as the Victor formation, and the topographic plain as the Victor alluvial plain. The Victor plain, which has a much gentler gradient than the restored surface of the Arroyo Seco pediment, has been slightly trenched by the streams which cross it.

Although the Sierra Nevada was repeatedly subjected to alpine glaciation during the Pleistocene ice age, none of the glaciers succeeded in getting within 30 miles of the foothill region. Yet some of the ice streams may have been as much as 60 miles long. Outwash from

these glaciers, however, contributed to the development of some of the landforms of the Great Valley.

The great volume of debris carried down into San Francisco Bay by the Sacramento, San Joaquin, and a number of smaller streams, has been gradually reducing the area of the bay by delta deposition. This deltaic encroachment was significantly accelerated by the floods of debris released in hydraulic gold mining in the years prior to 1884. Within a very short time geologically, the bay will be completely filled and the Sacramento River will meet the sea near the Golden Gate. That is, unless a new crustal elevation or depression complicates the picture.

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PART III  
GEOLOGIC HISTORY

**Editorial Note:**

PART THREE summarizes the events of the geologic past and discusses the nature of the formations in which the history of rocks is recorded in depositional sequence. To appreciate how geologists have climbed the broken steps of the remote history of rocks and reconstructed their original orderly form, a review of the history of early scientific investigations is presented. Geologic time scales are charted, and geologic maps of the region are included which will require careful study by the reader in conjunction with all the discussions which follow. In recapitulating the sequence of events of rock formation and rock movement, it has been necessary to prepare several vertical structure sections along definite surface profiles, coordinated with the maps, in order to show how the rock formations are architecturally arranged. The last great earth movement in the region was experienced by an astonished population in 1906. It gave to the San Andreas fault a worldwide fame and to the community a deep respect for the activities of nature.

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## HISTORY OF GEOLOGIC INVESTIGATION IN THE BAY REGION

BY V. L. VANDERHOOF \*

The bay region and its 12 counties does not lend itself readily to an historical treatment restricted exactly by the present political boundaries. Geologic boundaries are natural boundaries and investigators, both past and present, are interested in these rather than county or even state lines. Nevertheless, the earliest real geologic investigation in California happens to be a study of the rocks of San Francisco Bay.

This study was made by Edward Belcher and Alex Collie of His Majesty's Ship *Blossom*. The *Blossom* was a 16-gun sloop built in 1806 and carried one small boat. She sailed from England in May, 1825 with nearly 100 men aboard, and her mission was to meet the explorers Parry and Franklyn in the Bering Strait. Captain Frederiek W. Beechey, skipper of the *Blossom*, nosed her through the Golden Gate on the 6th of November 1826, and immediately paid his respects to Ignacio Martinez, acting commandante of the presidio. This gentleman showed Captain Beechey every courtesy and gave him permission to make a map of the bay if he would leave a copy for the archives of the Mexican government. This he did, for there is recorded at Martinez a manuscript map † filed in 1862 in connection with a property claim of Martinez' heirs. This map covers the entire bays of San Francisco and San Pablo and most of Carquinez Strait. Sierra Bolbones (Mount Diablo) is shown as being 3770 feet high; which was an excellent figure, since the actual height is 3849 feet. One suspects, since the figure for height is so close to the truth, that the Belcher party actually climbed Mount Diablo and that they had a mercurial barometer with them. The compass deviation from true north is given as 15° 30' E.

As previously noted, the *Blossom* entered San Francisco Bay on the 6th of November, 1826. She hoisted anchor on the 28th of December, headed for Monterey. Thus her stay in the bay region covered 54 days. Lieutenant Edward Belcher, R.N., (later Admiral Sir Edward Belcher) is entered upon the ship's roster as "Surveyor," Alex Collie as "Ship's Surgeon" and George Lay as "Naturalist." These three explored the bay in the ship's boat, going as far northeast as Rio Vista and as far south as the head of navigation (Alviso) on the Guadalupe River. In addition, they made a map of the whole area with detail confined, of course, to shore outlines. As nearly as one may judge from the available evidence, the geologic notes were restricted to that portion of the bay system shown on the map. The geology is

somewhat sketchy and, like the planimetric mapping, is confined to shore areas. But it is a remarkable fact that the mapping is in general accord with our ideas of today and is a much better job of all-around cartography than many subsequent maps, especially those of the gold rush period designed as "guides" for the gold seekers.

Belcher and Collie's map, made with little more than a compass but with exceptional skill, was delayed in publication until 1839, when it appeared in a volume entitled *The Zoology of Captain Beechey's Voyage in H.M.S. Blossom*, edited by Sir William Buekland, a famous English geologist of the time. The map is an engraving and was hand colored by Belcher himself. The legend explaining the colors in terms of rock types is a technique little different from that employed today. The rocks noted were not assigned to any geologic age, perhaps because of the lack of fossils or even because of the primitive understanding of their significance. One must remember that this map was made 125 years ago, only 11 years after William Smith published the first geologic map of any region and only 7 years after William Maclure produced the first geologic map of any part of North America.

A short text accompanies the Belcher map, written partly by Belcher and partly by Collie. These men are quoted here, with some omissions; their words probably represent the first serious geologic field notes ever taken in California.

"The specimens collected in and near the Bay of San Francisco consist of many varieties of common serpentine, noble serpentine, bronzite, and asbestos; clay-slate and mica slate, horn stone, brown, green and red jasper, and rolled blocks of glassy actynolite, grey sandstone and imperfect wood coal. . . . Many of the summits of the hills are composed of jasper, forming elongated ridges, of which the general direction is north and south. . . . The appearance of the jasper, at its contact with the sandstone, is often very remarkable. The jasper appears not to have acted upon or displaced the sandstone. . . . The Island of Los Angeles [Angel Island] is of a very confused formation. . . . The rounded hills of the peninsula on which the Presidio of San Francisco is placed, are variously formed of sandstone, loose sand, serpentine, flinty slate, and jasper. . . . Earthquakes are rather common, and one in 1806 so shook the building of the Mission of Santa Clara that a new one was obliged to be erected. A few years ago [1820?] a boat belonging to a whale ship, when lying in several feet of water, was thrown on the beach and left dry. . . . At 10 o'clock on December 26, 1827, a shock was felt at San Josef [San Jose]. The shocks are said to come along the coast from the Northward, and when they are also felt at Monterey, it is some minutes later. One was perceived at the Presidio of San Francisco in April, 1827. It continued a short time, but the shaking was so slight that it injured nothing."

One of the earliest references to fossil vertebrates in California is made by Belcher in these words: "Petrified bones of a cylindrical

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† Beechey, *Visit to California, 1826-1827*, Grabhorn Press, 1941.



FIG. 1. Geological plan of the Port of San Francisco, California, by Belcher and Collie, published in 1839. "Alluvium" covers shaded areas on east side of bay, San Francisco peninsula, Angel Island (I. de los Angeles), and from the Marin peninsula north to Mission San Rafael. "Sandstone" is shown by the slightly darker shading along the west shore on the east side of the bay, from Point San Pablo southeast to Brooks Island (unnamed); along the northeast shore of the San Francisco peninsula; on the southeastern shore of Yerba Buena Island; on Aleatraz Island (Los Aleatrazes); along the northwest shore of Angel Island; and along the southern and eastern shores of Marin peninsula and the west side of the bay. "Clay slate" is shown on the northwest shore of Yerba Buena Island and on the south shore of Angel Island. "Jasper" is shown on Molate Island, on the northeast shore of Brooks Island, on the southeast shore of Angel Island, on Needle Rock, and at Punto Diavolo in Marin County. "Serpentine" is shown from south of Point Lobos to the Port, on San Francisco peninsula; near Point Boneta on Marin peninsula; and on the tip of the peninsula just northwest of Angel Island. Photo courtesy of Bancroft Library, University of California.

form were found in this cliff [at Santa Cruz] of sand or loose sandstone in 1827." The vertebrae of Miocene whales are of common occurrence at this locality and one may safely assume that these are the "cylindrical" bones to which reference is made.

An earlier though geologically less important visit to San Francisco Bay was made in 1816 by the Russian ship *Rurik* under command of Otto von Kotzebue. The voyage of the *Rurik* was ostensibly a scientific expedition. The ship's naturalist was Adelbert von Chamisso, primarily a botanist, and Johann F. Eschscholtz was ship's surgeon. During the ship's stay in San Francisco from October 2 to November 1, 1816, Chamisso collected plants. He was the first to describe the California poppy, naming it *Eschscholtzia californica* in honor of his shipmate. In his published notes is the following geological observation:

"A low ridge of mountains borders the coast of California, where we saw it; and intercepts the prospect into the interior of the country. It has not a volcanic appearance. Near St. Barbara (34° north latitude) there arises from the coast a still burning volcano, the foot of which is washed by the sea; and in other places of the peninsula [of San Francisco?] there are proofs of a volcanic nature. The harbor of San Francisco . . . enters through a narrow passage, receives some rivers from the interior, branches out behind the eminences, and forms into a peninsula, the country lying south of the entrance. . . . The hills on the northern side of the harbor are composed of flinty slate. The hill opposite to them on the southern side, and on which the fort lies, is of serpentine. On going along the strand, towards the south, to the Punta de los Lobos, the serpentine ceases, and you meet several almost perpendicular strata of flinty slate, which rest against coarse-grained sandstone, veined with calc-spar; and this sandstone, of which the more southern hills of the Punta de los Lobos consist, seems to be the kind of rock that lies the lowest. Quicksand [dune sand?] lies in many places at a considerable height over the stones, and in many places new sandstone has been formed."

Here again it is obvious that the conspicuous Franciscan rocks have caught the eye of an early observer.

In the appendix to Kotzebue's account of his voyage of 1815-18 is a list of rocks and minerals Eschscholtz collected, which were later given to the University of Dorpat and were described by his colleague, Moritz von Englehardt. The specimens were accompanied by "information respecting the situation in which each specimen was found," enabling von Englehardt to make the following observations:

"The northern tongue of land running into the sea, on which the little fortress of St. John [San Joaquin, site of present Fort Winfield Scott] at the entrance of the Bay of San Francisco, lies, consists of serpentine rock, which is also found farther south on the steep shores of the sea coast. With it are mixed amianthus, scaly tale, magnetic pyrites, and bronzite (or Schiller Spar) minerals which in other countries usually accompany the serpentine in a similar manner, and afford here an additional proof of the regular course of the formation of the earth. The same is shown by the manner of the stratification. It is well known that in most primitive rocks, the serpentine appears on the outside, that is, where its last layers (that uniformly cover the other rocky

strata) border on the floetz mountain. . . . the vicinity of the sea is common to the serpentine of New California, with the serpentine at Cape Lizard, on the Shetland Islands, and on the Cordillera of the Coasts of South America. If we consider that the sea formerly covered those countries which contain the floetz mountains, which are rich in petrifications, and admit the hypothesis that the primitive mountains, which were not covered by the floetz mountains, rose as islands above these seas, it appears how the serpentine of what is now the interior country formerly lay equally situated on the coasts; an analogy which, if thoroughly investigated, may lead in future to important conclusions respecting these and other kinds of rock; in the history of the formation of the surface of the earth."

Von Englehardt follows this with a detailed description of 14 rock and mineral specimens collected by Eschscholtz. All were apparently collected in the vicinity of Fort Scott and consist largely of serpentine and associated minerals, jaspers, greenstone, and sandstone. Some of the minerals listed are amianthus, bronzite, pyrites, tale, chaledony, heliotrope, and calc spar. This is perhaps the first list of California minerals ever published.

Timothy A. Conrad, a printer by profession, but one of America's early specialists in Tertiary molluscan paleontology, enters the California scene at this time by reason of his studies of fossil shells collected from there by others. One of the earliest of these collections was made by the Wilkes Exploring Expedition of 1838-42. Writing in the *American Journal of Science* for 1839, Conrad, in *Notes on American Geology*, remarks that "on the coast of California, Mr. Nuttall found shells of recent species 200 feet above the sea." Here is one of the earliest notices of the extent of the uplift of Pleistocene terraces in California.

James Dwight Dana was one of the first professional geologists to do any work in California, and this was of the most cursory nature. The great Yale mineralogist, then 28, was a member of the Wilkes Expedition, officially known as the United States Exploring Expedition. After sailing around the Horn and exploring the Pacific coasts and islands, the ships tied up at Astoria, Oregon, in the summer of 1841. Here, Dana and a party took a pack train southward, came into California and headed for Sutter's Fort by way of Mount "Shasty." Dana was the first to publish, in 1849, an account of the volcanic nature of Mount Shasta and also of the Marysville Buttes. These latter he called the "Sacramento Butte" or the "Three Buttes." Dana took his field notes 7 years before the discovery of gold, but his account of California geological observations did not reach print until March, 1849, more than a year after the discovery at Coloma. He therefore included an appendix covering something of the current excitement. Among other pertinent comments, he said:

As there is much misapprehension among those interested in the gold of the west, respecting its modes of occurrence, a few words are added upon this subject. Many think to find the sands glittering with gold

dust, and others, in exploring the mountains, hope to lay open rich massy veins of the precious metal, like those of ordinary ores."

Then follows a discussion of how the gold is actually disseminated in the veins in tiny particles.

On placer gold, Dana remarks that:

"The occurrence of alluvial gold commonly in flattened grains arises directly from the forms it had in the rocks, and partly from the wear and tear to which the whole has been subjected . . . the abrading and battering action of the moving waters and gravels breaks up the metal to fragments, and wears off the rough exterior of the larger lumps."

A better account of the origin of placer gold and nuggets had not yet been written.

In the Proceedings of the St. Petersburg Mineralogical Society for 1847 (published in 1848) there appears a short account of the general geology of Upper and Lower California. It was written by Dr. C. Grewingk, who, like von Englehardt, had never seen California. Grewingk's notes were based upon a collection of specimens obtained by J. G. Woznesenski (or as Grewingk has it, Wossnessenski) a zoologist on a Russian ship which traversed the Pacific coast in 1841 and 1842, presumably to contact Russian footholds on the North American coast, including Fort Ross and Sitka. Woznesenski's labels and notes were poor, but by studying published accounts of the California region, including Fremont's, Kotzebue's and Chamisso's, Grewingk was able to work up his paper into something resembling a geological report. A small scale and moderately inaccurate planimetric map of the Pacific coast is included. The rocks, inadequately described, are typical serpentines, jaspers, and sandstones of the northern Coast Ranges, as well as sediments and lavas from the southern Coast Ranges. Fossil oyster beds are mentioned from near the mouth of the Sacramento River; this is no doubt the Pleistocene occurrence at the town of Rodeo. An active volcano is mentioned as occurring near Santa Barbara, though Grewingk says this is not proven! He had no doubt been reading Chamisso's account of the same phenomenon. From a distance at sea, perhaps a burning tar-seep at Carpinteria could create the "volcano" illusion.

Grewingk gives a geologic column for California in this fashion, with number one the youngest:

1. Loose sand, clay, volcanic tuff
2. Sandstone Tertiary?, limestone, sandstone
3. Conglomerate
4. Coarse sandstone
5. Fine, brown sandstone
6. Siliceous slate, quartzite, horn stone, jasper
7. Slaty schist, serpentine
8. Tale and mica schist
9. Syenite and granite

By 1849, the whole world was aware of and interested in the discovery of gold in California. This led to the "gold rush" and the peopling of the region so fast that California attained statehood in September, 1850, without going through territorial status. The miners, most of them amateurs, soon learned, or invented, something about the geology of the foothill belt of the Sierra Nevada. There grew a natural demand for more precise information, and among the participants and spectators on the scene were gentlemen with some geological training, however vague. One of these was Phillip T. Tyson,\* who hailed from Baltimore and who came to California soon after the discovery of gold. He seems to have accumulated some notes and geologic sections in the Sierra Nevada and in middle California across to the Pacific coast at the latitude of the bay counties. The fathers in Washington were naturally interested in the new source of wealth on the Pacific coast and printed Tyson's report in 1850 as Senate Executive Document 47. This marks the first federal report dealing exclusively with the geology of California. Though the Tyson material was crude and superficial, he did have a fair picture of the geologic situation on the west flanks of the Sierra and correctly showed that the placer gold was derived from steeply dipping veins in the slates and schists. Like Dana, he warned prospective fortune hunters that gold was hard to come by, and in reporting a conversation with an "old-timer" on the ship from Panama to San Francisco, Tyson quotes him as saying "As soon as you reach San Francisco, you will find that everyone is crazy, and without great caution, in three days you will be crazy yourself!" This condition Tyson refers to as the Auriferous Excitement. The base map upon which Tyson's "geology" is given covers the bay region and the Sierran foothill mining belt. There are no contacts outlined in the usual sense, but the rock names are spelled out in such a way as to coincide with Tyson's idea of their distribution, much as stream names are placed on a modern map. The base map was made by Lieutenant George H. Derby (John Phoenix, pseud.) of the United States Topographical Engineers less than a year after gold was discovered and at the height of the stampede.

One of the first acts of the new legislature of California was to appoint a state geologist in 1853. The man chosen was John Boardman Trask, M.D., a former army surgeon and one of the founders of the California Academy of Sciences. He wrote four reports in as many years, all without maps. The first one, of but a few pages, apparently was based upon notes and observations already in the author's possession made from trips on foot during the preceding 3 years. The title of the report is *Geology of the Sierra Nevada or "California Range."* An interesting statement in this initial effort

\* Not to be confused with James L. Tyson, M.D., who wrote *Diary of a Physician in California* . . . (New York, Appleton, 1856). P. T. Tyson returned to New York on the steamer *Oregon* with J. L. Tyson, who referred to P. T. as "an eminent geologist." Dr. Tyson, in his diary, also declared that "California is not suited for agricultural purposes."

is that the "great valley † is not a drained prehistoric lake, but is attributable to those causes which have been so clearly demonstrated by Mr. Dana, as having arisen from the process of gradual elevation by forces from beneath the surface." Trask's second report (1854) is entitled *Geology of the Coast Mountains and Part of the Sierra Nevada*, his third (1855) is called *Geology of the Coast Mountains and Portions of the Middle and Northern Mining Districts*. This is an amplification of the second report and includes comments on southern California and far northern California. Trask's fourth and final report, marking the closing out of the office of the first state geologist, bore the imposing title *Geology of Northern and Southern California and Statistics of the Northern, Southern and Middle Mines*. The post of State Geologist seems to have withered on the vine because a disinterested legislature failed to appropriate any funds from an impoverished treasury. But it appears likely that Trask's labors, as well as those of George Davidson, served to stimulate the eventual appropriation, in 1860, of enough money to begin the famous Geological Survey of California under J. D. Whitney.

Before Whitney's survey is discussed, however, the monumental Pacific Railroad Reports (*Reports of Explorations and Surveys to Ascertain the Most Practical and Economical Route for a Railroad from the Mississippi River to the Pacific Ocean Made Under the Direction of the Secretary of War in 1853-4*) must be considered.

The 13 fat quarto volumes of the Pacific Railroad Reports, replete with illustrations and maps, represent not only the route reports of the army engineers, but also the extensive writings of the accessory botanists, zoologists, and geologists. It is amazing how much pure science these early congresses would pay for as "riders" to the various surveys of the west.

One of the army engineers on the survey was Lieutenant R. S. Williamson, who made two trips, one from San Francisco south for the purpose of exploring Sierran passes, and one into northern California and Oregon. W. P. Blake was geologist on the first trip, J. S. Newberry on the second.

William Phipps Blake was undoubtedly the most extensive writer and accurate observer of the early geologists in California. He was with the Pacific Railroad Survey from 1854 until 1856 and saw most of the state. His 300-page report (vol. 5, 1856, issued separately as *Geologic Reconnaissance in California*) is still entertaining and thought-provoking. Among the various maps, sections and views in this volume is the first attempt to produce a geologic map specifically and exclusively of California. It is hand colored, has many blank areas and is of course very generalized. Jules Mareou's colored map

† One of the earliest uses of this phrase to connote the combined Sacramento and San Joaquin Valleys, perhaps following usage in Hasting's Emigrant Guide of 1845. Professor B. L. Clark, in the 1930's, proposed that geologists use the Spanish equivalent Valle Grande, but his efforts were without success.



FIG. 2. Detail of stone construction on the Stanford campus. Rock used is Upper Cretaceous sandstone from Graystone Station quarry located nine miles southwest of San Jose. Photo courtesy of Stanford University.

of the United States, published in the Bulletin of the Geological Society of France a year earlier, includes California but is less accurate and on a much smaller scale than Blake's map.\* Blake was, for a year, professor of mineralogy, geology, and mining in the College of California at Oakland in 1864, holding the first such post in Cali-

\* Much of Marcou's geology was from some psychic source, for all of the state is colored, as it was in a later (1883) map of California, published in the same journal from notes made while he was a member of the Pacific Railroad Survey and the Mexican Boundary Survey of 1849-51. Marcou's map of 1855 is noteworthy in one respect, at least: it was one of the first if not the first, multicolored geologic map to be printed by lithography. All previous ones were colored by hand.

fornia. At the same time Blake was geologist to the California State Board of Agriculture and published under its aegis the first official list of minerals produced from the state. A comparison of Blake's slim list with the most recent *Minerals of California* published by the State Division of Mines reveals an astounding increase in known species. Blake died in Berkeley in 1910, soon after receiving an honorary LL.D. from the University of California, robust offspring of the little school where he had instituted the formal teaching of earth sciences 46 years previously.

John Strong Newberry, later to become an authority in paleontology and a great teacher, made some of the earliest geologic observations in the Shasta-Redding country while with Lieutenant Williamson; of particular interest here however, is the fact that he made the first published geologic section in the upper reaches of the bay area. This was along the south shore of San Pablo Bay at Pecten Point and Rodeo, a locality mentioned 10 years earlier by Grewingk as the "oyster beds."

Lieutenant G. G. Parke had charge of another Pacific Railroad Survey party that explored from San Francisco to Los Angeles along the general route taken by El Camino Real. The geologist was Thomas Antisell, M.D., and he wrote the first serious report on the whole of the southern Coast Ranges. He noted on his map many "bituminous effusions" and recognized that the main uplift of the Coast Ranges was post-Miocene. He believed that the elevating force was greatest at two points, one north and one south of San Francisco. The center was quiescent, thus forming San Francisco Bay! He also called attention to the structural parallelism of the Coast Ranges, the Sierra Nevada, and the Basin Ranges. Antisell's map is beautiful in its simplicity and freedom from faults, yet it was the most accurate available for many years after its publication (1857).

An account of the California Geological Survey, or, as it is commonly known, the Whitney survey, is perhaps the most interesting in the history of geological inquiry in California. Only the most brief treatment can be given here of the rugged characters who made up this Survey and of the enormous difficulties they encountered, both in the field and in the legislative halls of Sacramento. On April 21, 1860, the legislature, largely through the efforts of Stephen J. Field, a supreme court justice, passed an act creating a state geological survey and the office of State Geologist. Field realized that the hit-or-miss, easy come—easy go days of the gold rush were over and that there was need for a sober, scientific assessment of the mineral resources of California as a guide to effective development. The Act of 1860 itself named Josiah Dwight Whitney as state geologist and directed him to engage assistants ". . . to make an accurate and complete Geological Survey of the State, and to furnish, in his Report of the same, proper maps and diagrams thereof, with a full and scientific description of its rocks, fossils,





FIG. 3. Aerial view toward the northeast, showing University of California campus. Edwards Field is in left foreground and Memorial Stadium in right background. Photo courtesy of San Francisco Chronicle.

soils, and minerals, and of its botanical and zoological productions, together with specimens of the same". Whitney's advance selection was made through inquiries by Justice Field of eastern scientists, among whom was Louis Agassiz of Harvard. Whitney had participated in a survey of the iron regions of Lake Superior and had written a well-known book, *The Metallic Wealth of the United States*. There is no doubt that the choice of Whitney, so far as scientific background went, was the best that could have been made; but perhaps a more realistic survey would have been conducted by W. P. Blake, who was among those considered for the job. The survey lasted from 1860 until 1873 and included on its staff, beside Whitney, such men as William H. Brewer, Clarence King, Charles Hoffman, James T. Gardiner, William M. Gabb, and William Ashburner. Brewer, Whitney's chief lieutenant, was officially

the botanist, but this phase was always subordinate to general geology. He was a man of tact and judgment and often supplied the lack of these qualities in Whitney, who was somewhat dogmatic and who finally lost the support of the legislature completely. This was largely because of his insistence upon a complete scientific survey with all the trimmings while ignoring the fact that the average taxpayer was more interested in where and how to develop economic wealth from the earth than the (to him) dull aspects of theories of ore deposition, the taxonomic characters of *Sturnella neglecta*, or the molluscan fauna of the Upper Cretaceous. Nevertheless, the Whitney survey accomplished a monumental amount of work and eventually produced eight large quarto volumes: three on geology, two on paleontology, two on botany, and one on ornithology. In addition, there were issued four editions of the Yosemite Guide Book and numerous topographical

maps of a high degree of accuracy, though the representation of topography by hachures left much to be desired. The Whitney survey two-sheet hachure map of the bay region is even to-day a model of planimetric accuracy and a delight to historians with an interest in place names and in geographic development since the seventies. Many of the quarto volumes, printed in Cambridge, were done at Whitney's personal expense and after the discontinuance of the survey. The well-known report on the "auriferous gravels" contains the only geologic maps by the California Geological Survey ever made public. It also contains a complete account of the notorious Calaveras skull, thought by Whitney to be a Tertiary human skull, but demonstrated subsequently to be an intrusive burial of a modern Indian. Bret Harte even wrote a poem about it which was remarkably prophetic about the skull's real origin, though Harte made out the owner of the skull to be a Missourian who had somehow fallen into a mine shaft!

Many of the men of the Whitney survey were Titans by any criterion, and one wonders how the Titans of today would measure up if confronted by the tough going in the pioneering days when motor transport, base maps, canned food and previous information were unavailable.

Clarence King, who came to Whitney as a volunteer assistant, later headed the Fortieth Parallel Survey, and when the United States Geological Survey was organized in 1879, King, a relatively young man, was chosen as its first director. King held the post for one year, when he voluntarily relinquished it and was replaced by Major Powell. One of King's monuments to himself is his *Mountaineering in the Sierra Nevada*, a delightful book with real literary merit. Another is that the federal geological survey is not a military, but a civilian function. Captain George Wheeler, United States Engineers and head of the Survey west of the 100th Meridian, had openly and in print maintained that civilians could never conduct a successful scientific survey because they could not make maps! Charles Hoffmann has been credited with developing the methods of topographic surveying used by the federal survey; Henry Gannett, first chief topographer, was his pupil.

After 4 years on the California Geological Survey, Brewer returned to New Haven to take the chair of Agriculture in the Sheffield Scientific School, from which he retired in 1903. Whitney, at the close of the survey in 1873, returned to his post as Professor of Geology at Harvard. Ashburner later practiced mining engineering, became a regent of the University of California and a trustee of Stanford, and donated a clock and bell once installed in Bacon Hall at the University of California, but now used to sound the hours from the Campanile. *Sic transit gloria Altiora Petimus.*

In 1880 a need was again felt for some formal organization to care for the inquiries of such citizens as might find mineral statistics

and information of some use. At about this time petroleum was beginning to be produced in commercial quantities in southern California in spite of Whitney's well known statement that oil would not be found south of the Tehachapi!—and there was an added incentive to provide up-to-date information on this phase of California's mineral wealth. Hence the State Mining Bureau was launched, with its chief officer known as State Mineralogist. As of today he, as the Chief of the Division of Mines of the State Department of Natural Resources, actually functions as State Geologist.

With the organization of the United States Geological Survey in 1879 and its subsequent expansion, California naturally came in for its share of attention, or rather more than its share, if one notes the preponderance of California geologic folios issued in the early series. This was no doubt a result of general interest in the great Mother Lode gold belt and the placer belt in the Sierran foothills. Such names as Diller, Lindgren, Turner, and Gilbert stand out among these early United States Geological Survey geologists who formed the vanguard of the "modern" era of geologic inquiry. By 1900 emphasis was placed by the federal survey on the southern Coast Ranges, because of the rapid development of the petroleum industry. Here was the beginning of the florescence of Tertiary stratigraphic terminology of which there seems to be no end. Such men as Arnold, Anderson, Paek, Johnson, Kew, and English are representative of authors of the numerous "oil bulletins" which are basic to any subsequent work in the areas covered. The bay region, relatively free from outstanding economic deposits, was not the subject of extensive attention by survey geologists.

But on April 18, 1906, the bay region became the center of attention of the entire world. The earthquake of that day, described elsewhere in this guidebook, drew immediate attention of geologists, and an earthquake investigation committee, under the chairmanship of Andrew C. Lawson, lost no time in studying the geologic aspects of the famous temblor. This commission presented its report (two quarto volumes and an elephant folio atlas) in 1908. Beside delineation of the San Andreas rift,\* which had remained literally unnoticed before, the elastic rebound theory for this type of quake was developed by Harry Reid.

Not to be overlooked is the tremendous influence the two great pioneer universities of the state have played in the role of geologic understanding here. This is particularly true of mapping in the bay region, since practical instruction can be carried out in the environs

\*The San Andreas fault was named by A. C. Lawson in 1895 in the 15th Annual Report of the U. S. Geological Survey, page 468. The type locality is the rift zone between Mussel Rock and Woodside, San Mateo County, on which is situated San Andreas (artificial) Lake of the San Francisco water system. The term "rift" was given currency in the Earthquake Commission's Report of 1908, though it was used by Fairbanks in 1907.



FIG. 4. View east down Palm Drive, Stanford University. Arch in the foreground is part of the arcade typical of the Stanford Quadrangle. Tile-roofed columns in middle ground are remnants of Memorial Arch partly destroyed during the earthquake of April 18, 1906. *Photo courtesy of Stanford University.*

of Berkeley and Palo Alto with greater facility than in areas farther afield. The University of California, formally chartered in 1868, began instruction in the Earth Sciences under Professor Joseph Le Conte. Its subsequent graduates in this field have been in the forefront of geologic investigation ever since. Perhaps the dean of them all is Harold W. Fairbanks, whose best known work is the San Luis folio (1904). Dr. Fairbanks received his Ph.D. from the University of California in 1896 and has written more than 60 articles on the geology of California. His name "Golden Gate series" is equivalent to and actually antedates the name "Franciscan" of Lawson. The San Francisco folio, consisting of the Tamalpais, Concord, Hayward, and San Mateo quadrangles, was mapped by University of California students under the direction of Professor A. C. Lawson and John C. Merriam.

Stanford University began instruction in geology with John C. Branner in 1898, and, as at Berkeley, its graduates also are in the vanguard of professional geologists. Branner, Newsom, J. P. Smith, and students were responsible for the United States Geological Survey Santa Cruz folio. The other universities of the state come into the picture too late to be considered here, as do the multitude of living workers in the field of earth sciences in California. Those who have gone on to the Valhalla of continuous outcrops can have no objection to being left out or included in this historical treatment, but those who are still active may feel it presumptive of a writer to select or reject anyone whose work cannot be judged in historical perspective. Thus, we close, with no other comment than the observation that California (and the bay region) is receiving the greatest geologic going over in its history.

# GEOLOGY OF THE SAN FRANCISCO BAY COUNTIES

By N. L. TALLAFERRO \*

The geologic history of California has been anything but monotonous. In many parts of the United States, especially the central portion, the geologic history is long but comparatively simple, the flat lying or gently folded sediments recording only slight fluctuations in sea level. In California not only is there a long record of sedimentary deposition but also one of great volcanic episodes and frequent crustal disturbances shown by severe folds and faults.

California fronts the Pacific, the largest and deepest ocean, and because of deep-seated pressures stemming from the suboceanic crust which push against the continental margin, or of continental forces which push outward into the deep ocean basin, has been subjected to forces that have caused repeated, and often violent, uplifts and depressions. The region entering around San Francisco Bay is typical in this respect of the Coast Ranges as a whole.

In thinking of the past geologic history of any region, and especially of a Pacific coastal region such as California, it must be remembered that the present configuration of the land is of relatively recent development and that the now familiar landscapes were very different in the past. The "everlasting hills" actually are very ephemeral from the point of view of geologic time, and the populous and fruitful regions of today were once either a waste of marine waters or a rugged mountain range. During several long intervals in the past a high and precipitous mountain range lay to the west of the present coast line and the Coast Ranges were completely submerged beneath a sea that lay between this western land mass and the ancestral Sierra Nevada, which was probably a low sprawling range. Great changes have taken place in the past and equally great changes will take place in the distant future. The life span of the individual is so brief compared with geologic time that there can be but little general appreciation of the changes of the surface that go on constantly but slowly.

Because of strong uplifts and consequent strong erosion of the uplifted areas there are many great gaps in the geologic record. However, from knowledge of adjacent or even distant regions, a reasonable picture of the conditions that probably existed and the changes that have taken place can be obtained.

The San Francisco Bay country contains most of the geological units present in the central Coast Ranges and these units have been folded and faulted into structures that also are typical of the Coast Ranges as a whole. Many rock types are represented and these range widely in age; the only important geologic era not certainly represented is the Paleozoic.

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The area here defined as the bay counties covers 10,417 square miles. The writer has personally investigated much of this area but in preparing this paper has drawn freely on published information. Although most of the material presented here already has appeared in print in widely scattered publications, much is new and much is based on the writer's publications and his detailed mapping in many parts of the state. Large as the area is, many of the conclusions presented could not have been reached without a general knowledge of the geology of the state as a whole.

*Basement Complex in the Central Coast Ranges.* The oldest rocks known in the central Coast Ranges consist of ancient, rather highly metamorphosed schists, quartzites, and crystalline limestones or marbles that have been intruded by plutonic igneous rocks ranging from granites to diorites. In the San Francisco Bay region actual exposures of these rocks are not extensive, being limited to Montara Mountain, the extreme southern end of the Point Reyes peninsula, Bodega Head, and the Farallon Islands. In these localities the intrusive plutonic phase, known as the Santa Lucia granodiorite, greatly predominates; only small included blocks of the schists and marbles, into which the plutonics were intruded, remain. However, to the south in Santa Cruz County there are extensive exposures of schists and crystalline limestones.

The old plutonic mass of granodiorite, with small included remnants of schist and marble, is exposed along the coast from Devil's Slide to Montara Point and extends southeastward to Pilareitos Creek. On the north it is unconformably overlain by sediments of Upper Cretaceous and Paleocene age. On the east it is bounded by the Pilareitos fault along which the Franciscan has been thrust toward the southwest over the granodiorite and the Cretaceous and Paleocene sediments. On the south it is covered by Miocene sediments. Evidently the old granodiorite surface slopes steeply southward and is covered by many thousands of feet of Miocene and Pliocene sediments. This surface rises again 27 miles to the south and the ancient crystalline rocks are again exposed in Ben Lomond Mountain in northern Santa Cruz County.

The Montara Mountain-Ben Lomond Mountain zone, along which the bedrock complex is exposed in two fairly large areas, is the northern part of an important belt that runs diagonally through the Coast Ranges. Along this belt the bedrock is always found to be ancient crystalline rock on which sediments of Tertiary age rest. The basement complex is exposed at the surface in places, especially in the northern part of the Santa Lucia Range, the Sierra de Salinas, and

the Gabilan Mountains. In places this old crystalline rock surface rises to elevations of 5200 to 5800 feet above sea level and in other places it is buried beneath as much as 10,000 feet of Tertiary sediments.

This broad belt, along which the ancient crystalline complex is either exposed at the surface or buried beneath Tertiary sediments, is known as the Gabilan Mesa-Santa Cruz Mountain block. It is bounded on the northeast by the San Andreas fault and on the southwest by a series of en echelon faults. On either side of this block, which is in places nearly 40 miles wide, the ancient crystalline complex is buried under several tens of thousands of feet of Jurassic, Cretaceous, and Tertiary sediments. This belt of relatively rigid crystalline rocks, either exposed at the surface or buried beneath a comparatively thin cover of Tertiary sediments, is flanked by wide belts of very thick and pliable sediments susceptible to acute folding; this fact is of fundamental importance in any consideration of Coast Ranges geology. This block underlaid by basement complex first came into existence as a simple, broad, irregular upwarp in the late Upper Cretaceous. In the Eocene, profound normal faulting took place and the block was uplifted, tilted to the southwest, and stripped of its former cover of Jurassic and Cretaceous rocks.

Several names have been given this ancient crystalline complex. Originally it was called the Santa Lucia series, a name applied to the crystalline complex as a whole. As more detailed mapping progressed it was realized that the same name should not be given to the ancient metamorphic rocks and to the later plutonic rocks intruding them, so the name Sur schists was given to the metamorphosed sedimentary and volcanic rocks and the name Santa Lucia retained for the plutonic rocks. The crystalline limestones, marbles and dolomites are commonly called the Gabilan limestone, from the occurrence of thick beds of these rocks in the Gabilan Mountains. It has become customary to call all schist the Sur series, all crystalline limestones, marbles, and dolomites, Gabilan limestone, and all plutonic rocks Santa Lucia granodiorite. These names, therefore, are essentially petrographic and not formational in the usual sense since rocks of very different ages might be included under any one of the names.

The age of the basement complex is not definitely known as no fossils have been found. Shortly after the beginning of the present century supposed crinoid stems were found in a limestone belt near Gabilan Peak (also known as Frémont Peak). Recently collections of these supposed crinoid stems have been made and submitted to several paleontologists who all agree, not only that they are not crinoid stems, but also that they are not fossils. They are merely branching tubular segregations of graphite in a crystalline marble included in granodiorite. These crystalline rocks are known to be older than the Franciscan, which is late Upper Jurassic as Franciscan conglomerates

contain pebbles, cobbles, and boulders of all phases of the basement complex. They are also older than the Amador and Mariposa groups of the Sierra Nevada, as conglomerates at the base of the Amador contain debris of the Sur schists.

Frequently these ancient rocks have been correlated with the Sierran Paleozoic series of rocks called the Calaveras group. However, the Sur schists and associated rocks are in a much more advanced stage of metamorphism than the Calaveras and, even discounting the metamorphic effects, the two have little lithologic resemblance. There is no valid reason for correlating the Sur schists and Gabilan limestones with the Calaveras slates and limestones. There is more reason for the correlation of the Sur schists with certain supposed pre-Cambrian schists of southern California, similar schists in northern California and the Colebrooke schists of Oregon. Similar schists in northern California are almost certainly pre-Silurian and probably pre-Cambrian in age. The writer believes that the Sur schists, Gabilan marble, and Santa Lucia granodiorite are either pre-Cambrian or early Paleozoic, probably the former.

Exposures of these rocks may be seen on the road from Crystal Springs Lakes to Halfmoon Bay on the west side of the crest of the ridge, on the road across Montara Mountain, along the coast south of Devil's Slide, and on the southern tip of the Point Reyes peninsula. At the last-mentioned locality the granodiorite is overlain by coarse sands and breccia conglomerates largely made up of granodiorite debris. Since the granodiorite weathers readily none of the outcrops mentioned, except those immediately adjacent to the ocean, are particularly good or interesting.

In the San Francisco Bay region the ancient crystalline rocks have little or no present economic importance. Most of the plutonic granitic rocks are strongly weathered and irregularly jointed and hence unsuitable for building stone. However, in Santa Cruz County the crystalline limestones are extensively quarried and used in the manufacture of portland cement. Northwest of Salinas dolomites in the basement complex are extensively quarried for their magnesia content. Limestones south of San Juan Bautista are quarried for cement manufacture, and 10 miles south of Hollister there are several dolomite quarries from which high quality dolomite is obtained. There are several pure crystalline limestone and dolomite lenses in the Gabilan Range in San Benito and Monterey Counties. Although not in the San Francisco Bay region as here defined, they are in country tributary to San Francisco, and supply San Francisco industries.

*Paleozoic Era.* There are no known rocks of Paleozoic age either in the San Francisco Bay region or the central Coast Ranges, unless the basement complex might be, in part, of lower Paleozoic age.

From all available evidence, the central Coast Ranges, including the San Francisco Bay region, were a low land mass throughout the

Paleozoic, whose duration is commonly estimated at over 300 million years; they formed the eastern edge of the ancient land mass of Cascadia that lay off the coast of California. The Paleozoic sea lapped against this lowland mass from the east. Paleozoic sediments undoubtedly were deposited as far west as the site of the present great central valley of California. In fact, Paleozoic sediments may have been deposited in the area now occupied by the central Coast Ranges, and subsequently removed by erosion. However, no sediments of Paleozoic age have been found in the central Coast Ranges, from Santa Barbara northward to Humboldt County. If sediments of this era ever had been deposited in the central Coast Ranges some remnant should exist in one or more of the strongly downfaulted areas. The fact that none are found is only presumptive evidence that none were deposited.

In the Klamath Mountains to the north, the Sierra Nevada to the east, and the great desert region of California to the southeast thick sections of Paleozoic rocks are found, and it is known that these regions were invaded, not once but many times, by Paleozoic seas.

*Geology of the Sierra Nevada.* Although the area herein defined as the San Francisco Bay region only reaches the low foothills of the Sierra Nevada, there are good exposures of typical Sierran igneous and metamorphic rocks, especially on the Cosumnes River in the eastern part of Sacramento County. Also, deep water wells a short distance east of the city of Sacramento have penetrated Sierran plutonic rocks. Events in the Sierran region initiated the extensive trough from which the present Coast Ranges evolved; furthermore, this history fills a chronological gap in the geology of the San Francisco Bay region.

Work in the gold belt in the Sierra Nevada, even as early as 80 years ago, showed that, in a general way, the rocks could be divided into two broad groups, the Bedrock series and the Superjacent series. The Bedrock series consists of strongly folded and metamorphosed Paleozoic and early Mesozoic sediments and volcanics intruded by a great variety of igneous rocks in masses ranging from thin dikes to great plutonic bodies covering wide areas. The sediments and volcanics were folded and metamorphosed in the late Jurassic; invaded by intrusive rocks; uplifted into a low mountain chain, the ancestral Sierra Nevada; and then worn down to a region of low relief during the Cretaceous and early Eocene. Various nonmarine Tertiary sediments, including the famous auriferous gravels, were deposited on this low surface cut into the upturned edges of the older rocks. These flat lying or gently dipping Tertiary sediments and volcanics are known as the Superjacent series.

In that part of the Sierra Nevada extending from the American River southward to the Merced River the oldest known rocks are Paleozoic. These consist of slates, sandstones, conglomerates, lime-

stones, cherts, and volcanics that have been folded at least twice and intruded by igneous rocks. These are called the Calaveras group and undoubtedly consist of rocks of several ages. Just how much of the Paleozoic is represented is unknown but it is known that sediments and volcanics ranging from Mississippian (Lower Carboniferous) age through Upper Permian are represented. In all previous publications the Calaveras has been stated to be of Mississippian age. However, in the summer of 1948 a party of students working under the direction of the writer found fossils of Upper Permian age in "Calaveras" limestones a few miles east of the eastern boundary of Sacramento County. In other localities Lower Carboniferous fossils have been found in "Calaveras" limestones. Thus the "Calaveras group" actually is a heterogeneous assemblage of rocks of Upper Paleozoic age. In fact, it may contain rocks of Lower Paleozoic age also.

Calaveras rocks are not exposed at the surface within the area here defined as the San Francisco Bay region. However, they are very poorly exposed beneath Eocene sediments on Highway 54 a few miles east of the eastern boundary of Sacramento County.

At the close of the Paleozoic the sediments and volcanics now known as the Calaveras group were folded and probably uplifted. This occurred at the same time as the Appalachian revolution that folded the Appalachian Mountains. At the same time mountains were uplifted in the southwestern part of the United States, in Europe, and in many other parts of the world.

In California, as a result of the mountain-making movements at the close of the Paleozoic, the sea which had extended at least as far west as what is now the Great Valley, was driven farther eastward, and much of California stood above sea level and still faced a sea toward the east.

The Lower Triassic sea occupied parts of what is now Nevada but only reached into the extreme eastern part of California, the Owens Valley region, where fossiliferous Lower and Middle Triassic sediments and volcanics are found. By Upper Triassic time marine waters had encroached westward into the region now occupied by the crest and high western slopes of the Sierra Nevada and into the Taylorsville and Redding regions in northern California. No Triassic sediments are found in the San Francisco Bay region, which still stood above sea level as a low land mass.

The Lower and Middle Jurassic seas had about the same distribution as the Upper Triassic sea except that the Middle Jurassic sea extended as far south as the Oroville region. The present site of the town of Oroville is very close to the southern margin of the Middle Jurassic sea.

By the beginning of the Upper Jurassic the sea had encroached as far west as the central part of the Great Valley of California and extended eastward and northward over a considerable part of the

state. The first deposits were conglomerates and sandstones derived from the west; these were followed by fine elastics, sandstones, and impure dark limestones. These sediments have been called the Cosumnes formation by the writer. After the deposition of these sediments violent submarine volcanic activity broke out in the region that now lies just to the west of the Mother Lode. Several thousand feet of coarse volcanic breccias, finer pyroclastics and flows of augite andesite and basalt accumulated. So rapid was the accumulation of these volcanics that they masked the more slowly accumulating sediments. Shortly after the beginning of the outpouring of basic volcanics on the east equally violent submarine rhyolitic volcanic activity took place in what is now the extreme western foothills of the Sierra Nevada. Although these two areas, the Mother Lode region and the area of low foothills lying immediately east of the Great Valley are now less than 10 miles apart they were probably at least four or five times this far apart in the Upper Jurassic; intense folding and crustal shortening have brought them fairly close together. These volcanics, with their interbedded sediments, are known as the Logtown Ridge formation.

Volcanism waned and sediments again had a chance to accumulate; over 6000 feet of shales, with thin interbeds of sandstone and an occasional thin conglomerate formed. These are now known as the Mariposa slates.

After the deposition of the Mariposa, but still well before the close of the Upper Jurassic there was a profound period of diastrophism, during which the sediments and volcanics, both of Paleozoic and Jurassic age, were intensely folded and then intruded by great batholithic bodies of plutonic rocks, chiefly granodiorites. This episode, known as the Nevadan revolution, profoundly affected not only the geologic history but also the early and rapid settlement of California as at this time the rich gold veins of the Sierra and the Foot-hill copper deposits were formed.

Both the Paleozoic and Jurassic rocks were thrown into great folds that are overturned toward the west, the rocks having been pressed against the foreland, which was the low land mass that then occupied the present site of the Coast Ranges. Many of the larger overturned folds broke and the stretched anticlinal limbs and the anticlines were thrust over the synclines. The largest and greatest of these broken folds is the Mother Lode thrust zone, an imbricated belt of strong thrust faulting along which the Paleozoic rocks were thrust westward over overturned Jurassic rocks. It is along this zone of thrusting that the gold quartz veins of the Mother Lode system were deposited. Other smaller thrust zones, both in the Paleozoic rocks to the east and the Jurassic rocks to the west, were mineralized by emanations from the deep-seated plutonic rocks that intruded the region after the folding

and faulting. The present Mother Lode thrust and vein system is the root of the late Jurassic Mother Lode thrust.

Subsequent erosion of the region during the Cretaceous and early Eocene released the gold from the veins, notably along the Mother Lode system but also from the innumerable smaller veins in the Paleozoic to the east, and formed the rich placers and channel deposits on the Sierran slopes. It was, of course, these gold placers that played so large a part in the early settlement of California.

Paleozoic rocks lie chiefly to the east of the Mother Lode thrust and Jurassic rocks to the west. However, there are several narrow belts of Paleozoic rocks west of the Mother Lode that have been brought up from beneath the Cosumnes, Logtown Ridge, and Mariposa formations, by faulting or along strong anticlines.

There are good exposures of the Logtown Ridge volcanics and the Mariposa slates along the Cosumnes River in the eastern part of Sacramento County. Here the rocks have been wrinkled into many overturned folds. These exposures may be easily seen both to the east and west of Michigan Bar bridge over the Cosumnes River.

*Nevadan Revolution.* Just prior to the Nevadan revolution, the present site of the Coast Ranges was a low land mass that sloped gently eastward toward a broad seaway in which the Mariposa sediments were being deposited. As a result of the great and widespread Nevadan revolution the Sierra region was wrinkled into innumerable folds, overturned toward this old western land mass, and elevated into the ancestral Sierra Nevada. These ancestral Sierras probably were comparatively low. At the same time the ancient western land mass was rejuvenated, and either upbowed or upfaulted into a high and rugged range that lay to the west of the present coast line. The region between these two newly uplifted ranges, the high range of crystalline rocks off the present coast and the low ancestral Sierras to the east, was bowed downward and, for the first time in several hundred million years, was flooded by a shallow sea that extended from the Santa Barbara coast northward well into Oregon. Immediately both the high western land mass and the ancestral Sierra Nevada were attacked by normal erosional processes and the sediments resulting were washed into the shallow trough that occupied the present site of the Coast Ranges. The bulk of the sediments, rather coarse arkosic sands, were derived from the western land mass of ancient crystalline rocks.

The sinking trough or geosyncline thus developed in the late Upper Jurassic continued, with minor marginal disturbances and slight shiftings of its major axis, to sink slowly and to receive deposits throughout the remainder of the Jurassic and all of the Cretaceous. Thus, it was the Nevadan revolution, responsible for the introduction of the Sierran gold and the elevation of the two mountain masses, that created the geosyncline in which the present Coast Ranges had their birth.

In this geosyncline were deposited from 20,000 to 30,000 feet of late Jurassic sediments and volcanics and 45,000 to 50,000 feet of Cretaceous sediments. Although there were minor interruptions, marginal folding and faulting and slight eastward shifting of the major trough, this great geosyncline persisted throughout the remainder of the Mesozoic and in it was deposited an enormous thickness of shallow-water sediments.

Thus, throughout the late Jurassic and all of the Cretaceous, a time interval of at least 50 million years, the Coast Ranges, including the entire San Francisco Bay region, except the eastern part in eastern Sacramento and San Joaquin Counties, was covered by a shallow sea. To the west, probably more than 10 miles off the present coast, lay a mountain range made up of the old crystalline rocks. In the early stages of downsinking of the geosynclinal trough this range was high, with many sharp canyons occupied by streams of high gradient. As time progressed this range was lowered by erosion, relief decreased and the streams became broader and more sluggish. There were probably periods of slight rejuvenation and local re-elevation, but in general the wearing down of the old land mass, which is now buried beneath thousands of feet of marine waters, continued.

Toward the east rose the ancestral Sierra Nevada, probably a relatively low land mass with streams of only moderate gradient carrying minor amounts of sediments into the sinking trough. In the Cretaceous the Sierra Nevada appears to have been arched upward again and to have contributed proportionately more and more debris into the geosyncline as the western land mass was worn down.

During the period that the western land mass was high it probably acted as a barrier to rain-bearing winds from the Pacific Ocean. Precipitation was high in the crestral region and the eastern slope was well forested. Macerated plant material is abundant in the sediments deposited in the geosyncline. It is probable that the mountains east of the geosyncline, the ancestral Sierra Nevada, were comparatively arid during the time the western range was high enough to cut off the rain-bearing winds from the Pacific. As the western land mass was worn down rainfall became more and more abundant in the eastern land mass, which also probably became well forested.

The geosyncline was not of uniform width and depth everywhere, and the sediments deposited in it varied considerably in thickness and kind from place to place throughout its extent. Many formational units, which have been given many different names, were deposited. However, there is a marked similarity in type of deposits for any given time interval.

*Franciscan-Knoxville Group.* The oldest rocks deposited in the geosyncline that occupied the site of the present Coast Ranges are appropriately known as Franciscan, from the excellent exposures

found on the San Francisco peninsula. These rocks, which consist of a heterogeneous assemblage of sediments, contemporaneous volcanics, and intrusives, are well exposed in the San Francisco Bay region, especially in San Francisco, San Mateo, Santa Clara, Alameda, Contra Costa, Marin, Sonoma, and Napa Counties.

Franciscan-Knoxville rocks have an outcrop area of approximately 14,000 square miles in the Coast Ranges of California. Furthermore, they either crop out at the surface, or are known to underlie the surface rocks over an area of fully 30,000 square miles, or approximately one-fifth of the total area of the state. This is only a part of the area of the original basin in which these beds were deposited.

The slowly sinking geosyncline in which the Franciscan-Knoxville group as well as the later Cretaceous sediments were deposited extended from Santa Barbara northward well into Oregon. On the east it was bordered by the recently uplifted ancestral Sierra Nevada and on the west by a high and rugged land mass of crystalline rocks (Suisun schists and Santa Lucia plutonics).

The oldest sediments deposited in the geosyncline that occupied the site of the present Coast Ranges are the arkosic sandstones of the Franciscan that were chiefly derived from the land mass to the west. Because of the cold and rainy climatic conditions that existed in the high regions in the western range, mechanical rather than chemical decomposition of the old crystalline rocks predominated. Because of this the feldspars and other soluble minerals were not decomposed but were carried into the basin of deposition in a fresh condition. Thus the sandstones making up the lower part of the Franciscan contain an unusually large proportion of fresh feldspars and are called arkosic sandstones.

Conglomerates occur but they are not abundant; the pebbles, most of them small, are made up largely of materials from the old crystalline complex. Thin dark shales interbedded with sandstones are common and lenses of sandy shale 50 feet or more in thickness may occur; these represent the fine detritus derived from the adjacent land masses.

After the deposition of 5000 to 10,000 feet of prevailing coarse shallow water mechanically derived detritus in the slowly sinking geosyncline, rather widespread submarine volcanism began, and there were sea floor outpourings of basic volcanics, chiefly pillow basalts. Submarine explosions also resulted in ejection of coarse to fine fragmental material which formed beds of volcanic ash intermixed with varying amounts of normal sedimentary material; coarser volcanic detritus was laid down as volcanic breccia and agglomerate. Flow and fragmental volcanic rocks are commonly interbedded with sandstones and shales and also with rather distinctive siliceous chemically deposited sediments, the radiolarian cherts, which are so common in the



Franciscan. So constant is the association of the cherts with the volcanic rocks, particularly the pillow basalts, that the conclusion is inescapable that the volcanics were instrumental in contributing an unusual amount of silica to the sea water. Both iron and manganese also were contributed in local areas by the volcanics and these, having been added in colloidal form, occur in the cherts, which were originally colloidal also. The association of pillow lavas and radiolarian cherts is not confined to the Franciscan of the Coast Ranges but is of world-wide distribution in formations of many ages.

The cherts are always rhythmically bedded, the individual beds or lenses ranging from less than an inch to 6 inches in thickness and averaging between 2 and 3 inches. The individual chert lenses are separated by partings of shale that range from paper thinness to an inch in thickness. The chert lenses always are thicker than the shale.

There is considerable variation in color in the cherts, but the prevailing color is red; most of the thin shale partings have the same color as the chert. Although the prevailing color is deep red the cherts may be white, pale pink, yellow brown, various shades of green, chocolate brown, and even black. The color depends largely on the state of oxidation of the iron and to a lesser extent on the presence of manganese.

The silica making up the cherts was originally colloidal but because of the great depth of burial and the strong folding suffered by the Franciscan as a whole, the cherts have become crystalline and are largely made up of a fine mosaic of quartz or chalcedony or both. Excellent exposures may be seen in Golden Gate Park, on Twin Peaks, on the road up Mount Diablo and on many of the roads in Marin County. Thick bodies of cherts and shales, with accompanying pillow basalts, occur on the Marin peninsula immediately north of the Golden Gate Bridge.

In thin section under the microscope the tests or hard coverings of radiolaria, silica-secreting protozoa, may be seen. However, some cherts are barren of radiolaria. The radiolaria are not the source of the bulk of the silica in the cherts but are present because the unusual amount of silica in the sea water provided abundant material for the growth of their tests.

Limestones occur in places in the Franciscan, either in association with the sandstones or, more rarely, with the cherts. Most of the limestone occurs as small lenses less than 100 feet in length but exceptionally it may form beds of considerable thickness and extent, such as the one in Permanente Canyon which has been extensively used in the manufacture of cement. Most of the limestone is light to dark gray in color and contains numerous small irregular areas of black flint; but much of the limestone directly associated with the cherts is red in color. Although limestones may be of local importance, they make up

but a small fraction of one percent of the Franciscan as a whole. Remains of small organisms, such as foraminifera tests, echinoderm spines and sponge spicules, are found in some of the lenses but, as a rule, these are poorly preserved, or very nearly obliterated by recrystallization of the limestone.

The volcanics, cherts, and limestones are interbedded and occur with normal detrital sediments, such as sandstones, conglomerates, and shales. All were formed in shallow water in a slowly sinking basin.

Both the Franciscan and the Knoxville formations are extensively intruded by basic and ultrabasic igneous rocks. The ultrabasic rocks, peridotites and dunites made up of varying proportions of the heavy basic silicates olivine and pyroxene, have been completely or almost completely serpentinized. Large, irregular areas of serpentine, with minor amounts of closely associated gabbro and diabase, are widely distributed throughout the Coast Ranges. Some of these basic and ultrabasic intrusives locally metamorphosed the adjacent Franciscan sediments into glaucophane schists. These beautiful blue and green schists are especially well developed on the Tiburon peninsula, in the north Berkeley Hills, and to the west of Healdsburg.

The total thickness of the Franciscan is not known as there are no continuous sections from base to top exposed anywhere in the state. In fact, the base of the Franciscan never has been found. This seemingly peculiar situation stems from the fact that the Coast Ranges were strongly folded and faulted several times both in the late Mesozoic and in the Tertiary; all of the known contacts with older rocks are faults, and hence the basal portion of the Franciscan always is buried beneath the surface.

The thickest reported section of Franciscan rocks, including practically all of the recognized rock types, is in Alameda and Santa Clara Counties, in the northern part of the Mt. Hamilton Range, where the exposed thickness is estimated to be 12,000 feet. There are several continuously exposed sections 10,000 feet thick along the east side of the Diablo Range. All of these are only partial sections, neither the top nor the bottom being exposed. It is estimated that the total thickness of the Franciscan is not less than 20,000 feet.

The Franciscan nearly everywhere is strongly folded and faulted, and most of the stratified rocks stand at high angles.

As the western land mass that supplied the bulk of the detrital Franciscan sediments was slowly worn down by long-continued erosion, there was a gradual change in the character of the sediments supplied to the basin of deposition. As the land was reduced in elevation, the streams became more sluggish and erosion less rapid; chemical decomposition increased and silts and clays became more abundant. Therefore, in the upper part of the Franciscan and in the Knoxville stage, fine-grained clastic sediments predominate over coarse sediments.

The Knoxville stage of the Franciscan-Knoxville group is chiefly made up of dark, silty, clay shales with thin interbeds of fine-grained sandstone. The Knoxville sandstones are also arkosic, containing much unweathered feldspar, but they are finer grained and in general contain a greater proportion of silt and clay than the Franciscan sandstones. The dark clay shales of the Knoxville are identical with those in the Franciscan. Conglomerates occur in the Knoxville but they are not abundant. They consist of small, well rounded pebbles of black recrystallized chert and various types of igneous porphyries; these are the same types that predominate in the Franciscan conglomerates.

Dark impure limestones occur in the Knoxville as thin lenses and as concretions in the shales; many of these limestones are fossiliferous.

In several places thin flows of pillow basalt and thin impure red cherts are found in the lower part of the Knoxville well above typical Knoxville fossils.

For many years the Knoxville was considered to lie unconformably on the Franciscan. The writer searched for this unconformity for several years in practically all parts of the Coast Ranges without success. Instead of the contact being unconformable, it is gradational wherever exposed, and for this reason the writer has proposed that the two be united as the Franciscan-Knoxville group. The Knoxville is merely an upper stage or phase of the Franciscan.

The maximum thickness—approximately 12,000 feet—of the Knoxville stage is found on the west side of the Sacramento Valley in Tehama County. The Knoxville stage is present in most of the bay counties but, because of the southward thinning and faulting it is in most places less than 3000 feet in thickness.

Fossils, other than the small poorly preserved radiolaria and foraminifera in the cherts and limestones, are rare in the Franciscan. The best fossils found thus far are two ichthyosaur snouts found in Franciscan chert boulders in western San Joaquin County. These were carefully studied by Dr. C. L. Camp of the Department of Paleontology, University of California, who concluded that they were of late Upper Jurassic age. Fossils are fairly abundant in the Knoxville stage and clearly show that these beds also are of late Upper Jurassic age.

Although the Franciscan-Knoxville group is very thick—maximum thickness is probably 30,000 feet—the rocks are chiefly coarse elastics and volcanics that accumulated rapidly, and therefore do not represent an excessively long period of geologic time. As the result of many years of field work over a large part of the Coast Ranges, the writer has reached the conclusion that the Franciscan-Knoxville group, in spite of its thickness and apparent inhomogeneity, is of definite stratigraphic value and is equivalent to the Tithonian or late Upper Jurassic rocks of Europe. It was deposited in a slowly sinking

geosyncline that came into existence as a result of the Nevadan revolution. The geosyncline created at this time received sediments during the late Jurassic and throughout the Cretaceous and was the birthplace of the Coast Ranges as they are known today.

When stripped of its weathered overburden the Franciscan sandstone is a hard, fresh, firmly cemented rock that makes excellent road metal. A number of quarries in Franciscan sandstone have been opened and an enormous amount of crushed sandstone taken from them. The large quarry near the Richmond terminal of the Richmond-San Rafael ferry is in Franciscan sandstone. There are several Franciscan sandstone quarries both in Oakland and San Francisco and many small quarries in Marin County. The hard red chert of the Franciscan also has been quarried for road metal, but is not as satisfactory as the sandstone because of the ease with which it fractures under heavy loads. It is, however, a suitable material for secondary roads carrying light traffic.

Franciscan sandstone is suitable for concrete aggregates but chert is wholly unsuited for this purpose and should be avoided, as it causes concrete to crack. Franciscan basalt has been quarried for road metal, but it often proves unsatisfactory because it is deeply decomposed to start with and breaks down readily. Because of its availability in local areas and the ease with which it breaks, Franciscan basalt frequently has been quarried for fill material. Many of the gravels in valleys, such as Livermore Valley, are made up of the harder rocks of the Franciscan.

The brightly colored blue and green glaucophane and actinolite schists, the deep red cherts, and the silica-carbonate rock with its fantastic solution forms are commonly used as decorative garden stones. Representatives of some or all of these rocks may be found in practically all commercial stone yards.

Limestones of the Calera type are used both for crushed rock and for cement manufacture. The large cement plant at Permanente utilizes Franciscan limestone.

All of the manganese mined in the Coast Ranges is associated with radiolarian chert. The manganese was deposited at the same time as the chert and occurs in the form of manganese carbonate or as high-silica manganese ore, interbedded with the chert. The Ladd mine in eastern Alameda County is the largest manganese mine in the state and surface oxidized ore was mined as early as 1866. The Ladd mine was operated continuously during World War I and produced several tens of thousands of tons of manganese ore. The second largest manganese mine, the Buckeye, is located in Stanislaus County about a mile from the San Joaquin County line. This mine yielded about 20,000 tons of high-grade manganese ore during World War II. Several thousand tons of ore still remain. There are scores of smaller

manganese mines that have yielded from a few hundred to 5000 tons of ore in Sonoma, Napa, Marin, Alameda, San Joaquin, and Santa Clara Counties. Should there be an appreciable advance in the price of manganese and a cheap process devised for the utilization of high silica ores, the bay counties could supply a substantial tonnage of low- to medium-grade ores.

The mineral chromite occurs as disseminated grains in the serpentine and, in places, as irregular magmatic ore bodies. During World War I many small chrome bodies were mined in practically all of the bay counties and a small amount of chrome was mined during the second World War.

Magnesite is another important substance which occurs in the Coast Ranges of California only in serpentine. The largest magnesite mines in the region are in eastern Santa Clara County, near the crest of the Diablo Range. Smaller, but more numerous, magnesite mines are in Napa County, both north and south of Pope Valley. Magnesite occurs as veins and irregular areas in serpentine. The alteration of the original olivine usually stops with serpentine but if there is further alteration, especially with the aid of carbon dioxide and water, magnesite is formed.

A third material of economic importance which occurs primarily in serpentine is chrysotile asbestos. Although there are many asbestos mines in California that have been operated intermittently in the past, only two of these are located in the bay region. One is in Napa County, about a mile west of the road between Napa and Monticello, and approximately 19 miles by road north of Napa. Mining operations began on this property in 1941 and ceased in 1945. In 1942 a 40-ton mill was installed at the mine. A considerable but unknown amount of short-fiber asbestos was produced and marketed under the trade name "Plastene" for use in fireproof plaster and stucco construction. The other asbestos deposit in the bay region is located in Alameda County, near the Contra Costa County line in the hills east of Fruitvale. In 1915 a few tons of asbestos were mined here and ground for use with magnesite in the manufacture of fireproof tile.

Quicksilver occurs in the Franciscan in many of the bay counties and is mined whenever the price warrants operations. Although the quicksilver was introduced in the late Tertiary or even in the Pleistocene, it is frequently found in Franciscan rocks, especially on the contact with serpentine and other Franciscan rocks, and particularly on fault contacts. The minerals found are red cinnabar and black meta-cinnabar; the former is the most common. There are several mines in the Mount Diablo region in Contra Costa County, the largest being the Mount Diablo mine. This is on the northeast side of Mount Diablo near the piercement fault contact between Franciscan and Lower Cretaceous rocks. This mine is only a short distance from the

Marsh Creek Road. There are many other quicksilver mines in the bay counties.

Oil usually is regarded as entirely foreign to the Franciscan formation and when wells drilling for oil encounter Franciscan rocks they are as a rule quickly abandoned. In fact, oil geologists nearly always cease mapping when the Franciscan contact is reached. However, the first oil well drilled in California that actually found oil started and finished in the Franciscan. A well drilled in 1863 or 1864 in the Petrolia district in Humboldt County obtained a very small quantity of high gravity oil in the Franciscan. There are oil seepages from dark Franciscan shales along the coast north of the mouth of Bear River in Humboldt County. Wells west of Monticello in Napa County obtain small quantities of oil from dark Knoxville shales. Wells in western Colusa County near Wilbur Springs also obtain very small quantities of oil from the Knoxville. However, the production in all of these areas is not commercial, being measurable in gallons per week rather than in barrels per day. Although oil does occur in the Franciscan-Knoxville group, it has not yet been found in commercial quantities.

*Diablan Orogeny.* At or near the end of the Jurassic there was a period of uplift and disturbance to which the writer has given the name Diablan orogeny. Although this disturbance resulted in the uplift of the western margin of the geosyncline in which the Franciscan-Knoxville rocks accumulated, the trough was not destroyed and sedimentation continued without interruption. However, the beginning of the Lower Cretaceous was marked by a coarsening of the sediments in the trough. The base of the Lower Cretaceous is in most places marked by a basal conglomerate which ranges from a few feet to several hundred feet in thickness and contains debris of both Franciscan and Knoxville. Therefore, in the region between the Sacramento Valley and the main Coast Ranges there is no angular discordance between the Lower Cretaceous and the Franciscan-Knoxville, but the contact is marked by a coarsening of the sediments and the appearance of pebbles and boulders of the Franciscan-Knoxville rocks derived from the uplifted margin of the geosyncline. Another effect of the Diablan orogeny was an eastern shifting of the major axis or trough of the geosyncline. This is indicated by the fact that the thickest sections of the Lower Cretaceous occur in the eastern foothills of the Coast Ranges not far west of the western edge of the Sacramento Valley.

The Diablan orogeny did not destroy or cause a withdrawal of the sea from the geosyncline in which the Franciscan-Knoxville group was deposited but it disturbed, uplifted, and exposed to erosion the western margin and shifted the axis slightly eastward.

*Lower Cretaceous-Shasta Group.* The Shasta group is a thick series of elastic sediments that is best developed and attains its maximum thickness along the west side of the northern Coast Ranges, a few miles west of the western edge of the Sacramento Valley.

The Shasta group may be divided into two faunal stages, the Paskenta below and the Horsetown above. These are not mappable units but merely faunal stages, and the line between them cannot be established satisfactorily. The fauna in the lower part of the Paskenta has strong affinities with the underlying Jurassic Knoxville and the fauna in the Horsetown has strong affinities with the overlying Upper Cretaceous.

The base of the Paskenta is in most places marked by a conglomerate which ranges from a few feet to several hundred feet in thickness. Along the west side of the Sacramento Valley, this conglomerate rests conformably on the Knoxville stage of the Franciscan-Knoxville group; but farther west in the Coast Ranges it rests on much older Franciscan rocks. It contains abundant debris of the Franciscan-Knoxville rocks as well as pebbles and boulders derived from the Sur series and Santa Lucia plutonics. This basal conglomerate grades upward into dark clay shales and thin, hard, fine-grained sandstones lithologically identical with those in the Knoxville. The Paskenta stage is made up predominantly of dark clay shales, thin impure limestones, and thin, hard, fine-grained sandstones. The Horsetown is chiefly composed of dark gray to black silty shales and thicker, somewhat coarser sandstones. The lithologic difference between the two, however, is not well marked and the same lithologic types occur in both. Thin conglomerates may appear in any part of the section. There are no contemporaneous volcanics in the Lower Cretaceous in the bay region, which is in marked contrast with the underlying Jurassic. The only evidence of contemporaneous volcanism in the Lower Cretaceous in northern California is a thin, 6- to 18-foot bed of cream-colored bentonite, an altered volcanic ash, that occurs in Glenn and Colusa Counties about 8000 below the top of the Lower Cretaceous. Locally this is the most consistent individual bed and the best marker horizon in the Lower Cretaceous. Although the Lower Cretaceous in general is made up of similar lithologic types there is great lateral variation and a given sandstone, shale, or conglomerate member is neither persistent nor of uniform thickness from place to place along the strike of the bed. Marked lateral variation is a feature characteristic of the Cretaceous as a whole. Although the present site of the best known belt of the Shasta group is some distance east of the former western margin of the basin of deposition, the location of the chief rivers emptying into the basin is indicated by a local coarsening of the sediments. A careful study of the lithologic types should disclose the location of the chief rivers draining the western land mass.

Although the Shasta group in general is made up of a monotonous sequence of ordinary elastic sediments, there are local phases in Paskenta stage rocks that are strikingly different in character. These unusual rocks are the direct result of local folding or faulting that took place at the end of the Jurassic—folding and faulting that extended into the geosyncline from its unstable border areas. A faulted fold developed in what is now western Colusa County, and brought serpentine and Franciscan-Knoxville rocks above sea level; this has been called the Wilbur Springs high. Landslides readily developed in hills of serpentine and as the fold rose above sea level, great landslides took place, sending enormous quantities of serpentine debris eastward and southeastward into the Lower Cretaceous sea. In some instances, these landslides were of such size that little sorting or lateral distribution was accomplished by marine waves and currents; but the smaller landslides were both reworked and redistributed by waves and currents. In the brief periods between landslides, fossiliferous detrital sediments accumulated, so that coarse serpentine landslide breccias are found interbedded with normal black clay shales, fine-grained sandstones, or fossiliferous limestones. Several landslide deposits of this kind occur in Napa, Lake, and Colusa Counties, but the largest is in western Colusa County. There the landslides may be traced for over 10 miles along the strike; they attain a maximum thickness of over 4000 feet, including a few hundred feet of interbedded sediments. These landslides thin and finger out both to the north and south into normal detrital sediments. Some of the landslide deposits are exceedingly coarse and contain blocks of serpentine up to 50 feet in diameter. Most of them, however, are made up of fine, flaky serpentine with scattered large blocks of serpentine and some fragments of Franciscan-Knoxville rocks. Landslide deposits of this sort may be seen along Highway 20 and at the junction of Highways 16 and 20 in western Colusa County, and in Pope Valley in Napa County.

The Shasta group forms a rather narrow continuous belt that extends from Shasta County southward to Suisun Bay. It has a maximum thickness of 22,000 feet in Tehama and Glenn Counties, thinning southward to 9500 feet in Colusa County as it passes over the Wilbur Springs high. From there it thickens southward and has a thickness of over 18,000 feet in northern Napa County. It again thins to the south toward Suisun Bay where it disappears beneath younger sediments and the waters of the bay. South of the bay it reappears from beneath later sediments in the Mount Diablo anticline where it is only about 5000 feet thick. Southeast of Mount Diablo the Shasta beds disappear beneath later sediments along the plunge of the anticline. The Shasta reappears again south of Livermore and in the southwestern part of San Joaquin County on the east side of the

Diablo Range, where only the Horsetown stage is represented, the Paskenta stage having been cut out by faulting. Both the Paskenta and Horsetown stages occur in small areas on the west side of the Diablo Range in Santa Clara County. North of the bay the Shasta is preserved in rather deep, faulted synclines in western Napa County, near Healdsburg in Sonoma County, and in Potter Valley.

Neither the eastern nor western limits of the Lower Cretaceous basin of deposition is known with certainty. However, near the center of both the Sacramento and San Joaquin Valleys deep wells pass directly out of Upper Cretaceous sediments into granitic bedrock, showing the Lower Cretaceous to be absent in the center of the Great Valley. From evidence obtained from deep oil wells it is concluded that Lower Cretaceous sediments never extended as far east as what is now the center of the Great Valley, which, during the Lower Cretaceous was the western edge of the ancestral Sierran land mass. From the rather wide distribution of the Lower Cretaceous in the Coast Ranges and from the fact that the sediments have the same lithologic character and faunal assemblages throughout, it is concluded that the Shasta group was deposited continuously over the Coast Ranges west of the Great Valley in the area covered by this report. Therefore, during the Lower Cretaceous the present Coast Ranges were the site of a shallow sea which occupied a geosyncline whose eastern margin was near the present center of the Great Valley and whose western margin lay near, but west of the present coast line. The present width of this belt is about 80 to 90 miles, but in Lower Cretaceous time it must have been over 100 miles, as the region of the present Coast Ranges has been greatly compressed and shortened during the several periods of intense folding and crustal shortening in the Tertiary.

*Mid-Cretaceous Orogeny.* At or near the close of the Lower Cretaceous there was another crustal disturbance that somewhat resembled the Diablan orogeny at the close of the Jurassic. The geosynclinal trough was not greatly disturbed but the western margin was again uplifted and exposed to erosion and the axis of the trough again shifted eastward. In a few places the marginal disturbances extended into the basin as folds and faults and deposition was interrupted locally, resulting in strong local unconformities. Areas within the basin of deposition that were uplifted and eroded at this time are found in the Mount Diablo region and in Mount Oso area in San Joaquin and Stanislaus Counties. Strong marginal disturbances also resulting in strong unconformities are found in the Santa Lucia Range, well south of the bay region. Except in areas noted above, there is no unconformity between the Upper and Lower Cretaceous along the west side of the Sacramento and San Joaquin Valleys, an area that lay near the center of the trough in which the Lower Cretaceous was deposited. Although there is no break in sedimentation along

this belt there is a marked coarsening of the sediments and the appearance of conglomerates containing debris of Franciscan, Knoxville, and Lower Cretaceous rocks.

*Upper Cretaceous.* Although there are thick shale units in the Upper Cretaceous the sediments are, in general, somewhat coarser than those in the Lower Cretaceous. The predominant sedimentary types are silty shales, sandy shales, sandstones, many of which are coarse and biotitic, and conglomerates. At the top of the Cretaceous along the west side of the San Joaquin Valley there is a continuous belt of brown organic shales and in northern California, in the lower part, there is a local member made up of dark, slightly organic shales with numerous lenses and concretions which are lithologically similar to some of the Knoxville and Paskenta shales. In general the Upper Cretaceous consists of a very monotonous sequence of silty and sandy shales and fine to coarse biotitic sandstones. Carbonized plant remains are abundant in both the Lower and Upper Cretaceous sediments indicating that they were derived from well forested regions.

Upper Cretaceous beds are widely distributed in the Coast Ranges. They form a continuous belt along the west side of the Sacramento Valley, and with a few interruptions in the bay area, a continuous broad belt along the west side of the San Joaquin Valley as far south as Coalinga. This long belt dips rather steeply toward the east or northeast either beneath the valley alluvium or later Tertiary formations. Upper Cretaceous beds are encountered in deep wells drilled in both the Sacramento and San Joaquin Valleys. Late Upper Cretaceous beds extend as far east as the edge of the Sierran foothills but they are mostly covered by later sediments on the east side of the Great Valley.

The thickest known sections of the Upper Cretaceous occur along the west side of the Great Valley of California where astonishing thicknesses are attained. North of San Francisco Bay measured sections show thicknesses of 10,000 to 15,750 feet and there are probably a few thousand feet more buried beneath valley alluvium and later sediments.

On the northeast side of Mount Diablo the Upper Cretaceous sediments are 19,000 feet thick, but they thin rather rapidly westward. They thin to about 8000 feet in southern San Joaquin County, where they pass over the Mount Oso high. From this locality they thicken rapidly southward and attain their maximum thickness of 29,000 feet in southern Merced County. The main axis of the geosyncline, in which this greatest thickness of Upper Cretaceous sediments was deposited, lay in the region that is now the boundary between the Coast Ranges and the Great Valley of California. The sediments thin rapidly away from this zone both to the east and the west. They are widely distributed over the Coast Ranges as a whole although there

are many regions from which they have been removed by erosion or where they are covered by later sediments. They are found as far west as the present coast line, and occur on both sides of the San Andreas fault. Late Upper Cretaceous sediments have a wider distribution than early Upper Cretaceous sediments, indicating that the basin of deposition gradually widened and expanded as Upper Cretaceous time progressed. The maximum width of the belt at present is not less than 130 miles and probably exceeded 150 miles in Upper Cretaceous time as there was great crustal shortening in the Tertiary.

Notwithstanding their great thickness the Upper Cretaceous sediments all were deposited in shallow water, probably well under 100 fathoms. The sinking of the geosynclinal basin of deposition kept pace with sedimentation so that the sea always was shallow.

Sometime—probably early—during the Upper Cretaceous, the ancestral Sierra Nevada was uplifted, and contributed a considerable amount of coarse debris to the basin of deposition. The western land mass, which lay west of the present coast, was still in existence and contributed a large volume of sediment.

There is great lateral variation in the Upper Cretaceous, even greater than in the Lower Cretaceous. Satisfactory lithologic units may be set up and mapped over local areas but few are of any value over wide areas.

A number of formational and group names have been given to various units in the Cretaceous but as yet there is no general agreement regarding many of them. The most commonly used name for the Upper Cretaceous as a whole is the Chico group but there are many objections to the term. The name was first applied to the relatively thin section on Chico Creek in Butte County, on the east side of the Sacramento Valley, and gradually extended to all of the Upper Cretaceous of the state. In the first place it is not known just how much of the Upper Cretaceous is represented by the 2000 feet of sediments on Chico Creek and in the second place the name Chico group frequently has been given to beds of both Upper and Lower Cretaceous age. If the name Chico group is to be retained it should be redefined.

In some localities no single group name could be applied to the Upper Cretaceous as a whole because of the diverse lithology of the formations and the presence of a profound unconformity within the Upper Cretaceous. In the present paper the use of formational and group names for part or all of the Upper Cretaceous will be avoided as far as possible.

In the midst of the Upper Cretaceous there was a very strong but apparently local disturbance which had its maximum effect in the Santa Lucia Range and died out in intensity both to the north and east. However, the effects of this orogeny extended into the bay area at

least as far as Mount Diablo. The writer has mapped a large part of the Santa Lucia Range and adjacent areas in Monterey and San Luis Obispo Counties and has shown the presence of a major unconformity within the Upper Cretaceous. The lower part of the Upper Cretaceous, the Jack Creek formation, rests unconformably on both Lower Cretaceous and Franciscan-Knoxville rocks. The mid-Cretaceous orogeny was stronger in this region than in other parts of California and the rocks older than the Upper Cretaceous were folded and eroded to a surface of low relief before the Upper Cretaceous sea spread over the area. After the deposition of at least 5000 feet of Jack Creek shales a profound disturbance folded and faulted the older rocks and brought them above sea level. After a brief period of erosion the Upper Cretaceous sea spread over a surface of strong relief and 8000 to 10,000 feet of coarse conglomerates and sandstones, with minor amounts of shale, were deposited. These rest with strong unconformity on all the older rocks, including the early Upper Cretaceous Jack Creek formation. These coarse late Upper Cretaceous sediments are called the Asuncion group. The upper part of the Asuncion contains an abundant late Upper Cretaceous fauna.

The writer has called this mid-Upper Cretaceous disturbance the Santa Lucia orogeny from its maximum development in the Santa Lucia Range. The effects of this orogeny were rather widespread although the Upper Cretaceous sea was not withdrawn from the central part of the geosyncline. It appears to have extended to the bay region as there is an unconformity 7000 feet above the base of the Upper Cretaceous in the Mount Diablo region in Contra Costa County. Rocks equivalent to the Asuncion group are more widespread in the Coast Ranges than those equivalent to the Jack Creek formation. Time equivalents of this late Upper Cretaceous group occur along the coast in the extreme southern part of San Mateo County and along the Gualala River in northern Sonoma County. The thick section of Upper Cretaceous sediments along the west side of the Great Valley represents all of the Upper Cretaceous and the Santa Lucian orogeny is indicated only by the presence of thick, coarse conglomerates, in the midst of the Upper Cretaceous, containing boulders of fossiliferous Upper Cretaceous sandstones.

Another result of the Santa Lucia orogeny was the beginning of the uplift of the northern part of the Gabilan mesa. The present site of the Gabilan Range in northern San Benito and Monterey Counties started to rise at this time either by faulting or gentle upbowing, probably the latter. It may never have emerged completely above sea level but the sea was shoaled over it and parts of it may have stood above sea level as an island or a group of islands. This late Upper Cretaceous uplift of a part of the Gabilan mesa was the first event in the disturbances that culminated in the Eocene and which finally dis-

rupted and partially destroyed the long-enduring Mesozoic geosyncline in which the Coast Ranges had their beginning.

Throughout the Cretaceous practically all of the bay counties except those flanking the Sierra Nevada were covered by a shallow sea. To the west of the present coast line lay a comparatively low but probably rugged, well forested land mass, while to the east rose the ancestral Sierra Nevada, also a comparatively low, well forested chain that was the western margin of a land mass that extended almost to the Rocky Mountains. The present Coast Ranges were occupied by a shallow marine basin that received an enormous volume of sediments. The basin continued to sink as sediments from both the east and the west were carried into it. Not until late in the Upper Cretaceous did land masses of any great extent emerge to break the wide expanse of water. About the middle of the Upper Cretaceous the Mount Diablo region was gently arched and probably stood for a time as a low island, only to be quickly submerged by the general downwarping and to receive an additional load of 14,000 feet of elastic sediments. At the same time the northern part of the Gabilan Range 70 miles to the south of Mount Diablo rose and probably remained above sea level as a low island or group of islands for the rest of the Cretaceous.

The Cretaceous was a time of quiet deposition uninterrupted by violent volcanic outbursts. It is the only long period of geologic time in the geologic history of California in which volcanism did not occur at rather frequent intervals. Considering all stages of the Cretaceous throughout the Coast Ranges at least 54,000 feet of fine to coarse elastic sediments were deposited. However, not more than 40,000 feet of sediments accumulated in any one place.

When the great thickness of the Cretaceous is taken into consideration, it is surprising that the economic importance of the preceding Jurassic sediments and the following Tertiary sediments is so much greater. Some of the Cretaceous sandstones make reasonably good building stones and they have been quarried in the past for this purpose. At present they are used to a limited extent for garden walls and flagstones. The buildings on the campus of Stanford University are largely faced with Cretaceous sandstone obtained in nearby quarries. Some of the older buildings in the northern Sacramento Valley towns were built of Upper Cretaceous sandstone quarried between Maxwell and Sites in northern Colusa County.

Cretaceous shales are suitable for making brick and are so utilized in several places, notably near Port Costa in Contra Costa County.

A small amount of oil has been obtained from sandstones interbedded with late Upper Cretaceous organic shales on the Coalinga anticline but the amount has been negligible. There are a number of seepages of light oil from both the Lower and Upper Cretaceous in

northern California. Oil has been encountered in a number of wells but no commercial production has been obtained.

There are several gas fields in northern California that obtain their supply from the Cretaceous. The first Cretaceous gas field to produce in northern California was the Tracy field, one mile east of the center of Tracy. It was discovered in 1935 and has been a small but consistent producer since that time. There is also a small gas field that produces from the Cretaceous at Vernalis, about 15 miles southeast of Tracy. A small amount of gas is obtained from the Upper Cretaceous in the Potrero Hills gas field in Solano County.

The largest Cretaceous gas field in northern California is near Marysville Buttes. This was discovered in 1935 and since then has been a steady producer of good quality gas, which is used in the nearby cities of Marysville and Yuba City.

The gas in the recently discovered Corning gas field in Tehama County comes from the Tehama formation, but is undoubtedly generated in the underlying Cretaceous.

Gas has been encountered in most of the wells drilled in the Cretaceous in northern California but aside from the localities mentioned no commercial production has been obtained. Some of the wells produce enough gas for domestic use in farm houses located near the wells.

Although the Upper Cretaceous has not yielded a particularly large amount of gas in northern California there are at least two fields which have been consistent producers and which give promise of having a long productive life. It is probable that other gas fields will be discovered in the Upper Cretaceous in northern California in the future, particularly in Sacramento Valley.

*Close of the Cretaceous.* The movement that began in the mid-Upper Cretaceous, the Santa Lucian orogeny, was the forerunner of a series of movements that followed at the close of the Cretaceous and continued into the Eocene. These disturbances extending from the Upper Cretaceous well into the Eocene are undoubtedly local manifestations of a world wide crustal disturbance or diastrophism known as the Laramide revolution, which, in the Rocky Mountain region, is known to have had essentially the same time range. In California some of these movements, such as the Santa Lucian orogeny, seem to have been of great intensity locally and to have died out rapidly away from the area most strongly affected. Some were of greater areal extent and left their record over larger areas. At present it is impossible to trace the effects of all of these movements but certain disturbances may be reasonably well dated. It is known that in certain areas strata are absent that are present in adjacent regions; but it cannot always be proved that the gaps in the section are the result of nondeposition, as in many cases they may have been caused by

removal by erosion. An excellent example of a gap of this nature has come to light, through deep drilling, in the Tracy region where wells pass through nonmarine Pliocene and Miocene sediments into Upper Cretaceous without any intervening Eocene. In the McDonald Island gas field 16 miles north of Tracy wells show the presence of 2900 feet of Eocene; in the Rio Vista gas field 32 miles north northwest of Tracy there is about 5000 feet of Eocene. The absence of Eocene sediments in the Tracy area might be the result of upbowing of the Cretaceous by diastrophism at the close of the Cretaceous or it might be caused by removal of Eocene sediments once deposited over the area by an uplift near the close of the Eocene. Since the area is covered by a thick blanket of alluvium and the gas fields are widely spaced a choice between the two possibilities cannot be made with certainty. However, from the thicknesses in the Rio Vista and McDonald Island fields there appears to be a thinning of the Eocene southward toward Tracy and hence it is presumed that this high was developed at the close of the Cretaceous. This is cited merely as an example of the difficulties of accurately dating some of the disturbances.

Considering all of the known facts there seems to have been a fairly strong but local diastrophism at the close of the Cretaceous which uplifted and exposed certain areas although the sea may not have been completely withdrawn from all parts of the region. It is certain that the Mount Diablo area rose and was subjected to erosion as basal Paleocene beds truncate several thousand feet of Upper Cretaceous sediments. It is possible that all of the bay region was elevated at this time. However, the Paleocene sea quickly spread over a part of the area.

Along the west side of the central part of the San Joaquin Valley and in parts of the Santa Lucia Range the sea was not completely withdrawn and Paleocene sediments were deposited in the same geosyncline as the Cretaceous sediments. Along the west side of San Joaquin Valley, from Coalinga northward to Patterson, it is difficult to determine the contact between Cretaceous and Eocene; deposition seems to have been continuous.

Movements at the close of the Cretaceous were sufficiently strong to destroy a part of the long-enduring Mesozoic geosyncline in which so many tens of thousands of feet of sediments were deposited, but it was not yet completely destroyed and sedimentation continued uninterruptedly in some parts of the trough. Later movements in the Eocene finally destroyed the geosyncline and subsequent deposition during the Tertiary took place in separate basins.

*Paleocene and Eocene.* Because of its economic importance as a producer of both gas and oil in California a great deal of work has been done on the Eocene. Even now, however, its nomenclature is far from settled and correlation is difficult. The Eocene has been divided

into seven faunal stages and into a large number of cartographic units or formations. In some cases faunal stage names are used in a formational sense; in other cases formations are either a part of one stage or include more than one stage. Furthermore, there is not universal agreement as to the exact age of all of the stages.

The stages, from bottom to top, are: Martinez, Meganos, Capay, Domengine, Transition, Tejon, and Gaviota. According to most workers the Martinez only is Paleocene but according to some both Martinez and Meganos are Paleocene. Again, some regard the Gaviota stage as Oligocene rather than Eocene. Furthermore, a part of the Martinez has been placed in the Cretaceous by a few workers.

The Eocene-Paleocene interval is commonly divided into Paleocene, lower, middle, and upper Eocene. However, the writer has found it more satisfactory to use three divisions only, namely, Paleocene, lower, and upper Eocene.

The following table shows the writer's interpretation of the Eocene in the bay counties and the relations between the stage and the formational names in general use.

Stage name		Formational name
Upper Eocene	Gaviota	Wheatland formation
	Tejon	Markley formation, Laird breccia? (including Kreyehagen shale)
	Transition	Nortooville shale
Lower Eocene	Domengine	Domengine sandstone —Unconformity—
	Capay	Capay, Ione
	Meganos	Vacaville shales
Paleocene	Martinez	Martinez formation
		Meganos formation
		Tesla formation

The simplicity of the above table is more apparent than real, however. For example, the Martinez formation, as mapped at its type section near the town of Martinez in Contra Costa County, is known to include, in its upper part, faunas characteristic of the Meganos and Capay stages. It is more than probable that few if any people familiar with the Eocene problem would agree with all parts of the above table. It is presented merely as an attempted solution of a difficult problem and as an aid in placing certain well-known diastrophic events.

The best exposed section of Eocene sediments in the bay region is on the north side of Mount Diablo where there is a reasonably complete section, approximately 9000 feet thick, from the basal Martinez through the upper Eocene.





FIG. 1. Aerial view northwest across Point Reyes. The prominent rift valley of the San Andreas fault zone, of which Bolinas and Tomales Bays are parts, diagonally crosses the photograph from the middle foreground to the right background. Rocks to the east of the fault are the severely folded predominantly marine complex assemblage called the Franciscan group, largely of Upper Jurassic age; those to the west of the fault are either granitic or else gently folded Tertiary marine sediments lying on the granitic basement. The bay-mouth bar, curved sand spits and sand dunes of Bolinas Bay are conspicuous features. *Photo by Clyde Sunderland, Oakland.*

As a whole the Eocene is made up almost entirely of elastic sediments, shales, sandstones, and conglomerates; thin limestones occur in the Martinez and Meganos. Sands suitable for the manufacture of glass and seams of lignitic coal occur in both the Capay and Domingine. Coarse breccias occur in the Martinez in San Mateo County.

The Martinez in most places is lithologically similar to the Cretaceous, being made up of dark, silty shales, rather thin hard sandstones, and a few impure limestones. Conglomerates usually occur at the base and small lenses are found higher in the section. Many of the sandstones are glauconitic, and have a greenish color.

At the beginning of and throughout the deposition of the Martinez much of the bay area stood above sea level. The Martinez sea, which probably came in from the south, extended as far west as Mount Diablo, which, of course, was not then in existence, and spread westward and northward over what is now a part of the Great Valley, covering the northeastern part of what is now Contra Costa County, the northwestern part of San Joaquin County, eastern Solano County, and western Sacramento County. It may have extended north through eastern Yolo County but of this there is no direct evidence. During Martinez time the western part of the Sierra Nevada extended farther west than at present and stood above sea level. The Sierra Nevada was being worn down to a surface of low relief; the climate was warm but not yet subtropical.

Most of the coast counties stood above sea level, but there was a marine embayment in San Mateo County. How far inland this embayment extended is not known, but it probably penetrated east as far as what is now the southern end of San Francisco Bay. Sediments laid down in this embayment may still be seen along the north flank of Montara Mountain. They consist of a coarse basal breccia, made up of angular blocks of Montara granite, succeeded by normal Martinez shales and sandstones. These Martinez sediments rest both on folded Upper Cretaceous sediments and basement granite.

The western land mass that had existed throughout the development of the Mesozoic geosyncline probably had become greatly diminished in size and it may have completely disappeared beneath the waters of the Pacific. At least it was not until the middle Miocene that detritus definitely derived from the west is found, and even then such western detritus is found only south of Carmel.

Although emergent, most of the coast counties appear to have stood at a comparatively low elevation. In western Alameda County the country was low and swampy and a fresh-water lake existed. Non-marine Martinez with fresh-water fossils is found in this region. Northeastern Alameda County and southwestern San Joaquin County stood above sea level as a low land area which probably extended eastward as a broad peninsula into the Paleocene sea.

Conditions during Meganos time were probably essentially the same as outlined above, as Meganos sediments have about the same distribution as the Martinez.

As the lower Eocene progressed the climate became warmer and by the upper part of the lower Eocene had become subtropical. The Sierra Nevada had been worn down to a surface of low relief and was covered by a deep mantle of decomposed debris, the result of deep chemical weathering under hot humid conditions. The Sierran rivers were sluggish and had developed intricate meanders. As the lower Eocene progressed the land sank and the sea expanded over much of the coastal region, reaching well into the area that is now the western foothills of the Sierra Nevada.

By the close of the lower Eocene, the sea had reached the greatest extent attained at any time during the entire Eocene epoch. The magnitude of this sea in coastal counties of the bay region is not known, but a seaway probably extended from the present coast through central Santa Clara County and then reached southeast to unite with the Eocene sea in the southern San Joaquin Valley.

As a result of the long-continued wearing down of the Sierra Nevada and the hot humid climate, a type of sediment unusual in California, although common in other parts of the world, appeared. Deep weathering in the Sierra Nevada dissolved the more soluble constituents of the rocks and released the harder more resistant minerals, particularly quartz. Deep, clayey soils were produced. This thick mantle contained an unusual amount of various clays and quartz, together with minor amounts of andalusite, and some gold released from the quartz veins. Debris from this mantle gradually found its way into the sluggish rivers and was deposited partly along their upper courses and partly on their flood plains; much of it ultimately reached the late upper Eocene sea which now stretched well to the east.

The late upper Eocene sea also expanded northward up the region of the Sacramento and Capay Valleys, as far as Redding in the Sacramento Valley and as far as Rumsey in Capay Valley. The Rumsey Hills probably extended into this sea as a peninsula. The surface over which the sea spread was one of low relief, but it was not entirely flat and featureless; therefore the sediments deposited vary in thickness from place to place and probably are absent over higher areas that stood above sea level. Thus a broad, usually shallow sea stretched across what is now the Sacramento and northern San Joaquin Valleys and extended a short distance into what are now the margins of the Coast Ranges and Sierra Nevada. In the Coast Ranges the late upper Eocene sea spread over southern Napa County and northern Solano County and extended through northern and eastern Contra Costa County as far south as Mount Diablo. It also covered a part of eastern Alameda County. There is no evidence that the coastal counties were



FIG. 2. View southeast down San Andreas fault zone on San Francisco peninsula, showing San Andreas and Crystal Springs Lakes. Mussel Rock is in the right foreground. The surface trace of the dislocation of April 18, 1906, passes out to sea north of the large overgrown landslide north of Mussel Rock, or approximately 1½ inches to the left of the rock in the photograph. It crosses Skyline Boulevard slightly to the left of the column of smoke seen near the center of the picture, and continues on through the lakes in the background. The large landslide near Mussel Rock resulted from the powerful earthquake waves set up by the 1906 earth movement. *Photo by Clyde Sunderland, Oakland.*

submerged. Southwestern Solano County stood above sea level as a low island. Most if not all of the area now occupied by San Francisco Bay probably stood above sea level.

Sediments of the Capay stage, late lower Eocene, along the Sierran front are called the Ione formation. The river channel deposits that supplied the Ione sediments, which are made up of the products of decay from the Sierra Nevada, contain the earliest auriferous gravels. The Ione is made up of clays, quartz-rich sands, laterites, high-alumina clays, anoxic sands, silts, and lignites. Pottery and refractory clays are quarried in many places. Beds of equivalent age in the Mount Diablo region are called either Capay or Meganos E. Along the east side of the Coast Ranges in Colusa, Yolo, and Solano Counties they are called the Capay formation, from their occurrence in Capay Valley. Eocene shales near Napa also are probably equivalent to the Capay. The shales in the vicinity of Vacaville have been called the Vacaville shales, but they are equivalent to the Capay formation in age.

After the deposition of the Capay, and the equivalent Ione, the Coast Ranges were affected by a rather strong diastrophism which was another pulse in the Upper Cretaceous-Eocene Laramide movements. At this time both folding and profound faulting took place and the former wide sea of the late lower Eocene was restricted. Although much of the region was uplifted, some areas that had formerly been emergent were depressed beneath sea level. Areas such as the Mount Diablo region that had been active previously were again folded.

One of the most important effects of this diastrophism was the formation of the ancestral San Andreas fault and the uplift of the Gabilan mesa. This mesa was upbowed in mid-Upper Cretaceous and probably was again uplifted at the close of the Cretaceous. The southwest side of the San Andreas fault, the Gabilan mesa, was uplifted and tilted toward the southwest; the northeast side either remained stationary or went down. Probably what actually happened was that the Gabilan mesa block had been strongly upbowed and tilted westward in the mid-Upper Cretaceous and at the close of the Cretaceous, and the northwest side collapsed and was downdropped at the close of the lower Eocene. The vertical movement on the ancestral San Andreas fault must have been in excess of 15,000 feet in the central Coast Ranges, decreasing in magnitude in Santa Clara and San Mateo Counties.

Other well-known faults that were again active in the Miocene, Pliocene, and Pleistocene were developed at this time. The Pescadero fault, so well exposed along the coast south of Pescadero, came into existence at this time. In the lower Eocene, movement on the Pescadero fault was down on the southwest and up on the northeast. The northeast side, which is the northern continuation of the Gabilan mesa,

rose and was stripped of its Franciscan-Knoxville and Cretaceous cover. The Pescadero fault passes beneath the ocean south of Pescadero and reappears on land just east of Pillar Point near Halfmoon Bay. It passes out to sea again just south of Montara Point.

The profound normal faulting in the lower Eocene left a strong imprint on all succeeding events in the geologic history of California in that it elevated a fairly broad block that runs diagonally through California from San Luis Obispo County northwestward to San Mateo County where it is intersected by the coast line; western Marin County is a part of this block. All the Mesozoic sediments were stripped from this block, exposing the ancient crystalline schists and plutonic rocks of the basement complex, but the depressed regions on either side retained their thick prisms of pliable sediments. When the Coast Ranges were subsequently subjected to strong compressive movements the two blocks on the sides of the Gabilan block were intensely folded and shortened but the central block, being directly underlain by rigid crystalline rocks incapable of folding, suffered negligible crustal shortening. Therefore, later Tertiary sediments on the Gabilan block are weakly folded except where unusually thick, while those on the two sides are strongly folded.

In the bay countries the lower Eocene seas retreated westward from the Sierran front but were not completely withdrawn from what is now the western part of the San Joaquin and Sacramento Valleys. The sea withdrew from the northern Sacramento Valley, which never has been covered by marine waters since that time, but remained in the area south of Woodland. Although there was a general withdrawal of the sea over most of the region, there were small, limited areas, previously emergent, which were depressed beneath sea level. The southwestern part of Solano County northeast of Vallejo, which previously stood as a low island, was depressed and covered by the upper Eocene sea. Here the upper Eocene rests on Lower Cretaceous sediments, all of the Upper Cretaceous and much of the Lower Cretaceous having been removed by erosion during the lower Eocene. There also was a slight expansion of the sea in eastern Alameda County.

The frequently active Mount Diablo region again was folded at the close of the lower Eocene. There upper Eocene sediments lap across lower Eocene and Upper Cretaceous beds and rest on the Lower Cretaceous on the northwest side of the mountain. The upper Eocene sea also expanded into Marin, western Sonoma, and Napa Counties, but its full extent is not known as only remnants of the upper Eocene remain in this highly folded region.

The thickest section, over 4000 feet, of upper Eocene sediments is found on the north side of Mount Diablo. These beds dip northward beneath later sediments. On the Potrero Hills anticline, north-northwest of Mount Diablo, the exposed upper Eocene is 2500 feet



FIG. 3. Aerial view southeast down San Andreas rift valley, which is occupied by Crystal Springs Lakes, San Mateo County. Old fault scarps and troughs may be seen in the linear en echelon arrangement in the center background leading off from the right side of Upper Crystal Springs Lake. *Photo by Clyde Sunderland, Oakland.*



Clyde  
SUNDERLAND

FIG. 4. Detail of background seen in Figure 3. Trace of the San Andreas rift diagonally crosses the photograph from right to left. Prominent highway on the left side of the picture is Cañada Road leading to Redwood City. Photo by Clyde Sunderland, Oakland.



FIG. 5. Aerial view toward the east, showing folded Tertiary marine deposits and the ghost coal-mining town of Somersville. The long parallel ridges extending into the background are Eocene sandstones which are more erosion-resistant than the intervening shale and siltstone beds along which the valleys have been carved. The north-dipping beds at the left of the photo are in the lower part of the Markley formation; the prominent ridge in the right background, beds of which also dip north, is in the upper part of the Meganos formation. Somersville is famous for its old coal mines and its newer silica-sand mines, both of which are in Eocene beds that are sandwiched between the principal ridges. *Photo by Clyde Sunderland, Oakland.*

thick, but the upper part has been overlapped by later sediments. Eastward in the Sacramento and San Joaquin Valleys upper Eocene sediments are encountered in the deep wells in the valley gas fields; using the Rio Vista area as a reference point, the following thicknesses indicate an eastward and northward thinning:

Field	Thickness of upper Eocene (feet)
Rio Vista.....	2,500
McDonald Island.....	1,000
Fairfield Knolls.....	430

The upper Eocene in the bay region is divided into three units, the Domengine sand at the base, the Nortonville shale, and the Markley formation at the top. Of these, the Markley attains the widest distribution and the greatest thickness.

In Marin County a deep well drilled for oil encountered Markley sediments beneath the Mioene between the San Andreas fault and Drakes Bay. There are no exposures of these beds at the surface in the immediate vicinity. At Point Reyes there are coarse sedimentary breccias, the Laird formation, resting on the granodiorite that forms the tip of the peninsula; it is possible that these breccias are the same age as the Markley. The Laird breccias have been tentatively assigned to the Mioene; as they contain no fossils, however, they may equally well be upper Eocene.

In central Napa County, along Conn Creek northeast of Rutherford, there are small downfaulted remnants of Nortonville shales. These have a maximum thickness of 600 feet and are either vertical or stand at high angles. Because of the intense folding and faulting in this region and the thick cover of Pliocene volcanics little can be said regarding the maximum extent of the upper Eocene sea.

The seaway that extended from San Mateo County to the Coalinga region in the Eocene apparently was expanded in the upper Eocene. Although sediments of this age do not form a continuous belt because of later folding and faulting and removal by erosion they occur in discontinuous belts from San Mateo County to Coalinga.

The Kreyenhagen shales, so important in the San Joaquin Valley, and the source of so much oil in that region, are only represented in the bay area by a thin local diatomaceous shale member in the upper part of the Markley formation. This lenses out to the northwest and disappears south of Antioch. It is called the Sidney shale member of the Markley.

In the vicinity of Wheatland in southern Yuba County a small isolated exposure of late upper Eocene sediments only a few hundred feet square is surrounded by valley alluvium. These beds contain a

late upper Eocene marine fauna referred to the Gaviota stage. Nothing is known regarding the extent of the sea in which these beds were deposited.

Climatic and physiographic conditions in the Eocene were such that a number of important and very diverse economic substances were formed; some of these are found only in the Eocene. The warm, humid climate, low relief, and sluggish rivers favored deep chemical decay, and at times the available detritus was chiefly insoluble material such as sand and clay. In California, pure quartz sands and high-grade ceramic clays are confined to deposits of Eocene or Paleocene age. Sandstones and shales of other ages which have resulted from sedimentation in places adjacent to land of great relief and turbulent streams are of much different character. The sandstones tend to be full of feldspathic debris characteristic of physical breakdown rather than chemical decay, and the clay shales tend to be silty or sandy.

Various types of clay are obtained from open pits from the Ione formation along the low Sierran front on the east side of the Great Valley. Excellent pottery clays, high-alumina clays, and refractory clays are obtained. These Ione clays form the basis of a large part of the ceramic industry of California.

The old high-alumina lateritic soils beneath the clays are quarried locally for their alumina content. Some of the highly colored Ione clays were, at one time, used as pigments.

Glass and moulding sands are obtained from the Capay (equivalent to the Ione) in the Mount Diablo and Byron regions. These are not quarried as extensively as formerly but large quantities are still available.

Toward the end of the last century a large amount of coal was produced in the Mount Diablo area. Nortonville and Somersville, on the north side of Mount Diablo, were towns of 1500 to 2000 inhabitants, all dependent on the nearby coal mining industry. Practically no sign now remains of these once populous towns. Mining of the coal was difficult because the Domengine sands, in which the coal occurs, are steeply dipping and highly faulted; the coal is not of particularly high grade, although satisfactory as a fuel. The advent of large quantities of cheap oil put an end to the Mount Diablo coal mining industry.

A considerable amount of lignite was mined from the Ione formation south of the town of Ione in Amador County. This was used in the operation of the Amador Branch Railroad and for local domestic consumption. Coal is still mined south of Buena Vista in Amador County but not for fuel. There is an extraction plant for removing the wax from the lignite. This Ione lignite is one of the best in the United States for the purpose as it contains up to 20 percent wax.



The wax thus extracted has a variety of uses; one important use is in the manufacture of typewriter carbons. The waste lignite remaining after extraction is used as the inert ingredient in commercial fertilizer.

Eocene coal also was extensively mined at one time in Corral Hollow west of Livermore in Contra Costa Valley.

Eocene shales are suitable for the manufacture of bricks and are occasionally so utilized.

As a result of the deep chemical weathering of the Sierra Nevada in the lower Eocene, a very large quantity of gold was released from the quartz veins that had been formed by emanations from the granitic magmas emplaced near the close of the Jurassic. This gold, together with the resistant materials such as quartz and quartzite, accumulated on the deeply weathered surface and ultimately found its way into the sluggish meandering rivers. Wherever the current slackened, either on river bends, or because of obstructing gravel bars, gold was deposited. Some of these channel deposits were remarkably rich and a large amount of gold was recovered. The richest and best known of the channel gravels are lower Eocene and are the "auriferous gravels," as the term was used by the early miners and the early geologists who mapped the region. Unfortunately the term "auriferous gravels" has been applied to any gold-bearing gravels in the Sierras. Any gravel derived from a Sierran source may contain gold but the auriferous gravels of lower Eocene age have certain definite characteristics that distinguish them from the younger stream and bench gravels. The Eocene gravels are, as a rule, far richer than other gravels, and the pebbles and sands containing the gold are almost wholly made up of grains, pebbles, cobbles, and boulders of quartz or quartzite; the constituents of other gravels, on the other hand, may be any of the rock types in the Sierra Nevada.

Although Eocene sediments either are the source or are both the source and the present reservoir of a very large amount of oil in the southern San Joaquin Valley, no oil is obtained from the Eocene in the bay counties. However, a large amount of gas is recovered in the bay area from the Eocene. One of the greatest and most prolific gas fields of the world, the Rio Vista field, obtains its gas from the upper part of the lower Eocene. In the McDonald Island field the productive gas sands are in the Paleocene Martinez formation. Gas is also known to occur in the Martinez in the Fairfield Knolls field. Gas from the Eocene is of great economic importance in the bay region. It is very possible that other Eocene gas fields will be discovered in the region.

*Oligocene.* A number of formations in California that once were regarded as Oligocene are now known to be of upper Eocene age. At one time the Kreyenhagen shale was considered to be Oligocene but

at present no one questions its assignment to the upper Eocene. The Markley formation, originally placed in the Oligocene, is now known to be upper Eocene. On the other hand, the Vaqueros formation, usually regarded as lower Miocene, is placed by some in the Oligocene.

The Oligocene was not included in the original subdivision of the Tertiary made near the beginning of the last century by Lyell but was proposed in 1857 for certain beds in the Paris basin that did not seem to fit into either the Eocene or the Miocene. Undoubtedly the Oligocene serves a useful purpose but, in California at least, beds referred to the Oligocene could be fitted into either the upper Eocene or the lower Miocene without detriment to a satisfactory understanding of the stratigraphy or structure. The Oligocene is especially useful in a discussion of the stages of evolution of the vertebrates.

In the Santa Cruz Mountains there is a moderately thick section of sandstones and gray, brown, and black shales to which the name San Lorenzo formation has been given. These beds were deposited in the same trough as the upper Eocene. During the Oligocene this trough was restricted and no longer formed a continuous seaway into the Coalinga region. Sediments were deposited in it as far south as Hollister in San Benito County, but because of erosion since the Oligocene only small remnants of these beds remain.

A small amount of oil was obtained from the San Lorenzo formation at Moody Gulch, in the western part of Santa Clara County. The wells were from 1000 to 1250 feet deep and produced a few barrels of high-gravity oil per day. The entire productive area did not exceed 10 acres and the total production from 1880 to June 1949 was only 62,168 barrels. An extensive fill along the Santa Cruz-Los Gatos highway has almost completely covered this small, unimportant field.

In the Martinez-Walnut Creek-San Ramon region there is a 500-foot sandstone of doubtful Oligocene age. This has been mapped with the Miocene and may, in fact, be Miocene in age. A similar, much thinner sandstone occurs on Carneros Creek about 5 miles west of Napa.

Aside from these areas there are no Oligocene sediments in the bay region. Thick sediments previously referred to the Oligocene are now known to be of upper Eocene age.

*Close of Eocene-Oligocene.* There was diastrophism at the close of the Eocene which continued into the Oligocene, and in most of California an almost complete withdrawal of the sea took place. Because of the scarcity of Oligocene sediments, the effects of these movements in the earth's crust may be considered together.

Apparently the sea was withdrawn completely from the bay region with the possible exception of a part of San Mateo County, which may have continued as a minor embayment. The greater part of California was uplifted by the post-Eocene movements and sub-

jected to erosion. In the bay area the Mount Diablo region was again folded and tilted to the south, toward the ocean whose eastern shore lay slightly west of the present coast. Southern and western Marin County probably formed a part of this tilted area.

Owing to rapid erosion of the uplifted land the relief was fairly strong over the state as a whole. The present subranges of the Coast Ranges, such as the Diablo, Mount Hamilton, Gabilan, and Santa Lucia, were outlined and stood well above the surrounding regions. The Sierra Nevada was still an area of low relief but had been gently warped and was beginning to rise slightly. The Great Valley of California stood above sea level as an area of low relief. This configuration of the Coast Ranges had a profound effect on the distribution of the succeeding Miocene formations.

*Miocene.* At the beginning of the Miocene, as the term is usually understood in California, there was a gradual down-sinking, and the low areas were flooded by the encroaching Miocene sea. At first the movement was one of gentle and fairly even sinking with gradual progress of the sea over the lower areas, but as the Miocene progressed, definite down-bowing of basin areas began, and thick prisms of sediments accumulated in the basins—prisms thickest in the central parts of the basins, and thinning toward the margins. The marginal zones of weakness thus created collapsed during the late Tertiary under powerful compressive forces.

The Miocene may be divided conveniently into three parts, lower, middle, and upper, the divisions being based on lithologic changes, faunas, and, in some localities, on diastrophic disturbances. The earliest Miocene deposits, those first laid down in the encroaching sea, are called the Vaqueros formation and are of lower Miocene age. Because of the conditions of deposition, a sea encroaching over an area of rather marked relief, the Vaqueros has a more restricted distribution than succeeding Miocene sediments. The Vaqueros formation is composed chiefly of sandstone, representing the coarse waste of the land deposited in a shallow encroaching sea. However, because of the diverse physiography—steep coast, gently shelving coast, broad tidal flats, protected bays, and straits with swift currents—a considerable variety of sediments was deposited, ranging from coarse conglomerates and sands, to fine sands, silts, glauconitic sands, tidal-flat muds, and even pure limestones. In the lower Miocene the Coast Ranges south of Monterey Bay were an archipelago, with numerous islands, gulfs, straits, and bays.

In the middle Miocene the sea transgressed over a wider area and, in the basins, the seas deepened and a great thickness of elastic and organic sediments was deposited. These organic sediments, diatomaceous and foraminiferal shales, were the source of a great deal of the oil found in California. In southern California there were local

disturbances between the lower and middle Miocene, but over most of the state the sandstones of the Vaqueros grade upward into the organic sediments of the middle Miocene without any evidence of a break in deposition.

There was widespread igneous activity resulting in flows, fragmental volcanics, and shallow intrusives. The great bulk of the volcanics are submarine and are interbedded with marine sediments but there was at least one large subaerial volcano which rose well above sea level and showered ash into the middle Miocene sea adjacent to it. This subaerial volcanic activity centered at the Pinnacles in San Benito County.

Several different names have been given the middle Miocene sediments not only in different parts of the state but also in the same area. The oldest and most commonly used name is Monterey shale, from the occurrence of white organic Miocene sediments at the town of Monterey. Unfortunately it has been found that most of the organic Miocene sediments at Monterey are of upper, rather than middle, Miocene age. A reasonably satisfactory substitute for the name Monterey is Temblor; the latter name will be used here for all the sediments above the Vaqueros and below the upper Miocene. In western Contra Costa County the Temblor has been divided into a number of formations on the basis of lithology, but as there is considerable lateral variation these names are only of very local significance.

Between the middle and upper Miocene there was another diastrophic event which was a stronger pulse in the movements that began the basin down-bowing at the beginning of the middle Miocene. At the close of the middle Miocene (or the beginning of the upper Miocene) the Coast Ranges were subjected to compression and general slight uplift. The interbasin areas were uplifted and their margins shoaled, but the sea was not withdrawn from the major basins and depression quickly followed uplift. As a result, the earliest upper Miocene sediments are marked by a coarsening of grain. Since the sea was not withdrawn from the larger basin areas, middle Miocene sediments grade upward into upper Miocene with only a coarsening of grain. In the central parts of the larger basins, far removed from shore, deposition often was continuous without change in grain. On the other hand, the marginal areas of the basins rose above sea level and were eroded, so that when the basins again quickly sank, upper Miocene sediments were deposited on the beveled edges of the middle Miocene beds. Thus there is conformity in one place between middle and upper Miocene beds and unconformity in others. On a smaller scale these apparently contradictory relations are similar to those during the development of the Mesozoic geosyncline where there were strong marginal movements that did not interrupt deposition within the central part of the basin.

A number of group and formational names have been given upper Miocene sediments in California. In the bay region upper Miocene sediments are called the San Pablo group, which is subdivided into three stages, the Briones at the base, the Cierbo, and the Neroly at the top. The San Pablo is largely made up of fine to coarse sandstones and gravels but there are a number of shale interbeds, some of which closely resemble some of the organic shales of the middle Miocene.

In the bay counties the Vaqueros occurs only in San Mateo and Santa Clara Counties but extends as far south as Hollister in San Benito County. It was deposited in a rather long, narrow bay, known as Santa Cruz Bay, that extended southwestward as far as Hollister. It was confined to the region now bounded by Ben Lomond Mountain on the west and Los Gatos on the east and represents the first encroachment of the lower Miocene sea into a low area that was a remnant of the Eocene seaway. The entrance from the open ocean seems to have been narrow and essentially confined to the present Halfmoon Bay-Pescadero region. The Vaqueros sea also covered a part of the present Point Arena area, but there is no record of its presence over any other part of the bay counties. Sands, gravels, and silts were deposited; these, together with later sediments, now stand at high angles because of strong folding and faulting in the Pliocene.

During the middle Miocene the sea expanded eastward, covering all of San Mateo, western Santa Clara, western Contra Costa, and western Marin Counties. A narrow arm extended northward into southern Napa County. It is possible that southern Marin County, the northern part of the San Francisco peninsula, and the present site of the southern extension of San Francisco Bay stood as a ridge separating the Santa Cruz Mountains basin from that in eastern Alameda and western Contra Costa Counties. The sea widened and expanded southward, as Miocene sediments are found east of San Jose and Morgan Hill, well up on the west side of the Mount Hamilton Range. In Contra Costa County the middle Miocene sea reached as far east as Mount Diablo and Martinez, then curved westward through San Pablo Bay and sent a narrow arm northward into Napa County. Middle Miocene sediments rest unconformably on practically all of the older rocks, including the ancient quartz diorite.

Middle Miocene sediments rest on the old crystalline complex between the San Andreas rift and Drakes Bay and extend as far south as Duxbury Point. In this region they have been divided into the Laird breccia, which may be upper Eocene, and undifferentiated Monterey. Actually there are three units in this area. From Duxbury Point northward to the eastern edge of Drakes Bay proper, there are typical cherts, porcellanites, organic shales, and thin hard sandstones. The basal sandstone rests on the old quartz diorite and marble. A deep well in the southern part of the area encountered upper Eocene sedi-

ments beneath the middle Miocene showing that the surface of the crystalline complex becomes rather deeply buried toward the south. No Eocene sediments are exposed in the region, unless the Laird conglomerate is Eocene. The middle Miocene sediments exposed along the coast southeast of Drakes Bay are strongly folded and stand at high angles. On the eastern shore of Drakes Bay proper these highly folded siliceous sediments are unconformably overlain by comparatively soft sands and silts of a prevailing brownish color which is in marked contrast to the grays and whites of the underlying beds. These upper sediments rest unconformably on the middle Miocene, and the basal glauconitic sandstone contains abundant debris of the siliceous beds beneath. The upper beds are exposed all along the north side of Drakes Bay and as far west as Point Reyes, where the basal glauconitic sandstone rests on the Laird conglomerate. Furthermore, these upper beds are only gently folded, whereas the lower siliceous sediments are strongly folded. The age of the upper beds is not known, but they are probably upper Miocene.

The middle Miocene sediments, consisting of cherts, porcellanites, foraminiferal shales, lenses of ferruginous magnesian limestone, bentonized volcanic ash and thin to thick sandstones, are well exposed in the Berkeley Hills and here and there along the Skyline Boulevard east of Oakland. The same types occur in Contra Costa County but they become increasingly sandy eastward as they approach the original shore line in the Mount Diablo region.

The same types found in the Berkeley Hills occur in San Mateo and Santa Clara Counties but the beds are thicker because they were nearer the center of the basin. Interbedded volcanics are abundant in the Santa Cruz Mountains, as this was one of several centers of strong middle Miocene volcanism in the state. These volcanics consist of rhyolite ash, flows of pyroxene andesite and basalt, andesitic breccias, and peperites. Dikes and sills of andesite, basalt, and analcite diabase are common. These intrusives, especially the diabase sills, some of which are over 300 feet in thickness, baked and altered the adjacent sediments with which they came in contact. The light-colored foraminiferal and diatomaceous shales are baked and blackened on the contact. Several such contacts may be seen on the crest road from Halfmoon Bay to La Honda.

There was marginal uplift and slight folding between the middle and upper Miocene, quickly followed by depression and a still greater expansion of the sea, especially eastward. The Briones sandstone, which is of early upper Miocene age, rests with slight discordance on the middle Miocene and its distribution is essentially the same, but by the time deposition of the Cierbo sediments began, definite expansion of the sea had taken place. The entire Mount Diablo region was submerged and Cierbo sediments are now found a short distance south

of Pittsburg and Antioch, north of Mount Diablo, where they rest on the upper Eocene. Thus the Cierbo sea extended well to the east of the middle Miocene shore line. There were movements between deposition of the Cierbo and Neroly, as the latter rests disconformably on the former in some localities. The Neroly sea, in the uppermost Miocene, expanded still farther east and may have spread over the western part of what is now the Great Valley. It also expanded northward, probably as a narrow arm or bay, as far as southern Yolo County. The previous position of this bay is now inferred from the presence of a narrow band of sandstone about 300 feet thick near the eastern edge of the Coast Ranges in Solano County; this sandstone rests on upper Eocene deposits and is unconformably overlain by nonmarine Pliocene.

The narrow middle Miocene arm or gulf also expanded slightly to the northwest as Neroly sediments are found on the line between Napa and Sonoma Counties 9 miles north of Sonoma.

In the Santa Cruz Mountains, in southern San Mateo County and northwestern Santa Clara County, there is a thick section of marine sediments that rest unconformably on the Temblor and even transgress onto Cretaceous and Franciscan rocks. These beds, which are nearly 10,000 feet thick, are known as the Purisima formation. They are usually regarded as Pliocene in age but there is a strong probability that the lower part is upper Miocene. If this is the case, the major break came in the midst of the upper Miocene, and the uplift at the close of the Miocene, so pronounced in some localities, had little or no effect in this region.

Even at its greatest advance the upper Miocene sea did not extend as far east as what is now the central part of the Great Valley. Upper Miocene beds are found extensively in the lower slopes of the Sierra Nevada, but they were all deposited on land. Sometime in the late upper Miocene there were violent explosions of rhyolitic material, probably high up in the Sierra Nevada. The lower slopes were covered with ash and the Sierran rivers became greatly overloaded with fragmental volcanic material in addition to the normal detritus usually carried. So overloaded did they become that, in places in the lower regions, they changed their courses. This detrital load was carried westward and deposited along the channels and on the flood plains of the rivers where the foothills merged with the flat plains that were the forerunner of the present Great Valley. The tuffaceous sediments formed a practically continuous sheet which overlapped across the older Ione and spread well out into the plains. In some places fairly pure rhyolitic tuffs were deposited, but over most of the region the sediments are tuffaceous sands, gravels and silts. These upper Miocene rhyolitic deposits were subsequently uplifted; erosion removed some of them, and some were covered with later Tertiary sediments or valley alluvium.

In central and southern California the Miocene is of great economic importance as it is the source and sometimes the present reservoir of a very large amount of oil. Miocene rocks of the bay region are organic and seepages have been found in them, but thus far neither oil nor gas in commercial quantities has been obtained.

The Miocene sands are feldspathic and are not suitable for glass manufacture, and many of the shales are too siliceous for making bricks. Some of the cherts and volcanics have been used, to a limited extent, for road metal. None of the diatomaceous earths in northern California are sufficiently pure to be quarried for diatomite. Bentonites are present but they are too thin and too highly folded for successful exploitation.

In the Sierra Nevada the purer rhyolite ash channel deposits have been quarried for building stone. The material breaks out in large blocks, is easily worked, and has surprising strength. The best stone is quarried near Altaville in Calaveras County where rather pure, well consolidated gray to cream-colored ash is found in the old Calaveras channel from which so much placer gold was obtained. A number of old buildings in adjacent towns are constructed of blocks of rhyolite ash.

*Close of the Miocene.* In the region under discussion there were movements in the upper Miocene, at the close of the Miocene, and probably in the early lower Pliocene. These varied in severity from place to place but their net effect was widespread uplift and a withdrawal of the sea from most of the region. It is not yet possible accurately to separate the effects or to determine the relative importance of these related movements, but it is known that they were not of equal strength everywhere.

An example of these uplifts is found in the Berkeley Hills and eastward where the Orinda formation, almost entirely continental and lacustrine, contains a thin discontinuous basal marine member that carries a marine upper Miocene fauna. This rests unconformably either on the Cretaceous or on the Claremont chert, a member low in the Temblor, indicating that there was considerable erosion in upper Miocene in this region. The sea withdrew northward because of uplift in the upper Miocene and retreated toward the Mount Diablo region, which continued under marine waters. The Orinda, in the Berkeley Hills, is entirely nonmarine, except for the basal member, and contains a late upper Miocene vertebrate fauna that is regarded as being equivalent to the marine Neroly. On the southwest side of Mount Diablo, where the beds are sharply upturned, and even overturned, the marine phase of the Neroly is present. This is overlain by a thin basal conglomerate and then marine lower Pliocene, the Diablo formation, 600 to 900 feet thick. The marine deposits grade upward into nonmarine lower Pliocene beds, which contain an abun-

dant nonmarine vertebrate fauna equivalent to the Siesta fauna above the Orinda in the Berkeley Hills. The withdrawal of the sea was caused by a strong uplift in the upper Miocene, which probably raised what is now the southern part of San Francisco Bay. At the same time there was continuous deposition to the north and east in the Mount Diablo region. Slight uplift at the close of the Miocene or very early in the Pliocene caused a further withdrawal of the sea and the deposition of continental beds.

It is clear, however, that the effect of movements in the late upper Miocene, at the close of the Miocene and possibly in the very early lower Pliocene was to cause uplift, a withdrawal of the sea from most of the region, and erosion of the uplifted areas.

A complication that greatly affects the question of the Miocene-Pliocene boundary must be mentioned here. As yet, the vertebrate and invertebrate paleontologists are not in complete agreement and actually two chronologies exist side by side. Nonmarine equivalents of sediments called upper Miocene by invertebrate paleontologists are nearly always called lower Pliocene by vertebrate paleontologists. Until complete agreement is reached between the two chronologies, discussion of the upper Miocene-lower Pliocene sequence is difficult in a region, such as the bay counties, where nonmarine and marine phases of both occur. Furthermore, there is not complete agreement among invertebrate paleontologists regarding the same subject. For example, some state that the entire Purisima is Pliocene; others that the lower part is definitely upper Miocene.

*Pliocene.* The Pliocene in the bay region is well represented, and a number of formations are recognizable. Most of these are land-laid or lacustrine, but some are marine. There was widespread volcanism in both the lower and upper Pliocene and volcanic rocks are widely distributed, especially north of the bay.

The most important diastrophic event in the development of the Coast Ranges as we know them today, since the late Jurassic Nevadan revolution, occurred in the late middle Pliocene. All of the rocks older than upper Pliocene were strongly folded, faulted, and uplifted. This strong diastrophism brought into existence or further accentuated practically all of the major topographic and structural features of the state. At the close of this violent but brief orogenic period, the major ranges and valleys had a form and location very similar to those of today.

The Purisima formation consists of nearly 10,000 feet of marine elastic and organic sediments that extend from Halfmoon Bay along the coast to Pescadero and for a considerable distance inland. They are again found at the Sargent oil field in southern Santa Clara County. They were deposited in a seaway that extended from the coast to the Coalinga region and the southern San Joaquin Valley.

Their most northerly exposure is in a narrow belt lying west of the Pescadero fault between Pillar Point and Seal Cove, north of Halfmoon Bay. Usually the Purisima formation is regarded as lower and middle Pliocene in age but it is possible that the lower part is late upper Miocene. The Purisima beds rest unconformably on middle Miocene, Eocene, Cretaceous, and Franciscan rocks.

Diatomaceous and foraminiferal shales in the Purisima have been the source of a small amount of high-gravity oil. Seepages are numerous and a number of wells have been drilled. Sporadic production has been obtained since 1882 although the first is said to have been obtained in 1867. The Purisima trough was the most important marine seaway in the bay region during the Pliocene.

For a better understanding of the lower and middle Pliocene of the bay region, it is necessary to discuss the general physiographic conditions that came into existence in the late upper Miocene and continued, with shifting of basins and withdrawals of the sea, into the middle Pliocene.

As a result of late upper Miocene diastrophism a nonmarine trough, extending at least from the latitude of San Jose northward for 90 miles almost to Santa Rosa, came into existence. This may not have been fully developed everywhere in the late upper Miocene and it undoubtedly was affected by minor warpings at the close of the Miocene and in the lower Pliocene, but by the close of the middle Pliocene, when the trough was folded and uplifted, sediments had been deposited in it throughout its full length. In some parts of this long narrow basin the sea remained until early in the lower Pliocene, but in other parts it was withdrawn in the late Miocene so that nonmarine sediments extend down into the upper Miocene.

This long trough always stood near sea level; as it continued to sink, sediments were added at such a rate that the depositional surface continued to remain slightly above sea level. Because of a number of factors, such as destruction of the trough at the close of the middle Pliocene, the intense folding and faulting of the beds, the scarcity of vertebrate fossil remains, and the dual chronology previously mentioned, it is impossible at present definitely to establish the stage of each unit or to correlate all of the units throughout the full extent of the long basin.

Another similar trough developed on the east side of the Diablo Range at about the same time. This basin extended from southwestern San Joaquin County to the Coalinga region. All of the Pliocene sediments deposited in the latter trough are nonmarine as far southeast as northern Fresno County, where they start to interfinger with marine sediments. In the Coalinga area all of the Pliocene sediments are marine. Thus this lower and middle Pliocene trough was a continental trough; land-laid deposits accumulated in the northern part; shallow

marine sediments in the southern part. In the area between the two parts there are numerous interfingerings of land-laid and marine beds. The depositional surface of the northern continental part of the trough never stood much above sea level and it continued to sink slowly as sediments from the adjacent highland were carried into it. The southern marine part also was shallow, the depositional surface being not far below sea level. There must have been a very slight but not uniform southeastward slope in the trough. That there were fluctuations of level is shown by the interfingering of marine and non-marine sediments in northern Fresno County.

The name Orinda formation originally was applied to all of the nonmarine Pliocene of northern Alameda and western Contra Costa Counties, although the Siesta lake beds were separated from the Orinda in the Berkeley Hills. Subsequent work has shown that all of the Orinda in this region is not lower Pliocene, and that sediments originally mapped as Orinda southwest of Mount Diablo are not equivalent to the Orinda of the Berkeley Hills.

In the Berkeley Hills, the Orinda, as herein defined, is of late upper Miocene age; the Siesta is of lower Pliocene age. From back of Oakland and Berkeley northwestward to the bay, the Orinda consists of continental flood-plain deposits, with thin discontinuous marine beds at the base. These rest on Franciscan, Cretaceous, and middle Miocene rocks, the overlap on older rocks becoming more pronounced to the northwest. The Orinda, which is strongly folded, consists of coarse to fine prevailing red gravels, sands, silts and clays. There is a thin rhyolite tuff in the upper part of the formation. These sediments were deposited on the flood plain of the highland that lay to the southwest in the present San Francisco Bay region, an area that stood well above sea level at that time. The gravels in the Orinda contain abundant debris of Franciscan and Cretaceous rocks derived from the west. In the Berkeley Hills the Orinda has a maximum thickness of about 1500 feet, thinning to the north.

The rhyolite tuff in the Orinda is of local derivation, resulting from explosions of rhyolitic volcanoes in the Berkeley Hills and north Berkeley; several local centers of rhyolitic volcanic activity are known. There are small rhyolite breccia necks intruding the lower part of the Orinda, some of which broke through to the surface with explosive activity. One is at Little Grizzly in the Berkeley Hills; another forms Cragmont Park.

The Orinda is succeeded by and interdigitated with the Moraga volcanics, chiefly andesite flows, tuffs, and agglomerates. These apparently came from the north, as they thicken greatly in that direction. The apparent northward thinning of the Orinda is merely the result of successive flows that came from the north into the Orinda basin; the lower flows did not travel as far south as the later flows. The flows are separated by Orinda sediments. There is no actual northward

thinning of the Orinda, as flows and fragmental volcanics on the northwest take the place of sediments on the southeast. Thus the contact between the Orinda and the Moraga is not a time contact but a lithologic one.

These flows and fragmental volcanics interrupted the drainage and formed temporary lakes in which the Siesta formation, which is of very limited extent, was deposited. The Siesta consists of marsh and lake clays, ostracodal clays and impure ostracodal limestones, banded impure cherts, silts, sandstones, gravels, thin lignitic beds and beds of volcanic ash. In the south the Siesta is about 700 feet thick but it thins to less than 50 feet north of Grizzly Peak. The Siesta contains lower Pliocene vertebrates.

The Siesta is succeeded by and interbedded with the Bald Peak lavas, which are chiefly flows of basalt and andesite. Actually the Siesta also is interbedded with the underlying Moraga volcanics. To the north, in the Bald Peak syncline, the Siesta thins to less than 50 feet so that the Moraga volcanics are almost in contact with the Bald Peak lavas. The volcanics are not traceable to the north since they lie in a southeastward-plunging syncline and hence rise to the north where they have been removed by erosion, exposing the underlying Orinda. All of the beds just described may be seen along Grizzly Peak Boulevard in the Berkeley Hills.

The Orinda-Siesta volcanic sequence in the Berkeley Hills is the result of deposition of continental sediments on the western edge of the San Jose-Santa Rosa trough in the late upper Miocene and lower Pliocene. If the northwestward thinning of the Siesta should continue the Moraga and Bald Peak volcanics would come together and form one continuous volcanic sequence. Unfortunately these volcanics are not again exposed at the surface to the northwest but certain sub-surface volcanics in the Petaluma region, beneath the Pliocene Petaluma formation, are believed to be equivalent.

As the Orinda appears to be late upper Miocene and the Siesta is Pliocene, the Miocene-Pliocene contact comes somewhere in this sedimentary-volcanic sequence and an arbitrary contact must be drawn for mapping purposes. Probably the simplest solution would be to draw the line at the base of the Moraga volcanics; however, this is not a time contact, and the volcanics interdigitate with the Orinda.

Although the beds described above are only of local importance the section has been fully described to show the difficulties frequently encountered in establishing a satisfactory contact between many important geologic time divisions.

The upper Miocene sea retreated northeastward toward the Mount Diablo region, which remained under water as late as the beginning of the lower Pliocene. Here the thin marine Diablo formation was deposited, which grades up into at least 6000 feet of nonmarine flood-plain and lacustrine sediments to which the name Green Valley has

been given. An abundant lower Pliocene vertebrate fauna, which includes primitive horses, antelope, foxes, dogs, and wolves, is found in the lower part of the Green Valley beds; it is probable that this formation is in part middle Pliocene in age. Although there are many gravel lenses in the Green Valley it is prevailing finer grained than the Orinda; reddish-colored sediments are present but the general color is gray to tan. During deposition of the Green Valley formation the basin lay near sea level and it is quite possible that brackish-water conditions prevailed at times as a result of minor fluctuations of level.

The name Tassajero formation has been suggested for exactly similar beds overlying the Green Valley formation but the beds never have been completely described.

The volcanic sequence of the Berkeley Hills does not extend into the Mount Diablo region. Volcanic ash beds high in the Green Valley formation that have been correlated with the Moraga volcanics are much younger.

A series of continental and lacustrine beds is exposed to the east and north of the city of Petaluma in south-central Sonoma County. Although the base of these beds is not exposed at the surface, considerable information has been obtained from wells drilled for oil. As exposed at the surface, the Petaluma formation consists of 2500 feet of brown and gray clay shales, silts, brown and gray sandstones, and thin gravels. The top is not exposed as the Petaluma beds are unconformably overlain by Merced sands and Sonoma volcanics. An unknown thickness of the Petaluma formation was removed prior to the accumulation of the later sediments and volcanics.

The lower 2000 feet of the Petaluma is not exposed at the surface but was penetrated by several wells drilled for oil. It is similar to the exposed beds, but there is also several hundred feet of gray to greenish-gray ostracodal shales with lenses of impure gray ostracodal limestones. The lower 150 feet consists of interbedded ostracodal shales and volcanics; beneath these transition beds there are known to be 4162 feet of volcanics, both flows and fragmental material. These rocks, which have been called the Tolay volcanics, consist of basalt and andesite flows, agglomerates, and tuffs. One 20-foot bed of silty shale was cored in the midst of the volcanics. The sedimentary part of the Petaluma formation, exposed and cored in wells, has a thickness of at least 4500 feet and the sediments grade downward into more than 4000 feet of volcanic rocks.

The lower part of the Petaluma formation closely resembles the Siesta formation which is exposed 30 miles to the southeast, and the Tolay volcanics closely resemble the Bald Peak and Moraga volcanics. Both the Petaluma and Siesta are known to be Pliocene but the exact position of the former in the Pliocene is not completely known. Vertebrate fossils from the exposed top of the Petaluma are thought to be

middle Pliocene; the lower part of the formation may well be lower Pliocene. The writer believes that the Tolay volcanics, as encountered in the wells in the Petaluma district, are essentially equivalent to the Orinda-Moraga-Bald Peak group of rocks of the Berkeley Hills, and that the Petaluma is the time equivalent of the Siesta and of sediments eroded from above the Bald Peak lavas. It is also probably equivalent to part of the Green Valley formation. The entire sequence of Tolay volcanics and Petaluma sediments is lithologically similar to the volcanic-Siesta sequence in the Berkeley Hills, and the two areas were formerly a part of the San Jose-Santa Rosa trough. The Tolay volcanics probably are late upper Miocene and lower Pliocene and the Petaluma formation is probably lower and middle Pliocene.

In the Petaluma district the Franciscan is thrust northeastward over the Petaluma formation on the southwest and on the northeast the Petaluma beds are unconformably covered by the Sonoma volcanics.

Since the base of the Tolay volcanics is neither exposed nor reached in wells nothing is known regarding the rocks on which the volcanics rest. The writer believes that these volcanics rest on Franciscan rocks.

A few seepages of oil occur in the Petaluma beds and a number of wells have been drilled. A small amount of gas and low-gravity oil has been obtained from sands in the Petaluma formation above the ostracodal shales and limestones. There is no evidence that organic marine Miocene sediments occur beneath the Tolay volcanics and no sign of either oil or gas was found in the volcanics, although they were cored continuously. Apparently the only available source for the low-gravity oil found in the sands above the lower shales was the organic matter in the lacustrine ostracodal shales themselves, and hence the oil is of fresh water, rather than marine origin.

The formations just described, both sediments and volcanics, ranging from late upper Miocene through, or at least into, the middle Pliocene, accumulated in a trough that was bounded on the southwest by a land mass that extended through western Marin County, the present San Francisco peninsula, and southwestward into northern Santa Clara County. Southwest of this highland lay the marine trough in which the Purisima was deposited.

The trough in which the continental Orinda, Green Valley, Petaluma, and volcanics accumulated seems to have been relatively narrow on both its southeastern and northwestern ends, but to have been wide enough across the central part to include Contra Costa, northern Alameda, and southern Solano Counties. The present Mount Diablo region might have risen slightly above the depositional levels in the middle Pliocene. The northern part of the Diablo and Mount Hamilton Ranges stood well above the depositional level and contributed detritus to the troughs at their bases. The western trough probably connected

with the basin, previously described, on the east side of the Diablo Range. The two merged with the plains fronting the Sierra Nevada.

During this time the Sierra Nevada was still fairly low, but the crestral region gradually had been bowed upward and may have reached elevations of 6000 to 8000 feet. In the higher parts of these mountains there were violent volcanic eruptions that gave rise to many andesitic flows and much explosive fragmental material. There were many andesite flows in the higher parts of the Sierra Nevada but few reached the lower slopes. The fragmental material, however, was carried westward in great quantities in two ways—primarily as stream sands and gravels, but also, more spectacularly, as pasty mud flows of fine to coarse andesitic material. Some of the flows traveled more than 60 miles down the low slopes, reaching almost to the present border of the Great Valley. The finer products of explosive activity were showered over the entire region and were washed into the streams, thus increasing their load. In fact, wind-borne ash from some of the more violent explosions may have been carried as far west as the Pliocene basins of the Coast Ranges.

The overloaded Sierra Nevada streams carried the andesitic material together with their normal detrital load westward. This debris was deposited by the streams along their courses and over their western flood plains. Coarse andesitic material, most of it fairly well rounded, is now found as far west as the edge of the Great Valley but, in general, the material becomes finer-grained toward the west. These andesitic sands, silts, and boulder beds covered the earlier Tertiary sediments, lone and rhyolitic material, and much of the bedrock, but subsequent erosion has exposed these formations in many places.

The great mud flows usually followed the old stream channels, but may have spread over some of the interstream areas. They evidently moved down the gentle slopes as pasty water-soaked masses of fine to coarse andesitic debris. Some of the larger blocks in the mud flows are over 20 feet in diameter. Blocks 10 to 15 feet in size are common.

Practically all of the volcanic centers were in the higher Sierra Nevada region; it is there that the flows are thickest and most numerous. On the lower slopes, in Amador and Calaveras Counties, a group of andesitic plugs now rise above the surrounding country; Jackson Butte and Golden Gate Hill are the most conspicuous. These may have been centers of explosive activity, but it is more probable that they never quite reached the surface. Vertebrate remains, many of which are identical with those found in the Coast Ranges, indicate that the andesitic explosions and the resulting debris that spread over much of the central Sierra Nevada are lower and middle Pliocene in age. The bulk of the explosions took place in the lower Pliocene, although the activity may have begun in the late upper Mioene. Only minor waning volcanic activity continued into the middle Pliocene.

In the lower Pliocene the climate appears to have been slightly warmer and more arid than at present. Vegetation was somewhat similar and the region abounded in primitive horses, antelope, foxes, dogs, wolves, and rodents. The ranges, such as Diablo, Mount Hamilton and those north of the bay, stood above the depositional level but they were much lower and had a more subdued topography than at present. Neither the Golden Gate nor San Francisco Bay were in existence. Most of the drainage in the Great Valley probably was southward into the lower Pliocene sea that occupied the southern part of San Joaquin Valley. The view eastward from central Contra Costa County or from the northern end of the ancestral Diablo Range in eastern Alameda County or southern San Joaquin County would have taken in the gentle eastern slope of the Diablo Range fronted by broad plains extending to the low western slopes of the Sierra Nevada. This plain, which was receiving the lower Pliocene deposits derived both from the east and west, was dotted here and there by lakes. Vegetation was scanty except in the higher regions, along stream courses in the plains, and about the lakes. Primitive horses, camels, antelope and carnivorous animals abounded in the region. Primitive vultures, eagles, hawks, and other birds, not greatly different from those of the present, pursued their usual lives in the air. In the distance toward the east the Sierra Nevada gradually rose and, in the higher regions, volcanoes sent up their showers of smoke and ash. In the winters the higher Sierra Nevada probably was snow covered. Aside from the volcanic eruptions it was a peaceful scene as yet untroubled by the advent of man.

In the late middle or early upper Pliocene the scene changed and the entire landscape was greatly modified. The bay region was subjected to compression and the rocks of the Coast Ranges area were acutely faulted, folded, even overturned, and the mountains rose. The smaller basins in which the preceding Pliocene sediments were deposited were destroyed. The sea was finally driven from the southern San Joaquin Valley and the present drainage system of the Great Valley had its earliest beginning. The climate probably gradually changed, becoming somewhat cooler.

Because of its rigid crystalline basement the Sierra Nevada region was not strongly folded but bowed gently upward. The general elevation increased slightly and the streams accelerated their work of down cutting.

These changes, although slow in comparison with ordinary standards, were rapid in comparison with the time required for the deposition of the earlier Pliocene sediments.

As the mountains rose, a small part of the coastal region, extending from the northern part of San Francisco peninsula northward through Marin and Sonoma Counties, sank and was flooded by the



late middle or early upper Pliocene sea. Debris from the rising mountains, which were subjected to active erosion as they rose, was washed into this sea, forming the marine Merced formation. At the same time volcanic activity began in the region north of San Francisco Bay, producing the andesitic, rhyolitic, and basaltic flows and fragmental material known as the Sonoma volcanics. Along the west side of the Great Valley the debris from the rising mountains was carried down to the plains and deposited, forming the Tehama beds.

Not all of these events occurred at exactly the same time but they occupied the space of time from the late middle Pliocene into the early Pleistocene. The diastrophism that brought about the changes occupied the late middle and early upper Pliocene. Erosion of the elevated ranges began immediately but the resulting sediments are not necessarily synchronous over the entire area.

The Merced formation consists of marine sands, silts, sandy shales, gravels, and volcanic ash. At its type section near Lake Merced south of San Francisco it is over 5000 feet thick, but elsewhere it rarely attains a thickness of 300 feet.

The uppermost Purisima beds farther to the south may be equivalent to the Merced, as the upper more sandy sediments now included in the Purisima formation overlap across the lower Purisima.

North of the bay there are small remnants of the marine Merced formation as far east as Petaluma and Santa Rosa where they rest on the eroded surface of the Franciscan. Volcanic ash, identical with that in the lower part of the Sonoma volcanics occurs interbedded with the marine Merced. South and west of Petaluma marine Merced sediments are interbedded with andesite flows of the Sonoma volcanics.

The upper Pliocene sea in which the Merced was deposited extended as far east as a line running from Sears Point on Tolay Creek in Sonoma County northwestward to Santa Rosa. No marine Merced is known east of San Francisco Bay.

Sonoma volcanics is the name given to a thick accumulation of flows, agglomerates, tuffs, and tuffaceous land-laid sediments that extend from the southern end of Sonoma Mountains, on the north shore of San Pablo Bay, northwestward through Napa, Sonoma, and Lake Counties. Owing to later gentle folding, faulting, and erosion, they now occur in large detached areas over the counties mentioned, but at one time they must have covered most, if not all this area. The centers of eruption, of which there must have been many, were all on land east of the easternmost extent of the sea in which the Merced was deposited but some of the flows extended into this sea and are interbedded with the marine Pliocene.

These volcanics were poured out over a surface of some relief and hence vary greatly in thickness and in sequence from one place to another. They rest unconformably on all older formations, including

the Petaluma. East of Petaluma they rest on the strongly beveled and eroded edges of the Petaluma formation, elsewhere they rest on Franciscan-Knoxville, Lower and Upper Cretaceous, and Eocene rocks.

As they are interbedded with the marine Merced they are equivalent, at least in part, to that formation; but their complete range is not known. Marine fossils in the Merced and plant remains in sediments below and interbedded with the volcanics indicate that the volcanics are at least in part of upper Pliocene age.

Their thickness depends on the nature of the surface over which they accumulated and the proximity of centers of eruption. In the bay counties their maximum thickness is about 1200 feet, but in places they are over 2000 feet thick.

They are well exposed in the rugged, rather bushy hills on both sides of Napa Valley and in the Sonoma Mountains. They also form Mount St. Helena, Mount Cobb, and Boggs Mountain. In places they are underlain by tuffaceous continental and lacustrine sediments that accumulated in topographic lows prior to the main volcanic outbursts, but in other places they rest on older rocks. The continental sediments beneath the volcanics range from a thin veneer to more than 800 feet in thickness.

In composition they have a wide range, including rhyolites, dacites, andesites, hypersthene andesites, basalts, and olivine basalts. Some of the flows are very glassy, and obsidians equivalent in composition to rhyolite, dacite, and andesite are found.

On the western side of Berryessa Valley, in eastern Napa County, the feathering-out eastern edges of the volcanics are interbedded with typical continental Tehama sediments.

The Tehama formation is entirely continental, being deposited on the flood plains of rivers and in lakes. It is typically developed along the west side of Sacramento Valley from Tehama County southward to Suisun Bay. There is a small area of Tehama sediment south of Port Chicago that extends southeast to the latitude of Antioch. Here it rests unconformably on the Neroly.

North of Yolo County the Tehama attains a thickness of over 2500 feet; but in the bay region its maximum exposed thickness is 1200 feet. It dips eastward at low angles and disappears beneath Pleistocene terraces and valley alluvium in Sacramento Valley.

The Tehama formation consists of coarse to fine gravels and sands, silts, clays, thin lignitic beds, and pumiceous volcanic ash. Commonly there is a bed of white pumiceous ash near the base; this is known as the Nomlaki tuff member. The beds usually are very lenticular, a characteristic of continental sediments deposited on the flood plains of streams, and the sands and gravels are strongly cross-bedded. Some of the bluish and greenish clays are evenly bedded, indicating lake deposition.

On the west side of Berryessa Valley, which was already a well-defined valley in the upper Pliocene, the Tehama is very tuffaceous and is interdigitated with the extreme eastern edge of the Sonoma volcanics. In the bay region the Tehama formation has been called the Wolfskill formation but since the Wolfskill as mapped and defined is continuous with the Tehama and as the name Tehama greatly antedates the name Wolfskill, the latter should be abandoned.

The marine Merced, the Sonoma volcanics, and the continental Tehama (including the Nomlaki tuff) are essentially synchronous. This does not mean that all parts of each of these units are of exactly the same age, but that they were deposited in different regions at approximately the same time. Usually all are called upper Pliocene but any or all of them may extend downward into the late middle Pliocene. It is also probable that any or all of them extend into the lower Pleistocene. They all accumulated after the mid-Pliocene diastrophism. Except near faults that either came into existence in the Pleistocene or old faults that moved again in the Pleistocene, all of the upper Pliocene beds have relatively low dips. This is in marked contrast to the adjacent lower Pliocene and older beds. All of these upper Pliocene beds have been warped to some extent, but the folding has been gentle compared with that suffered by the lower Pliocene and older rocks. The orogeny that folded the upper Pliocene and lower Pleistocene beds took place in the mid-Pleistocene. In southern California this orogeny was as strong or even stronger than the mid-Pliocene orogeny, but in central California the mid-Pliocene orogeny had by far the greater effect.

The Santa Clara gravels in Santa Clara County and the San Benito gravels in San Benito County are of late upper Pliocene and lower Pleistocene age. At present they cannot be correlated with the formations just described.

Oil occurs in the Purisima beds in the Halfmoon Bay-La Honda region in San Mateo County and in the Sargent oil field in southern Santa Clara County. In the Halfmoon Bay district the oil originates from organic shales in the lower part of the Purisima and accumulates in thin tight sands in the Purisima above the organic shales. In the Sargent area the oil originates in the underlying organic Monterey shales and accumulates in basal sands of the Purisima which rest unconformably on the Monterey. In the Sargent area the oil is of low gravity averaging less than 17 degrees Baumé, whereas in the Halfmoon Bay region the oil is of high gravity averaging 48 degrees Baumé.

Small quantities of oil have been sporadically produced in the Halfmoon Bay region since 1882. In the early days the oil was hauled across the mountains to San Mateo and thence to San Francisco. It is said to have been used to illuminate some of the old theaters on Mis-

sion Street in San Francisco. Although the gravity is excellent, the yield is too small to be commercial at present.

Attention was attracted to the Sargent area by large oil seepages, and some drilling was done as early as 1886. Commercial production began in 1904 and continued to 1948. The total production of the Sargent field has been 783,759 barrels.

Oil also occurs in the Petaluma formation about 5 miles east of Petaluma. A number of wells have been drilled and several have obtained oil and gas, but no sustained commercial production has resulted. There have been three main periods of activity, 1924-27, 1937, and 1948-49. Wells properly located structurally come in at 40 to 50 barrels per day but decline rapidly to a point where production ceases to be commercial. The oil is of low gravity, about 19 degrees Baumé, and appears to have originated from fresh-water ostracodal shales.

The Merced formation has yielded little of economic value except for sands and gravels used locally. A thick welded tuff in the Merced northwest of Petaluma has been quarried for railroad ballast, fill, and road metal.

The Sonoma volcanics supply a number of substances of economic value. Near Napa a rather pure pumice tuff is extensively quarried and, after simple treating, is used as a light-weight aggregate in concrete for a variety of purposes. It is also suitable, when finely ground, for an abrasive and as one of the components of fireproof roofing shingles.

The volcanic flows frequently are quarried, crushed, and used as road metal. At one time some of the volcanics were quarried and used as paving blocks. Both flows and tuffs are crushed, treated, and used for a great variety of purposes, particularly as cement aggregates. Some of the flows and hard tuffs are quarried and used locally for bridges, culverts, retaining walls, and even large wineries, particularly in Napa and Sonoma Counties. Some of the thin bedded flows, both rhyolite and andesite, have been quarried and sold for flagstones for gardens and patios.

Thin seams of lignite occur in a few places in the continental sediments beneath the volcanics but they have no present commercial value.

In a number of places the Sonoma volcanics lie in very gentle synclines along ridges, resting on impervious older beds. When this occurs, springs commonly issue from the lavas at the contact. The water in such springs is of excellent quality and forms an important local source of domestic water.

*Pleistocene.* After the deposition of the Merced and Tehama formations and the outpouring of the Sonoma volcanics the region was again folded, but less severely than in the mid-Pliocene in central California. Movement again took place on faults already established



FIG. 6. Offset fence near Crystal Springs Lakes. View west toward Cahil Ridge. Man is standing on furrowed ground marking the surface trace of the San Andreas fault movement of 1906; ground behind has been shifted to the right. *Photo from J. C. Branner collection, courtesy Stanford University.*

and it is possible that new faults came into existence. The combined effects of the two orogenies was to form the main structural and topographic features as we now know them. As a result of the mid-Pleistocene uplift and folding the sea was completely driven from central California except for minor embayments which persisted practically until the close of the Pleistocene.

The combined Sacramento and San Joaquin Rivers already had cut a channel through the ranges prior to the Pleistocene but San Francisco Bay was not yet in existence. In fact the basin, or rather basins, now occupied by San Pablo and San Francisco Bays did not come into existence until the late Pleistocene. The actual flooding by the sea may not have been accomplished until after the melting of the glaciers and the return to the sea of the vast quantity of water locked in the glaciers.

It is possible, even probable, that the depositional stage represented by the Merced formation, Sonoma volcanics, and Tehama formation continued into the early Pleistocene and that the upper parts of these units actually are Pleistocene. Regarding this point, however, there is little evidence. At any rate the Merced basin was destroyed and the sea driven from the land by the mid-Pleistocene orogeny. The effect of this orogeny, probably aided by milder movements later in the Pleistocene, was to gently fold and elevate the marine Merced as much as 1000 feet above sea level along the west side of Santa Rosa Valley. The up-arching appears to have been much greater eastward in the higher central part of the Coast Ranges east of Santa Rosa and Napa Valleys, as the Sonoma volcanics lie at elevations up to several thousand feet. However, as these volcanics are continental and not marine, their original elevation is not known with certainty.

There are certain wholly continental formations in the interior valleys, such as the Livermore, Santa Clara, and San Benito gravels, which appear to range in age from late Pliocene to middle Pleistocene. These are regarded by the writer as flood-plain and lacustrine sediments formed in interior valleys as a result of the strong uplift caused by the late Pliocene diastrophism. The uplifted older rocks were attacked by erosion and the debris from them deposited in the interior valleys which appear to have continued to sink by gentle down-bowing. These valley deposits were tilted and gently folded by the mid-Pleistocene orogeny.

The sediments deposited after the mid-Pleistocene orogeny are either flat-lying or very gently tilted except along faults on which there has been comparatively recent movement. In such places drag effects may produce very local steep dips.

There are flat-lying late Pleistocene marine deposits near Tomales Bay that extend a short distance inland. These must be late Pleistocene

as all of the marine invertebrates found in them are species which are living today.

There are extensive late Pleistocene nonmarine terrace deposits in the Montezuma Hills and along the west side of the Great Valley. Late Pleistocene marine terraces also occur along the coast.

The mid-Pleistocene orogeny was not the last disturbance to affect the Coast Ranges, as the late Pleistocene marine terraces are slightly deformed. An excellent example of such a warped terrace may be seen at the south side of Halfmoon Bay where the broad terrace that forms the elevated bench to the south tilts gently northward and the pholas-bored surface of the steeply dipping Purisima formation disappears beneath the present beach sands.

Both Santa Rosa and Napa Valleys appear to have been gently bowed downward in the late Pleistocene. San Pablo Bay, which is actually a continuation of the Santa Rosa-Cotati Valley depression, also appears to have been bowed downward. That part of San Francisco Bay lying west and south of Carquinez Strait also appears to have experienced contemporaneous down-warping. This down-sinking probably continued until recent times, as Indian kitchen middens on the bay shore near Emeryville extend downward several feet below sea level.

There seems to be no reason to doubt that slow warping movements are going on at the present time. It is, of course, known that there are sudden sharp movements along certain active faults, resulting in earthquakes, but the folding and warping of the crust is so slow and gentle as to be imperceptible in the short span of individual human life.

Late Pleistocene volcanism has taken place in the bay region in several localities. North and west of Clayton there are flat-lying olivine basalts that appear to be late Pleistocene in age. In the low hills along the east side of Santa Clara Valley, west of Morgan Hill, there are flat-lying olivine basalt flows that rest on a terrace cut on inclined Santa Clara gravels. Since the gravels are almost certainly early Pleistocene and were tilted and then beveled before the volcanic activity, the flows must be late Pleistocene.

In northern Napa County there are flat-lying olivine basalt flows that originated in the Clear Lake volcanic province to the north, that rest unconformably on gently folded upper Pliocene Sonoma volcanics. At present it is not known whether these are early or late Pleistocene in age.

There are several other known occurrences of Pleistocene basalts and olivine basalts in the Coast Ranges outside of the bay region. All of the Pleistocene flows, except those in the Clear Lake region, are of small areal extent.

*Conclusion.* From the foregoing it is clear that the geologic history of the bay region, as that of the Coast Ranges in general, has been anything but monotonous, especially since the late Upper Jurassic. Except for the rather long period of comparatively quiet deposition during the Cretaceous, when a vast volume of elastic sediments was accumulated, there have been repeated diastrophisms during which the region has been uplifted, folded, and faulted. Volcanic outbursts, both submarine and subaerial, have interrupted sedimentation and have left their record over wide areas. Movement takes place from time to time on still active faults and there is good reason to believe that im-

perceptible slow warping of the crust still continues. The present movements may well be comparable to many of the movements in the Tertiary, but there is good reason to believe that they are not of the same order of magnitude, with respect to frequency and severity of movement, as the great culminating pulses in the late Pliocene and mid-Pleistocene.

The various diastrophic periods and their chief effects already have been mentioned. To describe all of the structural features formed by all of these disturbances is beyond the scope of the present paper.



FIG. 7. Offset fence near Wright Station, Santa Cruz Mountains—a typical disruption of linear features that happened to cut across the San Andreas fault. Fault movement was predominantly horizontal but many complexly operating forces were active within the fault zone. *Photo from J. C. Brunner collection, courtesy Stanford University.*



FIG. 8. San Andreas fault zone where it crossed the old wagon road to Alpine, five miles west of Stanford University. Roadway in the background has been strongly offset to the right along the imbricated zone in the middle ground. *Photo from J. C. Brunner collection, courtesy Stanford University.*

## HISTORY OF EARTHQUAKES IN THE SAN FRANCISCO BAY AREA

BY PERRY BYERLY \*

The earthquake history of California as set forth by Townley and Allen in the *Descriptive Catalog of Earthquakes of the Pacific Coast of the United States* begins with a San Diego entry in 1769. Early reports are from the few isolated settlements of the day, mostly missions. The first entry from the San Francisco Bay area is for 1808. California's written earthquake history is thus a short one, although her geological earthquake history is long. The written record is not long enough to show any pattern which might help in predicting the time of future shocks.

The two major faults of the bay region, the San Andreas fault and the Hayward fault, have been the sources of the larger earthquakes and of many of the smaller ones. The earthquake catalog lists about one thousand earthquakes felt in the bay area between 1850 and 1927, exclusive of the swarms of aftershocks which followed the larger shocks.

From the fragmental reports on the early earthquakes it is difficult to conclude just how strong or widespread they were. The reports come from old diaries, or from the memories of old settlers solicited long after the event by newspaper reporters, who wrote them up after a later shock had stirred the public interest. In one interesting case the record is from a Honolulu newspaper. A ship captain newly come from Monterey recounted what he learned there of a shock which had preceded his arrival.

It is quite certain, however, that two of the shocks in the 1830's were severe.

*Great Earthquakes.* On June 10, 1836, at 7:30 in the morning a great earthquake took place which centered on the Hayward fault at the base of the hills on the eastern side of San Francisco Bay. Fissures opened along this fault from San Pablo to Mission San Jose. The quake "caused havoc" in Monterey and Santa Clara. The population at this time was very small, the whole area having about 1000 inhabitants, exclusive of Indians. It has been estimated that this earthquake was probably stronger than that of 1868.

As soon after this shock as June 1838 another severe earthquake occurred, this time on the San Andreas fault on the San Francisco peninsula. A great fissure is described, reaching from San Francisco south to a point near Santa Clara. The shock cracked walls in the Presidio of Yerba Buena (San Francisco), shook down a house in San Jose, and badly injured walls at the Missions of San Francisco, Santa

Clara, and San Jose. It cracked walls and broke crockery and glassware in Monterey.

Considerably more information is available concerning the two large earthquakes in the 1860's. On October 8, 1865, during the noon hour the bay area felt a damaging shock. In San Francisco the old Merchants' Exchange Building was shaken down and the City Hall and another building were badly damaged. Much glass was broken; and in marshy ground pipes were broken. At San Jose the jail and the Methodist Church lost walls. Buildings were damaged in Santa Clara, and there were rock falls and chimneys down on the Santa Cruz Gap road. It has been presumed that the shock centered on the San Andreas fault in the Santa Cruz Mountains.

On October 21, 1868, at 7:53 a.m., the great Hayward earthquake took place. Cracks and fissures opened up for about 20 miles along the Hayward fault from San Leandro to Warm Springs. If there was any displacement, it did not exceed a few feet. The shock was felt for a distance of about 175 miles from the source. Every building in Hayward was damaged and some were demolished. Buildings on filled



FIG. 1. Photo taken in 1906 showing view southwest down a wagon road that crossed Tomales Valley from Point Reyes Station to the mouth of Papermill Creek. San Andreas fault movement of April 18, 1906, offset the two segments of the road 20 feet. Photo by G. K. Gilbert, first published in *Carnegie Inst. Wash. Pub. 37, vol. 1, pt. 1, pl. 47B.*

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FIG. 2. Photo taken in 1939 just north of Bear Valley Ranch, showing view southeast down Tomales Valley. People in left middle ground are walking down the line of overgrown, partly filled scarps and depressions that were produced during the San Andreas fault movement of 1906. Compare photo with Figure 3, taken in the same vicinity in 1906, looking northwest.



FIG. 3. Detail of fissured earth north of Bear Valley Ranch, three miles northwest of Olema, Marin County. Marshlands of Tomales Bay may be seen in the background. *Photo from J. C. Branner collection, courtesy Stanford University.*



FIG. 4. Frame house at Olema, Marin County, knocked from its foundations during the 1906 earthquake. Wooden frame buildings usually withstand severe earthquakes if bolted to adequate foundations. *Photo from J. C. Branner collection, courtesy Stanford University.*



FIG. 5. Rock and earth dam between Upper and Lower Crystal Springs Lakes was offset but not disrupted by the San Andreas fault movement of 1906. Damage is no longer visible.

ground in San Francisco suffered considerable damage; five deaths resulted from falling walls. Chimneys went down and buildings were damaged from Gilroy and Santa Cruz north to Santa Rosa.

The great earthquake of April 18, 1906, made the San Francisco Bay area internationally famous in the geological world. Never before or since, in historic time, has faulting of such magnificent proportions occurred. True, the displacement was a mere bagatelle compared to the sum total of displacements which have raised mountain ranges in the past. But it was by far the greatest ever observed by man. This earthquake occurred at 5:13 a.m., and a great crack broke down the state from Upper Mattole in Humboldt County to San Juan in San Benito County. It left the coast in several places to re-enter again later. The fault entered the San Francisco Bay area from the north a few miles inland from the coast, passed into the sea at Fort Ross, crossed Bodega Head, went again under the ocean, and emerged once more at the head of Tomales Bay. It traversed the land down a beautiful rift valley to Bolinas Lagoon, where it again took to sea, cutting the sand spit. At Mussel Rock, west of Colma, it entered the San Francisco peninsula to remain on land. It left the area near Saratoga. Throughout its length the Pacific side of the fault moved northward relative to the continental side. The greatest displacement was at the head of Tomales Bay. A farmer lived near Olema in a cottage in front of which two plots of garden lay on either side of a walk which led up

to his porch steps. When he rushed outside after the earthquake he found the garden and the walk had been moved some 16 feet south of the front steps. The San Andreas fault lay just to the east of the steps between them and the garden. Fortunately the ranches in the area were large, and a 16-foot displacement of boundary fences seemed trivial. Imagine the trouble such a displacement would cause in a city! When the same farmer attempted to travel the road across the head of the bay, he found that it had been displaced 21 feet. Unfortunately, from one point of view, the road has been straightened and paved, the house has been rebuilt, and the garden and walk completely altered.

The actions of earthquakes seem very odd. The farmer whose garden was misplaced found his chimney still intact, whereas in some cases chimneys 20 miles from the fault went down. In the north Berkeley earthquake of 1937 one chimney was completely separated from the house, but a vase upon the mantle did not fall over! In the geology building at the University of California at the time of the 1906 shock there were large cases with locked glass doors which contained mineral and rock specimens on shelves. The doors opened, the rocks fell out, and the doors closed, unbroken.

It was in San Francisco where the effects of geological foundation on shaking and damage were most easily observed. There were people living on the rocky hills who were not awakened by the earth-





FIG. 6. San Francisco City Hall just after the earthquake and fire of 1906, showing the inability of some types of construction to withstand shocks of great intensity.



FIG. 7. San Francisco Post Office at Mission and Seventh Streets after the 1906 earthquake, showing that buildings can be designed that can withstand severe earthquakes. Most of the older buildings in the vicinity were demolished.



FIG. 8. Library at Stanford University after the 1906 earthquake. The steel supported rotunda was relatively undamaged, but the unreinforced masonry collapsed. *Photo from the J. C. Branner collection, courtesy Stanford University.*



FIG. 9. Memorial Arch on the Stanford campus, damaged in the 1906 earthquake. The basal pillars of the structure were restored afterward, but the damaged arch was removed. *Photo from the J. C. Branner collection, courtesy Stanford University.*

quake. However, on made land the damage was terrific. A structure on loose soil must be designed and constructed most carefully, for its experience in a large earthquake is much like that of a boat at sea.

Frame structures of moderate height rarely collapsed, although the annex to a San Jose hotel did fall, like a pack of cards. But some dwellings with insecure underpinnings fell off their foundations. The worst destruction occurred in buildings of composite character—wood frames with masonry facing and the like.

The length of the 1906 fault resulted in damage along a considerable zone. The destruction was great in San Francisco, San Jose, and Santa Rosa, as well as in smaller towns in the San Francisco Bay area, and also for some distance outside the area. The destruction in Santa Rosa was peculiar on account of the distance of that city from the fault. In San Francisco property loss caused by the earthquake (exclusive of the terrible fire which followed) was estimated at \$20,000,000; damage outside of San Francisco was estimated at \$4,000,000. It is quite common to find one building only slightly damaged after a shock which had almost leveled a neighboring building. It is therefore obvious that careful design and construction pay in the long run. One picture of San Francisco after the earthquake shows two buildings still to be seen on the skyline, among all the ruined structures. Although damaged by quake and fire, these two were not destroyed.

*Moderate Earthquakes.* During the period 1850 to 1927 the earthquake catalog lists about 20 shocks strong enough to do some damage to masonry in some part of the bay area. Since 1906 there have been four such shocks. On July 1, 1911, there occurred an earthquake which centered near Coyote in Santa Clara County. The shock was strong enough to throw down chimneys, break windows, and crack walls in San Jose, Gilroy, and Morgan Hill. It was felt as far as 140 miles from its center.

On October 17, 1914, an earthquake shook down a few chimneys in Piedmont. The shock was felt as far as Sebastopol and Santa Clara.

On May 16, 1933, there was a damaging earthquake which centered not far from Niles in Alameda County. This earthquake threw down many chimneys near Niles and did considerable damage to dwellings. Some chimneys went down, some cornices fell, and some windows were broken in Hayward, Martinez, Mission San Jose, and Walnut Creek. The shock was felt as far away as Marysville, Merced, and Spreckels.

On March 8, 1937, an earthquake felled many chimneys, cracked others, and cracked walls in Albany, El Cerrito, and North Berkeley. This earthquake was felt as far away as Santa Rosa, Isleton, and Gilroy.

*Distribution of Small Shocks in Recent Years.* The University of California has maintained two seismographic stations in the bay

area since 1887, one in Berkeley and one at Mount Hamilton. They are the oldest stations in the western hemisphere and among the oldest in the world. In 1927 a station at Palo Alto, on the Stanford University campus, was added to the network, and in 1931 one in San Francisco. The latter was first located in Golden Gate Park at the California Academy of Sciences but was moved in 1935 to the University of San Francisco.



FIG. 10. Part of the arcade at Stanford University, showing displaced keystone in the middle arch, a result of the earthquake of 1906. Photo from the J. C. Branner collection, courtesy Stanford University.

Since 1931 the locations of the sources of small earthquakes in the bay area have been determined with increasing accuracy. The addition to the network of a station at Fresno in 1935 has been very helpful. The station is located in the Fresno State College. All the epicenters of shocks in the area recorded at more than one station are located now.

The accompanying map shows the epicenters of earthquakes that occurred between 1930-41 and 1947-48. Seismograms for 1942-46 have not yet been worked up.

The epicenters shown by triangles are the loci of shocks large enough to shift small objects or do minor damage. Circles represent



FIG. 11. Old railroad which ran between Los Gatos and Santa Cruz, badly warped at the point of intersection with the San Andreas fault break of 1906. *Photo from the J. C. Branner collection, courtesy Stanford University.*



FIG. 12. Reservoir south of Saratoga damaged and partly drained as a result of the San Andreas fault movement of 1906. *Photo first published in Carnegie Inst. Wash. Pub. 37, vol. 1, pt. 1, pl. 64A.*



FIG. 13. Main San Andreas fault break of 1906 as it passes through a yard and under the porch of a house west of Saratoga. *Photo from the J. C. Branner collection, courtesy Stanford University.*



FIG. 14. Fence line on Folger Ranch near Woodside, San Mateo County, offset eight feet along the furrowed ground where the man is standing. Trace of San Andreas fault break of 1906 was discernible for many miles of its length because of features such as these. *Photo from J. C. Branner collection, courtesy Stanford University.*



FIG. 15. An escarpment produced in alluvial fill along the Pájaro River near Watsonville at the time of the earthquake of 1906. This feature was not a surface expression of major fault dislocation but was the result of the shaking motion of earthquake waves in deep, weakly consolidated alluvium. *Photo from J. C. Branner collection, courtesy Stanford University.*



FIG. 16. A series of stepped dislocations caused by the earthquake of 1906 as seen on a road crossing deep alluvial fill near Salinas, Monterey County. Like the scarp seen in Figure 15, these dislocations were caused by the action of earthquake shocks and were not direct surface expressions of deep-seated faulting. *Photo from J. C. Branner collection, courtesy Stanford University.*



FIG. 17. Disrupted roadbed near Spreckels, Salinas Valley, caused by lurching in deep alluvial fill. San Andreas fault passes through on the other side of the Gabilan Range in the vicinity of San Juan Bautista, many miles to the east. Some of the secondary results caused by shocks produced at times of major faulting often are more spectacular than direct dislocations in the fault zone itself. *Photo from the J. C. Branner collection, courtesy Stanford University.*



FIG. 18. Sand craterlets, another secondary effect of the shaking motion of earthquake waves in alluvial ground. Taken in a field near Milpitas at the time of the earthquake of 1906.



FIG. 19. A view between Hayward and Niles, Alameda County, taken east across the Hayward fault, which follows near the base of the hills. The tree-lined canyon originally reached the alluvial plain by a nearly straight course, but was deflected to the left (north). The ridge in front of the deflected canyon segment was produced by offsetting the end of the right spur. *Photo by Richard J. Russell.*

centers of shocks only strong enough to rattle windows and doors; most of these shocks were not even reported felt by anyone. Marin and Sonoma Counties are comparatively free from centers. This may seem remarkable, inasmuch as the great San Andreas fault passes through these counties, and inasmuch as the major displacement occurred in them in 1906; but probably the strain along the fault was more thoroughly relieved in this region. Perhaps the friction of the fault resulting from transverse forces is greater there than farther south.

Yolo, Sacramento, and San Joaquin Counties are quite free of epicenters. The fact that an earthquake does not originate in a county, however, does not mean that the shock is not felt there, or even that it may not do damage there to poorly built structures on loose soil. Solano County is the center of many shocks. In April 1892 there were two very sharp shocks which were quite destructive locally in Vacaville, Dixon, and Winters. In the remaining counties of the bay region activity is quite widely spread. There is not the strong grouping along the major faults which might be expected.

Dwellers in the bay region should see to it that their houses are sturdily constructed on ample foundations, and should not be overly concerned as to distance from well-known faults.

*The Faults Today.* The broad topographic features of the San Andreas and Hayward faults are well delineated. In some places

their displacements can be seen in detail. On the route north from San Jose up the east side of San Francisco Bay an old scarp of the Hayward fault, the east face of a low range of hills, can be seen to the west of Foothill Boulevard. These hills die out near Irvington. The fault traverses the alluvial fan of Niles Creek just below Niles and crosses the highway to follow the foot of the mountains. North of Niles, toward Hayward, the fault has been horizontally displaced; the west side moved north, as is always the case in this region. Small wooded ravines descending the slope roughly at right angles to the crest are all turned to the north for a short distance where the fault has moved. Then they again turn westward toward the bay. Their courses have been broken in ancient earthquakes.

From the outskirts of Oakland one may follow the wandering course of Mountain Boulevard, entering it back of Mills College. In general, this road follows the rift valley of the Hayward fault. To the right (east) are the Berkeley Hills, consisting predominantly of Cretaceous and Tertiary formations. To the left are the Piedmont Hills, consisting of pre-Cretaceous formations. The rift valley now followed by the Hayward fault has been an active seat of vertical displacements in the geologic past. At the northern end of the valley is Lake Temescal. North of the lake the rift follows the hill face. North of Berkeley, along Arlington Avenue, rift phenomena are again encountered. A short rift valley hangs on the hillside just south of the Country Club.



FIG. 20. Map of San Francisco Bay area showing principal active faults (heavy black lines) and the epicenters of earthquakes that occurred during the periods 1930-41 and 1947-48. The intensity of the various shocks is shown by the epicenter symbols listed in the legend to the left of the map.



FIG. 21. Bridge abutment at Chittenden on the Pájaro River, Santa Cruz County, disrupted by earth movement connected with the earthquake of 1906. Photo from J. C. Branner collection, courtesy Stanford University.

On this same route, the San Andreas fault may be reached via the Richmond-San Rafael Ferry, Fairfax, Olema, and Inverness. Where the road crosses the head of Tomales Bay, near Point Reyes Station, the fault is encountered. The road displaced 21 feet in 1906 followed this same route. To the south, down the beautiful rift valley, faint traces of the 1906 break can still be seen on the hillside. Rift phenomena are most conspicuous after rains, as drainage is always interrupted by faulting, and little ponds and swampy areas then mark the fault zone. Down the rift valley from Tomales Bay to Bolinas a hodgepodge of small hills can be seen, and also the drainage peculiarities caused by a checkered tectonic career. At Bolinas Bay the San Andreas fault goes out to sea. It is encountered again in the beautiful rift valley of Crystal Springs Lake and San Andreas Lake, south of San Francisco on Skyline Boulevard. Skyline Boulevard may be reached from Bolinas via Stinson Beach, Golden Gate Bridge, and San Francisco.

Beauty in landscape is intimately connected with earthquakes, past or present. If one demands high mountains near broad oceans, it seems that one must put up with earthquakes.

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# GEOLOGIC MAP OF THE SAN FRANCISCO BAY REGION

BY OLIVER E. BOWEN, JR. \* AND RICHARD A. CRIPPEN, JR. †

Geologic maps are designed to give a picture of the distribution, continuity, age, and general character of the rocks of a given area, together with as many data on rock structure as it is practical to show. For mapping purposes a rock unit is chosen by one or more of the following criteria: (1) Distinctive appearance or distinctive mineral composition; (2) Presence of some age-determining factor, such as a group of fossils; (3) Depositional continuity within the unit and discontinuity with adjacent units; (4) A character distinctive of some mode of origin or of some known event in geologic history; (5) Stratigraphic position among other units.

The unit ultimately chosen must also be adaptable to the scale of the finished map; that is, it must be large enough and persistent enough to show on the map. As the topography or configuration of land surface is often closely related to the character and distribution of the rocks of the earth's crust and as, conversely, the topography often governs the areal extent of a rock formation, contour lines which portray the topography commonly are found on geologic maps.

Before visiting a given area examination of a geologic map of that area can reveal a great deal of information usable to people in all walks of life. An engineer or builder obtains much advance information about probable difficulties to be encountered in road building or other construction projects. Geologic maps suggest to the prospector or miner the most likely places to search for mineral deposits or to relocate old mines. They reveal to the geologist a great deal concerning the geologic history of the area portrayed and they can supply the non-geologically trained tourist with answers to many questions about rocks seen along the way.

The composite geologic map found in this bulletin is a simplified representation of part of a very complex region. It covers most of 12 counties which have an aggregate area of more than 10,000 square miles and includes, in addition to the central Coast Ranges, parts of the Great Valley and Sierra Nevada provinces. The geology, which has been compiled from a great many sources and adapted to the purpose of this bulletin by field checking, originally was drawn on United States Geological Survey 15-minute topographic quadrangle maps on which one inch of map distance equals approximately one mile on the ground. Locations of the roads, towns, county boundaries, waterways, railways, and miscellaneous landmarks, which serve to orient the reader on the map, were taken principally from the California State Map of the U. S. Army Map Service, edition of 1947, and adjusted to fit geology, topography, and chosen scale of the map.

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In order to satisfy size limitations in printing map plates for a publication of this sort, it was necessary to reduce the original scale and consequently the geologic detail of the map, and to divide the map into sections. In the process of reducing the detail of the original geologic maps it was also necessary to eliminate as map units the large numbers of formational names referred to in the literature and to substitute broader divisions based primarily on time relations and secondarily upon lithology or general character of the rocks involved. The resulting draft is similar in rock units and representation of structural detail to the California State Geologic Map compiled by Olaf P. Jenkins in 1938, but includes revisions and additions based upon geologic mapping finished since completion of the State Geologic Map. The final scale used is somewhat larger than that of the State Map, 1:375,000 as compared with 1:500,000, and consequently allows greater cultural detail. The map scale and the patterns chosen to represent the rock units have, however, made it impossible to show adequately the topography of the region. Hence, topographic contour lines have been left out.

The list of map symbols that accompanies the various map sections consists of 12 divisions denoted by different patterns. Alluvium, that is, soil, sand, gravel, and coarser debris, which covers such areas as canyon bottoms, valleys, and coastal terraces, makes up one unit. Formations grouped together under the second unit, *TQs* make the least satisfactory division, as they overlap the other units both in time and in mode of formation. In general, however, the rocks grouped together under this symbol are poorly consolidated sands, clays, and gravels rather easily recognizable throughout the bay area. Under *TQv* are grouped the various late Tertiary scattered volcanic rocks, together with some sediments with which the volcanic rocks become interbedded. On a map of this scale it is impossible to completely separate the volcanic and sedimentary rocks, unlike as they are. Miocene sedimentary rocks, *Tms*, are predominantly coarse, well-cemented, commonly fossiliferous marine sandstones or else hard, thin-bedded marine cherts; but some diatomite and clay shale is present in Miocene sections. Miocene volcanic rocks, *Tmv*, are comparatively rare in the bay region but are important and conspicuous formations along the foothills of the Sierra Nevada, particularly the volcanic mud flows.

Under the symbol *Te* are grouped marine and brackish-water sandstones and shales of Oligocene, Eocene, and Paleocene age. The dividing line between rocks of these three time divisions is difficult to distinguish and not well established, so grouping of these rocks is fairly satisfactory for many purposes. Except where fossils are abund-



ant the layman will find it difficult to tell Eocene rocks from those of Miocene or Cretaceous age in the bay area, with one notable exception: The white sandstones which enclose the coal measures of the Mount Diablo-Tesla coal belt and the closely related Ione sands of the Sierra foothills are unlike other formations in the bay region.

Rocks grouped together under the symbol *K* are brown marine sandstones, dark shales, and conglomerates that on the whole are distinctive enough, but which from place to place are easily confused with sediments of other ages. Although most of these rocks are of Cretaceous age, it is convenient to include the Upper Jurassic Knoxville formation because of the similar appearance of Knoxville and Cretaceous shales, and because many authors have not defined the boundaries between rocks of the two ages.

The serpentines, *Js*, and their associated heavy, dark rocks form a very conspicuous unit recognizable by all. They are intrusive into sedimentary and volcanic rocks of the Franciscan group of Upper Jurassic age, but are separated from it here because of their universal distinctiveness. The predominant rock in the Franciscan group is a hard, tough, slightly metamorphosed greenish-gray sandstone different in appearance from Coast Ranges sandstones of different ages except when badly weathered. Also characteristic of the Franciscan group are the associated greenstone (altered basalt), chert, serpentine, sandstone, and shale, although in some areas thick sections are made up only of sandstone and shale. Dense, gray, siliceous limestones and dark blue glaucophane schists are other familiar rocks in the Franciscan group. Most people find Franciscan rocks easy to recognize.

In the Sierra foothills long, narrow belts of black slate, a metamorphosed shale, belonging to the Upper Jurassic Mariposa formation, *Jms*, are familiar to all connected with gold mining because many of the gold-bearing quartz-carbonate veins occur in them. Unfortunately there are slates of similar appearance in the Paleozoic formations of the Sierra Nevada, so that not all black slate is necessarily part of the Mariposa formation. Tightly folded with the marine Mariposa formation are green flow and fragmental volcanic rocks of the Amador group, *Jmv*. These originally were pyroxene andesites and related volcanic rocks laid down on the sea floor, but some have been so altered by the heat and pressure applied during creation of the mountain chain that they are not easily recognizable as volcanic rocks. Some have been completely recrystallized into platy schists.

The granitic rocks appearing on the bay counties map are the pre-Franciscan quartz diorite, *gd*, which includes pendants of gneiss, schist, and limestone, and the younger granodiorite, *grd*, of the Sierra Nevada.

The accompanying table (page 163) shows the formation names used by various authors in different parts of the bay area and how they have been grouped for purposes of this map.

The most conspicuous feature of the map is the complex fault pattern of the Coast Ranges portion. Many of these faults have been active in historic time; that is, there have been earth movements recorded along them with accompanying serious earthquakes. Consequently, the distribution of faults is both highly interesting and highly significant insofar as human occupation of the region is concerned. The most prominent rift system is, of course, the San Andreas, which transects the entire length of the map area. Although several segments of the San Andreas fault zone are buried beneath the ocean, most of its course over the land surface is so conspicuously marked as to be traceable by everyone. The slip which produced the memorable earthquake of 1906 had surface expression over virtually the entire length of the fault through the bay counties. Although not generally realized, the effects are quite as spectacular in the vicinity of Fort Ross as they are in the classic Tomales, Bolinas, and Crystal Springs rift valleys, or across the San Francisco peninsula north and east of Mussel Rock. These characteristics are described in detail in the text of the various road guides to be found in the last section of the guidebook. The San Andreas, therefore, is not some hidden theoretical line conjured up by geological cartographers, but is a very real, fundamental, active structural break in the earth's crust which happens to pass near one of the most heavily populated parts of the state and hence has special human as well as geologic significance.

Another persistent structural break, the Hayward fault, is along the eastern margin of the lowland surrounding San Francisco Bay, in some places outlining the hill-front and traversing hill land in others. Like the San Andreas it has been active in historic time and has produced several severe earthquakes. Surface effects of recent slips are most pronounced in hills east of El Cerrito, Albany, and Richmond and at the edge of the valley between Niles and Hayward. In the El Cerrito-Richmond area the fault is marked by a series of depressions extending from the Mira Vista golf course to El Cerrito Creek Canyon. North of Niles the line of faulting is clearly shown by a series of landslides and by offset stream courses. The clay-filled break which was created at the time of the severe Hayward earthquake of 1868 was uncovered just west of the town of Niles during excavations made in the fall of 1947.

The area lying between the San Andreas and Hayward rift zones south of San Francisco Bay is intricately sliced by a somewhat braided pattern of faults which appear to be transverse tears resulting from predominantly horizontal movements along the two major fault systems. The braided pattern would be even more pronounced if some of the fault segments were not concealed by the alluvium of Santa Clara Valley. Some of the faults of this tear-fault system probably were the avenues up which the mercury-bearing solutions travelled which gave

NAMES OF GEOLOGIC FORMATIONS OCCURRING IN THE SAN FRANCISCO BAY COUNTIES

GEOLOGIC AGE Epochs and Periods	NORTH OF SAN FRANCISCO BAY		MT. DIABLO VICINITY		BERKELEY—OAKLAND HILLS		SAN FRANCISCO PENINSULA		SANTA CRUZ REGION		MT. HAMILTON—TESLA AREA		SIERRA NEVADA FOOTHILLS		SYMBOLS ON MAP					
	Sedimentary	Igneous	Sedimentary	Igneous	Sedimentary	Igneous	Sedimentary	Igneous	Sedimentary	Igneous	Sedimentary	Igneous	Sedimentary	Igneous	Sedimentary	Igneous				
QUATERNARY	RECENT																Q			
	PLEISTOCENE																T <sub>Qs</sub>		T <sub>Qv</sub>	
	PLIO-PLEISTOCENE																			
	PLIOGENE																			
CENOZOIC TERTIARY	MIO-PLIOCENE																			
	MIOCENE																T <sub>ms</sub>		T <sub>mv</sub>	
	OLIGO-MIOCENE																			
	OLIGOCENE																			
CENOZOIC TERTIARY	EOCENE																		T <sub>e</sub>	
	PALEOCENE																			
	Position in Tertiary not determined																		T <sub>mv</sub>	
	Upper CRETACEOUS																K			
MESOZOIC	Lower CRETACEOUS																			
	Upper JURASSIC																J <sub>f</sub>		J <sub>s</sub>	
	PALEOZOIC or older																		J <sub>mv</sub>	
	OLDEST ROCKS IN AREA																		J <sub>q</sub>	

The column on the extreme left shows standard geologic age names in chronological order from youngest at the top to oldest at the bottom. The column on the extreme right shows symbols used on the geologic maps in this volume, the heavy horizontal lines showing the formations included in each map unit. Other columns show the names and approximate sequence of formations occurring in different parts of the bay area. Abbreviations used on the chart are as follows: fm. = formation; ss. = sandstone; sh. = shale; ch. = chert; ls. = limestone; gr. = gravel; cong. = conglomerate.

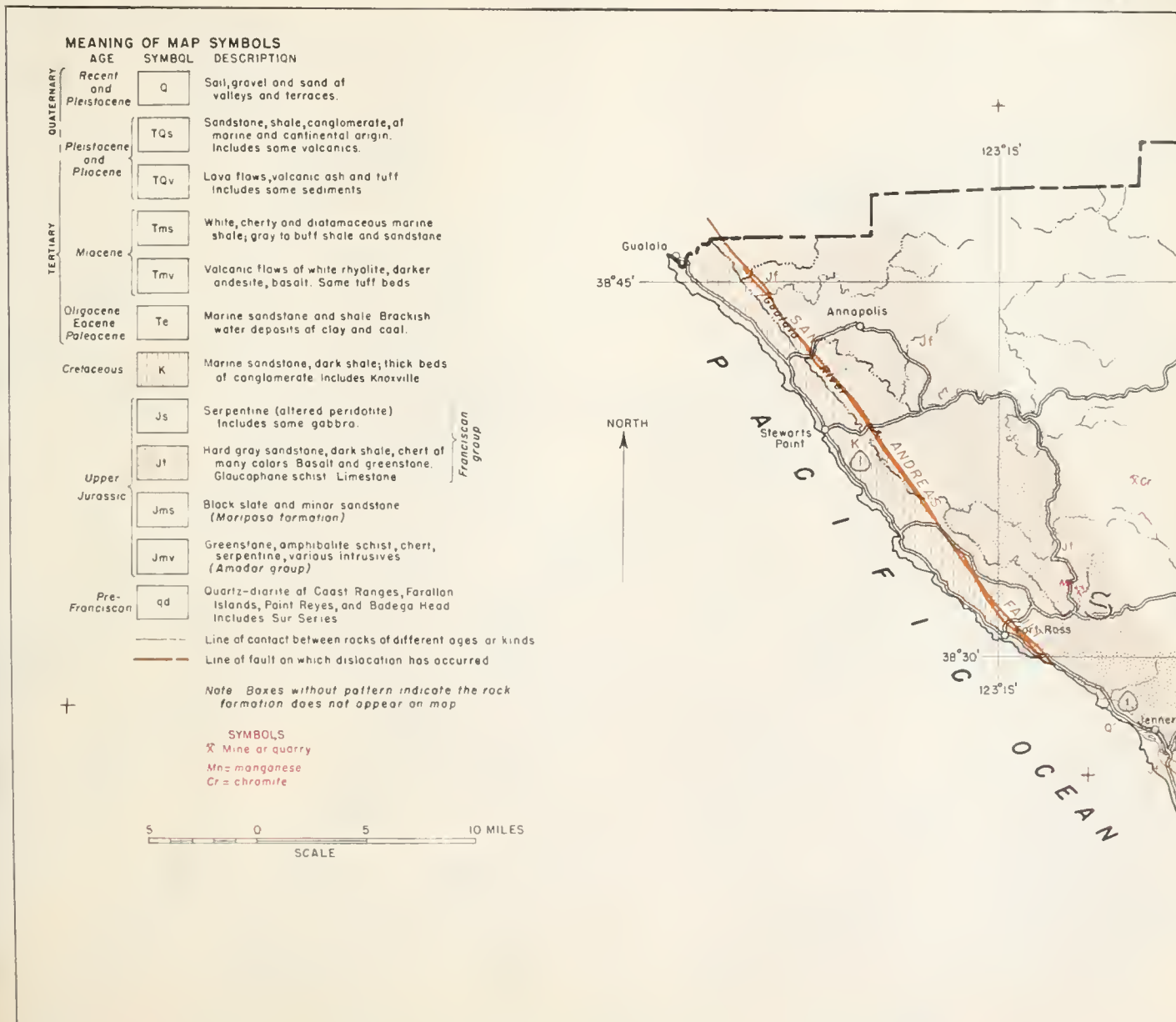


FIG. 1. Index map of the San Francisco Bay region showing county boundaries and limits of the seven sections of the geologic map.

BAY REGION GEOLOGIC MAP

SHEET I

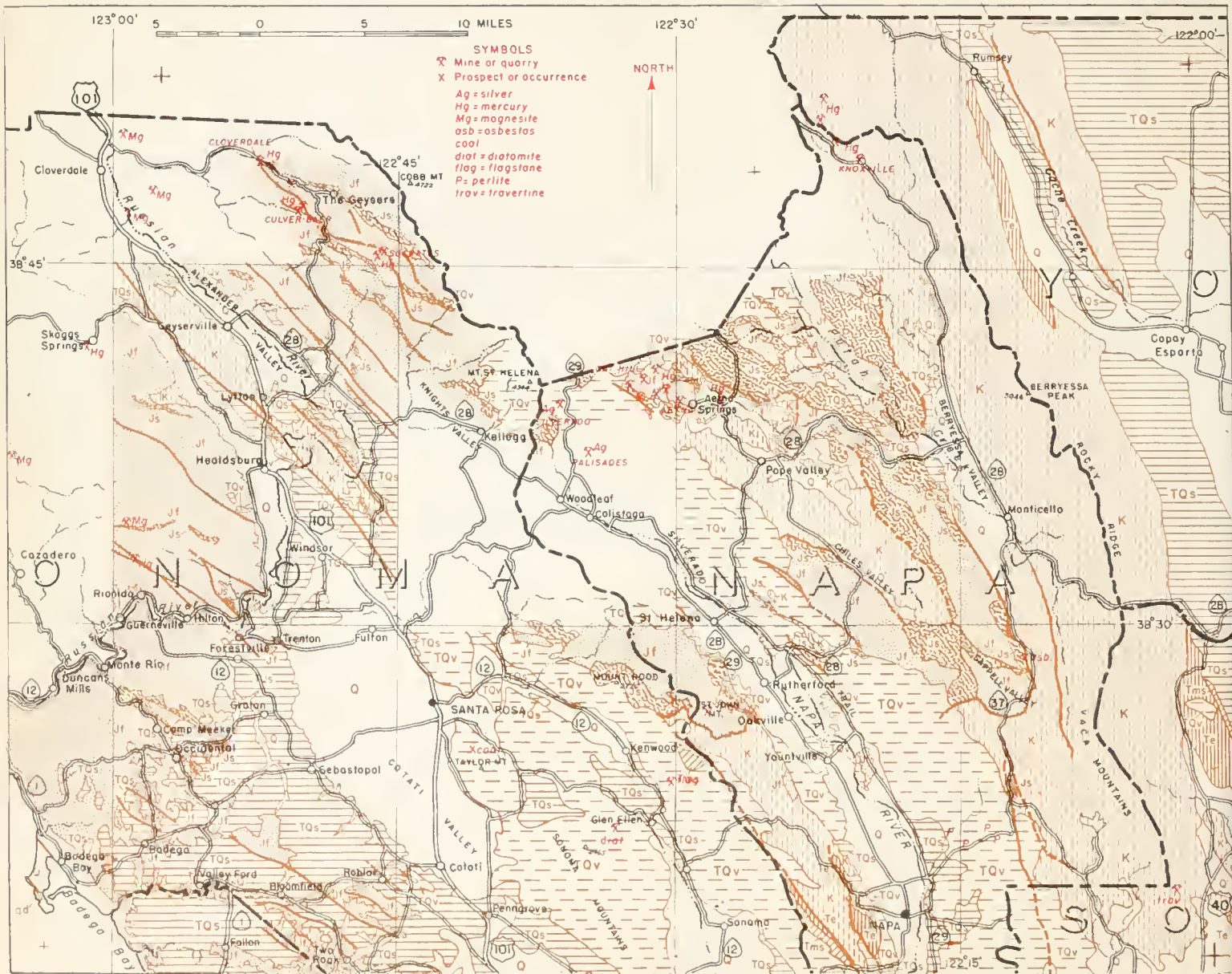
NORTHWESTERN SONOMA COUNTY



BAY REGION GEOLOGIC MAP

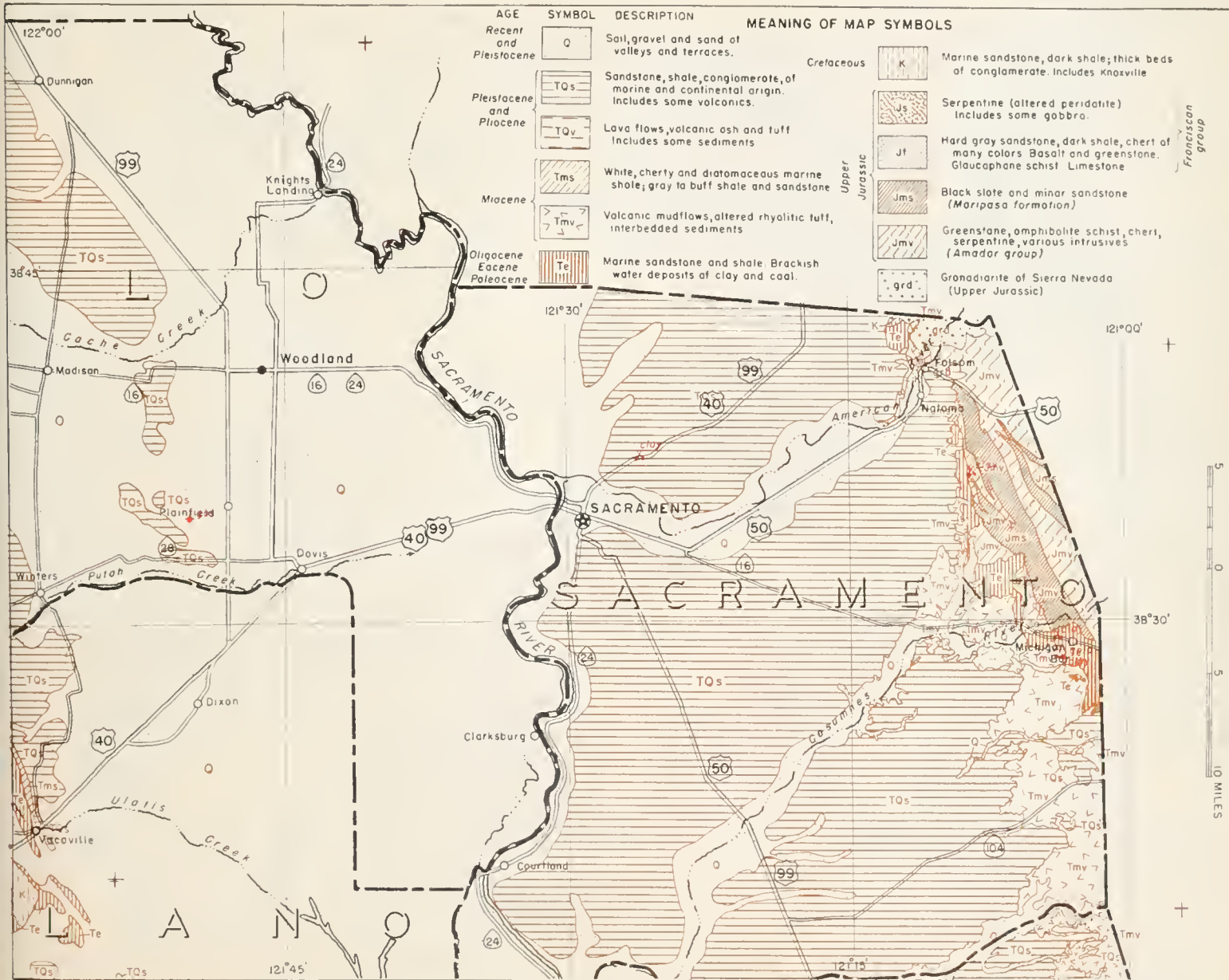
SHEET II

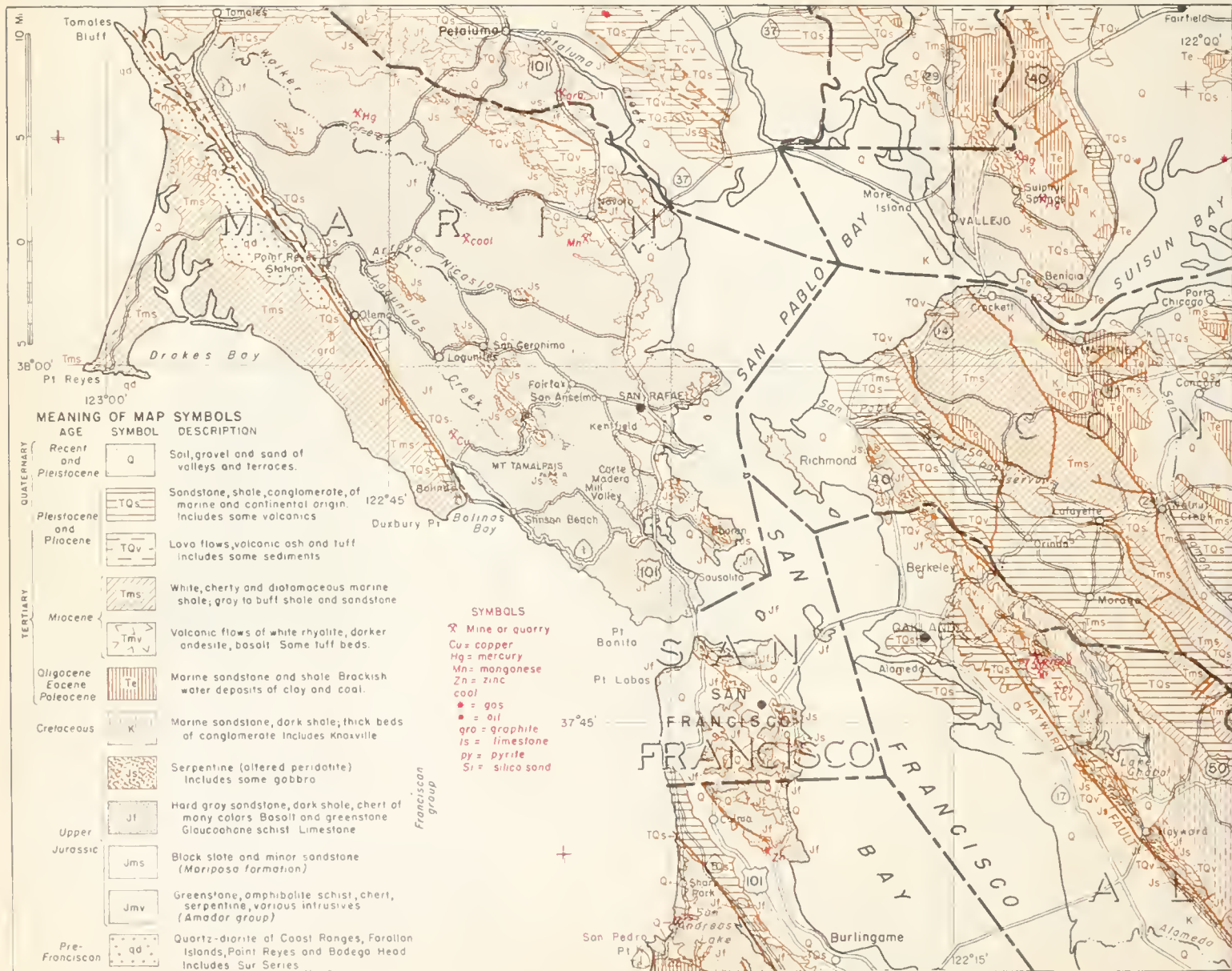
NORTH CENTRAL COUNTIES



BAY REGION GEOLOGIC MAP

SHEET III

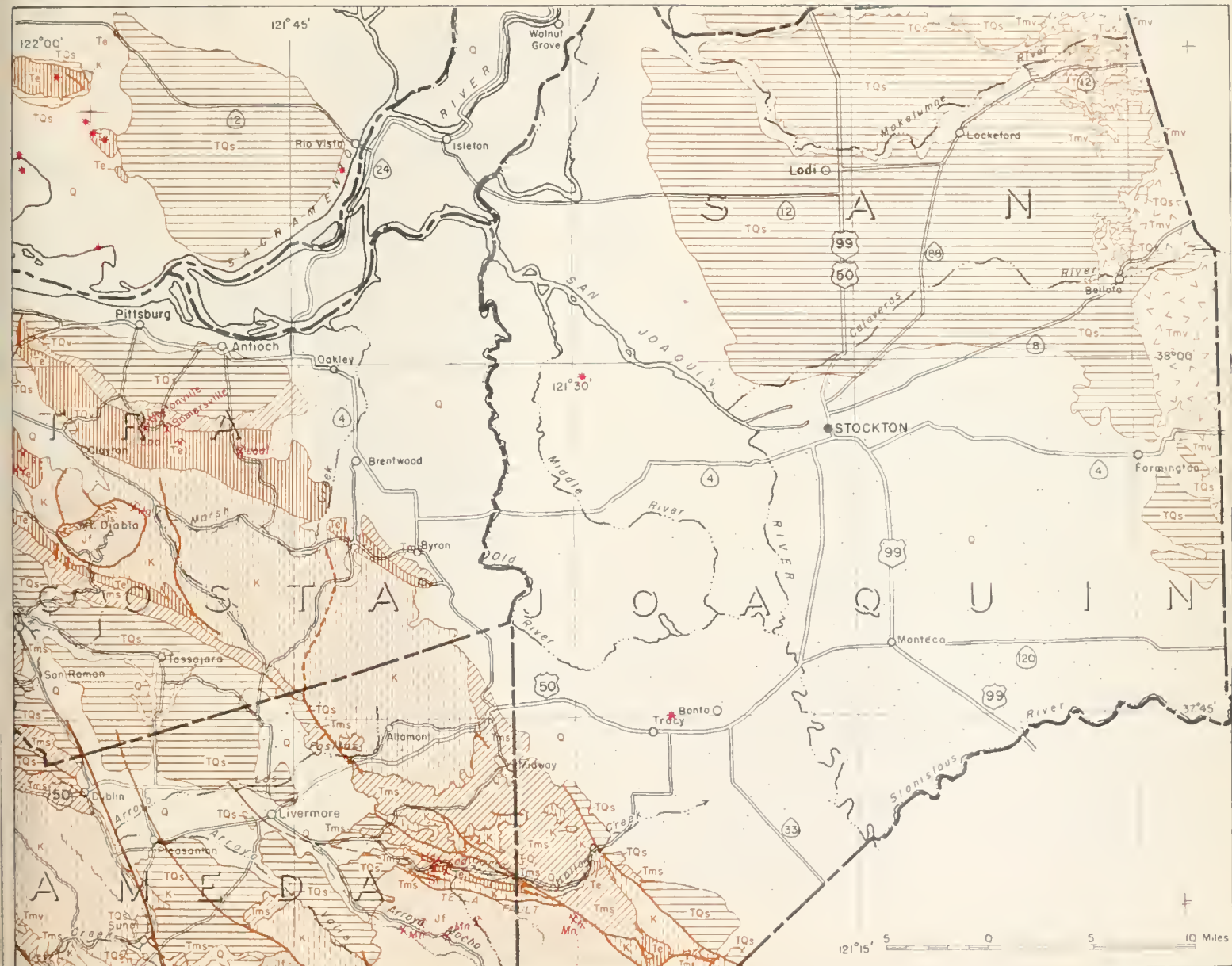




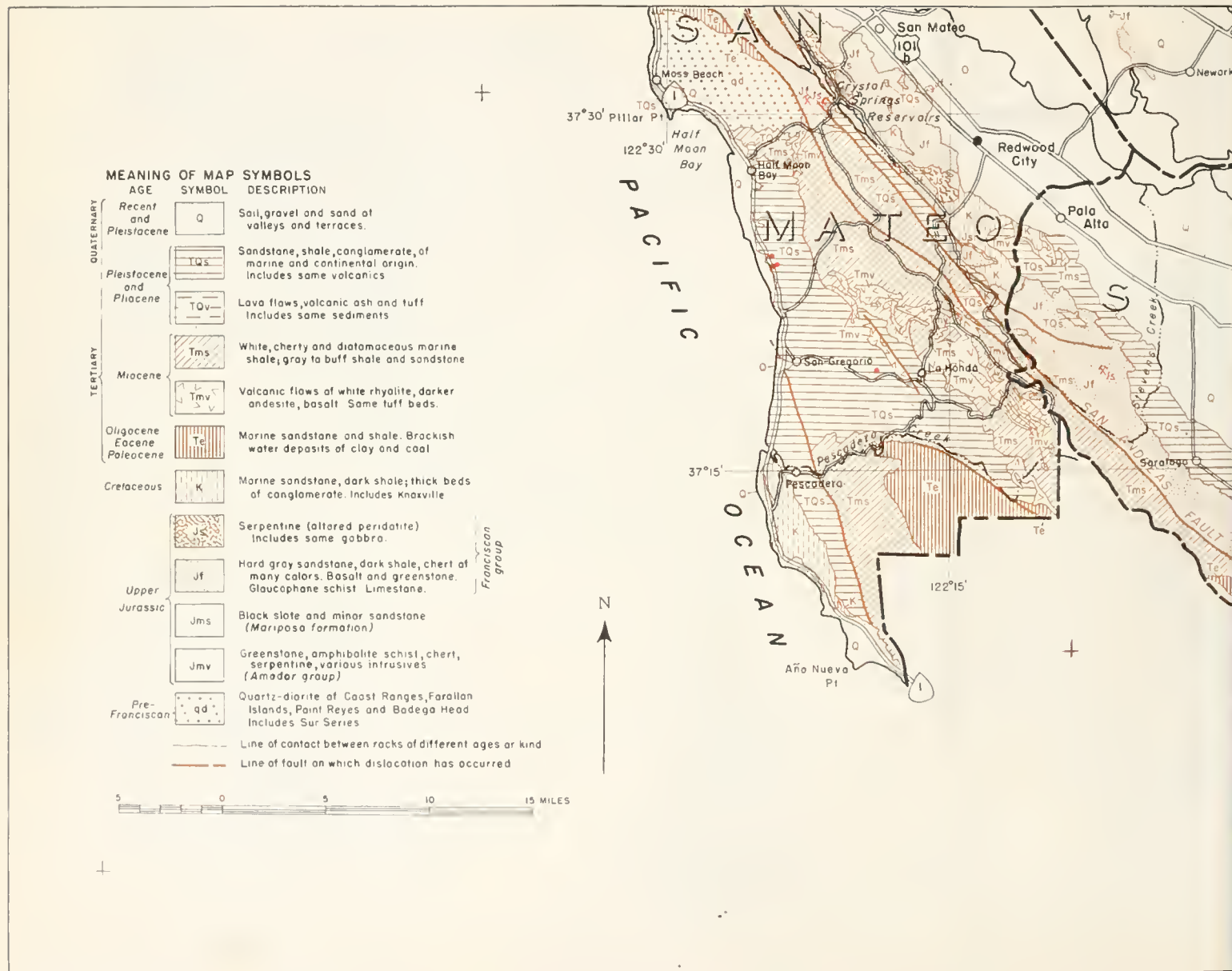
BAY REGION GEOLOGIC MAP

SHEET V

EAST CENTRAL COUNTIES







MISSISSIPPI  
1860  
L.F.

BAY REGION GEOLOGIC MAP

SHEET VII

SOUTHEASTERN COUNTIES



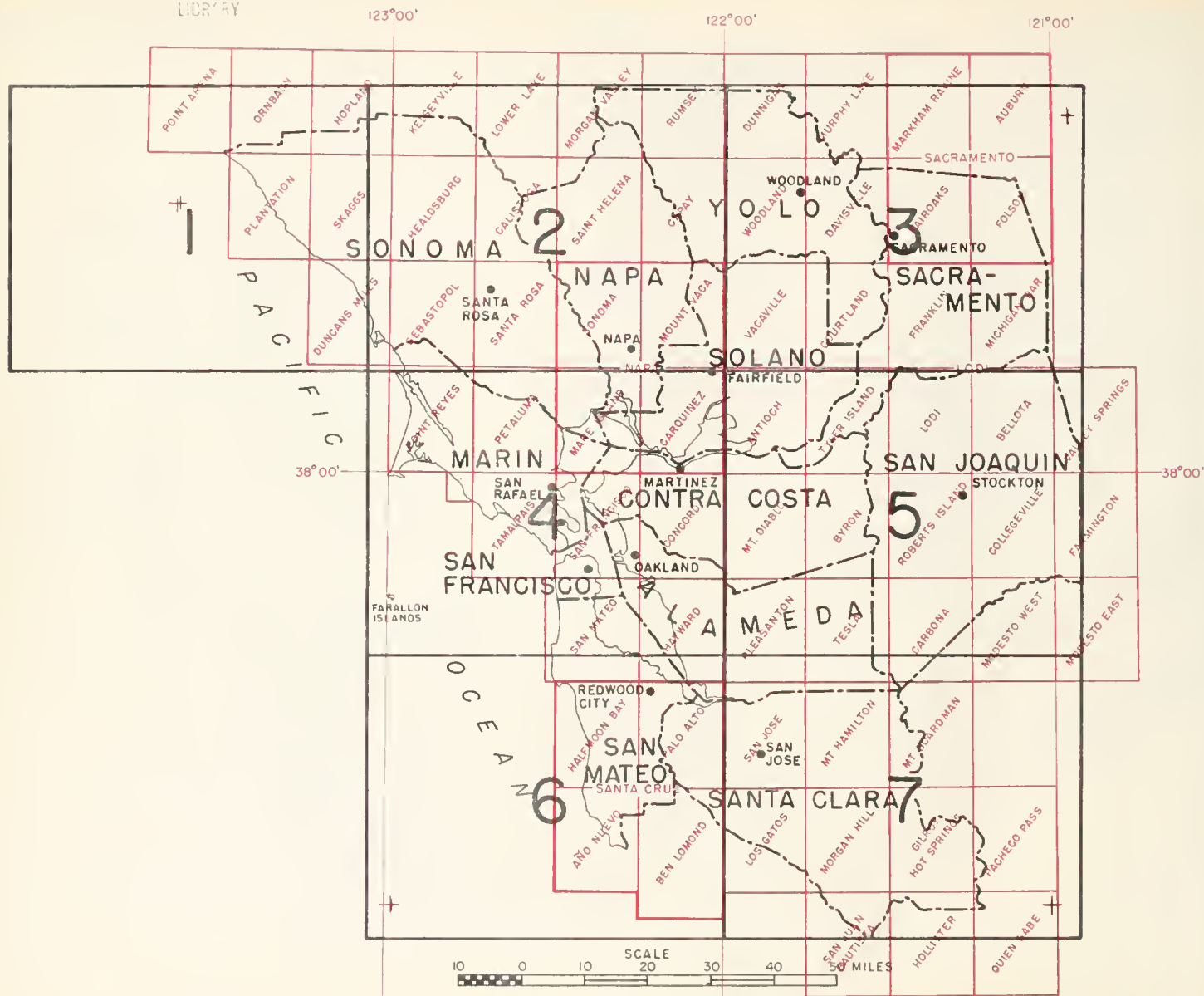


FIG. 2. Index map of the 12 counties of the San Francisco Bay region showing topographic maps available on a scale of 1:62500 and 1:125000, and limits of the sections of the bay region geologic map.

PHYSICAL  
SCIENCE  
LIBRARY

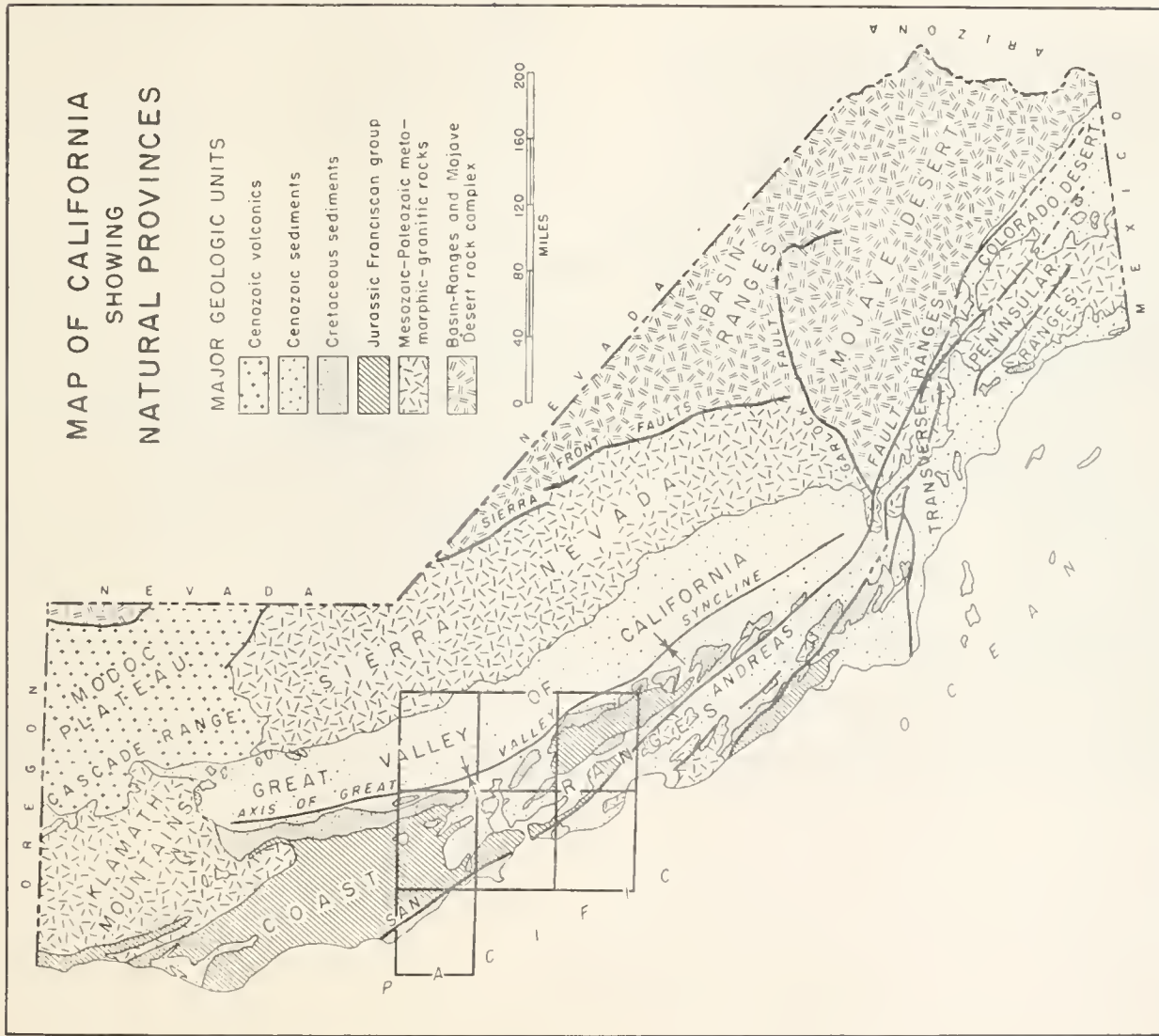


Fig. 3. The heavy black lines show the principal faults of the state and the axis of the structure trough of the Great Valley. Distribution of the major rock groups is shown in pattern and the seven rectangles show the position of the seven parts of the geologic map found in this bulletin. The Basin-Ranges and Mojave Desert complex is made up of intricately distributed rocks of many kinds and ages not readily separable on a map of this scale.

rise to the rich New Almaden deposits. The major development of this system has taken place during post-Miocene time and in many cases is still going on.

A third major zone of weakness traverses the central bay area beginning east of Port Costa on Carquinez Strait and passing off the map area a few miles east of Gilroy in Santa Clara County. The line cannot be followed continuously along its entire length owing to concealment by soil, alluvium, plant growth, etc., but the distribution of known segments leaves little doubt that the break is a major feature continuous for more than 100 miles. Various segments of the fault have been named the Sunol, Calaveras, and Franklin faults, names applied by various authors before continuity of the system was realized. Movements along the system have been predominantly of thrust type with rocks of the east side sliding over those of the west at a high angle. The general fault picture in the bay region is typical of the entire central and southern Coast Ranges, and gives some idea of the magnitude of the forces which have been and still are working in coastal California.

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## PART IV

### PREHISTORIC LIFE

**Editorial Note:**

PART FOUR exhibits to the reader a picture of the life that existed in the different geologic periods recorded by the rocks in the San Francisco Bay area. To the geologist, the fossil animals and plants which are found embedded in the sediments give proof of the age of the rock formations; to the biologist these fossils fit into the evolutionary history of life; to the layman a picture of the surface of the earth during early geologic periods can more easily be envisioned when its existing animal and plant life are restored. Therefore, the land animals, the prehistoric forests, and the marine life are described in PART FOUR as they are known to have existed in the early periods recorded in the rocks of the area.

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## PREHISTORIC LAND ANIMALS OF THE SAN FRANCISCO BAY REGION

By R. A. STIRTON \*

Citizens in the San Francisco Bay counties become actively concerned when a mountain lion is reported prowling in the hills, sometimes close to their backyards. The sheriff and his deputies are called to trail down and kill the intruder. Most of these average American folks know very little of the activities and heritage of the wild animals about them. Actually the lion may be doing far more good than harm in the welfare of man. It so happens that deer is the natural food of mountain lions, and the cougar's presence in the secluded spots among the hills and ravines is only a natural trend in wild animal populations to maintain a balance in the numbers of any given species in a given area. A balance in numbers among animals under natural conditions must be established in any biotic association, if all the kinds living there are to survive. Millions of years before man appeared on the scene to exercise his influence, animals controlled their numbers through natural processes. Civilized man, however has disturbed this balance in many ways. One example is his protection of deer and his untiring persecution of the big cats. Innocent though deer may look they are at times one of the most destructive crop and garden pests.

*Early Pliocene (Clarendonian).* The oldest known fossils of land animals in the bay area occur as scattered fragments in the lowermost rocks of Clarendonian age. These make up the Orinda fauna, deposited approximately 12,500,000 years ago. There are horse teeth, the tusk of a young mastodont, camel limb and foot bones, and part of the lower jaw of an oreodont. Specimens of this inadequately known fauna have been located in the Berkeley Hills, in the neighborhood of Lafayette, south of Saint Mary's College, in the foothills south of Mount Diablo, in hills at the edge of the San Joaquin Valley west of Tracy, and along the Stanislaus drainage in the Sierran foothills. There evidently were hills west of the area now occupied by the present Berkeley Hills, but their exact boundaries cannot be accurately determined. These hills supplied sediments to the Contra Costa basin where remains of some of the animal and plant life were buried. Mount Diablo and at least part of the Hamilton Range showed in their incipiency, but evidently as very low hills. Arms of an inland sea which had dominated this area in Miocene time still remained, but before the close of Clarendonian time the marine waters retreated, never again to flood this area in central California.

A more complete picture of the life of Clarendonian time in the ancient Contra Costa basin is obtained from the famous Black Hawk Ranch fossil quarry on the south side of Mount Diablo. The borders of

the basin in which the bones, teeth, wood, and leaves were buried have not been determined; but the basin extended from what is now Contra Costa County south across Alameda County to San Joaquin and Stanislaus Counties (perhaps partly interrupted by higher ground in the Altamont area), thence east across the San Joaquin Valley to the Sierras. The Sierra Nevada was a relatively low mountain chain at that time. The bay area was a low alluvial plain with numerous shallow lakes fed by meandering streams from the adjacent highlands. There must have been wide stretches of grassland dotted here and there with clumps of brush or groves of trees. Willows, sycamores, poplars, and elms outlined the stream courses, and willows extended out into the marshy flats with the heavier grasses and reeds. On higher ground and in the low hills was the woodland—chaparral association with its oaks, sumac, mountain mahogany and probably many other plants not yet found as fossils. The landscape varied but there was not the diversity over the same region that there is today.

Rabbits (*Hypolagus*) about the size of cottontail must have ventured out from sheltered brush patches during the cool of the day, but always ready to scurry to cover if the ever-watchful fox (*Vulpes vaser* (Leidy)) were to make his appearance. A primitive ground squirrel referable to the living genus (*Citellus*) was also present but probably inhabited the drier and higher ground away from the stream. He too had numerous enemies to keep his numbers reduced. These included a small gray fox (?*Urocyon*), a ring-tailed cat (*Bassariscus parvus* Hall) and a large mustelid probably with habits much like the wolverine.

Part of the jaw of a lizard was uncovered in the Black Hawk Ranch quarry. Two lower premolars of a racoon-like animal probably most closely related to the coati (*Nasua*) of Central and South America were an unexpected discovery. The ancestry of the coati is not known; and more evidence concerning the animal that roamed the woodlands of the San Francisco Bay region in the geologic past is being eagerly sought. The remains of these small animals are rare in the quarry; but the racoon-like creatures probably existed in limited numbers, and when individuals died the bones and teeth probably rarely were buried to become preserved as fossils.

Elephant-like creatures known as mastodonts (?*Gomphotherium simpsoni* (Stirton)) once occupied the bay country, ambling about in herds much like modern elephants. They differed from the elephant in that the head was flatter and the trunk possibly shorter; they had two pairs of tusks, and heavy, blunt, cusped molars; molars 6 inches long have been found. Unless trapped in a mud hole these four-tuskers

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FIG. 1. A landscape in late Clarendonian time. The area between Tracy and Knight's Ferry was a low alluvial plain with numerous shallow lakes fed by meandering streams. The mammalian population occupying the grassland and stream borders was varied. Mastodons (*Gomphotherium*), horses (*Hipparion*), camels (*Procamelus*), and small antilocaprids (*Merycodus*) were daily visitors to the streams and lakes as the water supply diminished in the late summer.



FIG. 2. The small hyaenoid dog *Ostcoborus*. The fossil remains of these small hyaenoid dogs were found abundantly in the Black Hawk Ranch quarry. This rather primitive species evidently was widely distributed in western North America in Clarendonian time. These animals have not been found in the Great Plains faunas, though later Pliocene representatives of the genus were common there. These dogs had heavy teeth and massive jaws, and probably had habits much like those of the Old World hyaenas.

CLARENDONIAN			HEMPHILLIAN				
ORINDA	BLACK HAWK RANCH AND SIESTA		MULHOLLAND		PINOLE		
		LACERTILIA <i>Crus conferta</i> Miller and Sibley	lizards crane	PHOENICOPTERIDAE	flamingos		
		<i>Hypologus Citellus</i>	rabbit ground squirrel	?VESPERTILIONIDAE <i>Hypologus</i>	bats rabbit	LEPORIDAE	rabbits
		<i>Eucastor lecontei</i> (Merriam)	beaver	?Cupidiniinus <i>Dipoides</i>	pocket mouse beaver		
				<i>Peromyscus</i>	deer mouse		
				<i>Pliotomodon primitivus</i> Hoffmeister			
				MEGALONYCHIDAE	ground sloths	MEGALONYCHIDAE	ground sloths
		<i>Vulpes rasfer</i> (Leidy)	fox	CANIDAE	dogs, wolves, foxes		
		<i>Aelurodon cf. aphbus</i>	large hyaenoid dog				
		<i>Osteoborus diabloensis</i> Richey	small hyaenoid dog			? <i>Osteoborus</i>	small hyaenoid dog
		PROCYONINAE	coati-like animals				
		<i>Bassariscus parvus</i> Hall	wolverine-like animals			<i>Cernictus hesperus</i> Hall	mustelid
		MUSTELIDAE	large cat				
		<i>Pseudaelurus thinabate</i> Macdonald					
GOMPHOTHERIIDAE	mastodonta	MACHAIRODONTIDAE ?Gomphotherium simpsoni (Stirton)	sabre-tooth cats mastodont	?GOMPHOTHERIDAE	mastodont tracks		
<i>Nannippus tchonensis</i> (Merriam)	horse	<i>Hipparion forcei</i> Richey	horse	? <i>Nannippus</i>	horse		
<i>Hipparion</i>	horse	<i>Hipparion</i>	horse			<i>Neohipparion</i>	horse
<i>Pliohippus</i>	horse	<i>Pliohippus cf. leardi</i>	horse	<i>Pliohippus cf. spectans</i>	horse	<i>Pliohippus coalingensis</i> Merriam	horse
MERYCOIDODONTIDAE CAMELIDAE	oreodonts camels	<i>Prosthennops</i> ? <i>Ustatochoerus</i> <i>Procamelus</i> <i>Pliauchenia</i> <i>Paracamelus</i> ? <i>Pediomeryx ruminalis</i> Stirton	peccary oreodont camel camel camel ruminant	RHINOCEROTIDAE ?TAYASSUIDAE ?MERYCOIDODONTIDAE CAMELIDAE <i>Pliauchenia</i>	rhinoceroses peccaries oreodonts camels camel	CAMELIDAE	camels
		<i>Merycodus</i>	antilocaprid	ANTILOCAPRIDAE	antilocaprids	? <i>Sphenophalos</i>	antilocaprid
						<i>Teleoceras cf. fossiger</i>	rhinoceros

\* Identifications in the faunal lists are referable to suborder, family, subfamily, genus, or species. For example, sabre-tooth cat remains MACHAIRODONTIDAE can

in the San Francisco Bay Region \*

BLANCAN		IRVINGTONIAN		RANCHOLABREAN			
PETALUMA		PITTSBURG AND WILLOW PASS		IRVINGTON		LONE TREE, LIVERMORE VALLEY, ETC.	
		TESTUDINIDAE	giant tortoises	EMYDIDAE	turtles		
				<i>Branta canadensis</i> (Linnaeus)	goose	<i>Uria aalge</i> Brisson	murre
LEPORIDAE	rabbits			<i>Citellus</i>	ground squirrel		
				<i>Thomomys</i>	pocket gopher		
				<i>Perognathus</i>	pocket mouse		
				<i>Peromyscus irvingtonensis</i> Savage	deer mouse		
				<i>Neotoma</i>	packrat		
				<i>Microtus</i>	meadow vole	<i>Microtus</i>	meadow vole
				<i>Megalonyx</i>	ground sloth	<i>Megalonyx</i>	ground sloth
						<i>Nothrotherium</i>	ground sloth
						<i>Paramylodon harlani</i> (Owen)	ground sloth
		<i>Borophagus pachyodon</i> (Merriam)	hyaenoid dog	<i>Canis irvingtonensis</i> Savage	coyote		
				<i>Canis cf. dirus</i>	dire wolf	<i>Canis dirus</i> Leidy	dire wolf
				<i>Dinobastis</i>	sabre-tooth cat	<i>Smilodon</i>	sabre-tooth cat
				<i>Mammuthus columbi</i> (Falconer)	mammoth	<i>Mammuthus columbi</i> (Falconer)	mammoth
<i>Neohippotion gidleyi</i> (Merriam)	horse	<i>Equus cf. simplicidens</i>	horse	<i>Equus</i>		<i>Equus</i>	
				TAYASSUIDAE	peccaries	<i>Tapirus cf. haysii</i>	tapir
CAMELIDAE	camels			<i>Camelops minidokae</i> Hay	camel	<i>Camelops hesternus</i>	camel
				<i>Tanupolama</i>	camel		
				<i>Odocoileus</i>	deer	<i>Odocoileus</i>	deer
				<i>Tetrameryx irvingtonensis</i> Stirton		<i>Breameryx cf. minor</i>	antilocaprid
				<i>Eucerotherium</i>	like a musk ox	? <i>Antilocapra</i>	antilocaprid
						<i>Bison cf. antiquus</i>	bison
						<i>Bison latifrons</i> (Harlan)	giant bison

be recognized in the Black Hawk Ranch assemblage, but the specimens have no distinguishable generic characteristics.

	NORTH AMERICA	SAN FRANCISCO BAY COUNTIES	EUROPE
PLEISTOCENE		Lone Tree Pt, Livermore Valley, etc Irvington	Eringsdorf Tegelen
PLIOCENE	BLANCAN	Pittsburg & Willow Pass	VILLAFRANCHIAN { CALABRIAN ASTIAN PLAISANCIAN
	HEMPHILLIAN	Petaluma Pinole Mulholland	PONTIAN
	CLARENDONIAN	Black Hawk Ranch & Siesta Orinda	SARMATIAN
			?

FIG. 3. Correlation chart showing the relative positions of the San Francisco Bay counties vertebrate faunas in relation to the North American provincial stages of geologic time. Faunal names are in lower case print. Hatched spaces indicate gaps in the faunal sequences.

were probably not disturbed by the large carnivores. Many of them must have gotten stuck in quagmires along the old stream courses, much as cows and horses bog down today. Such death traps are common along streams, and this seems to be the most likely manner in which so many of these huge pachyderms met their death. Once they sank in to their knees they never could extricate themselves, and within a few days would die of starvation and fatigue. Some of their bones remained in the mud, but others got into stream channels and in times of heavy rainfall washed down-stream where they sank into deeper holes or lodged and were buried with remains of other animals and plants. Craniums, lower jaws, isolated molars, and the different bones of the body skeleton are common in the Black Hawk Ranch quarry. Never has a party dug there for 3 or 4 hours without finding some part of a mastodont.

Horses, the vertebrate paleontologists' key to the ages of the Cenozoic formations, occur abundantly in the quarry, particularly a three-toed one known as *Hipparion forcki* Richey. They must have ranged over the brushy grassland in large herds where they were associated with herds of camels and small antilocaprids related to the present-day pronghorn antelopes. *Hipparion forcki* was heavier but

not taller than the mule deer of the Sierras. On each side of his foot were side toes, small hoofs much like the dew claws of the cow and the pig. A few remains of a slightly larger horse, *Pliohippus cf. leardi*, also are found. This creature was much more like the modern horse; it had lost the side toes.

At least three kinds of camels inhabited the bay area during the early Pliocene. One (*Paracamelus*), was much larger and taller than the camels living today in Asia and Africa. The others were smaller and fewer specimens of them are known.

The little hornless antilocaprid *Merycodus* was not as tall as a sheep and was very delicately constructed, yet must have been as graceful and as fast as a greyhound. Evidence in the quarry indicates that *Merycodus* was as abundant in this area 12,000,000 years ago, as were their descendants the pronghorns of our Great Plains at the middle of the nineteenth century. Obviously the merycodonts came in droves to the water holes; the collections are replete with jaws, teeth, and bones of these little ruminants.

The peccaries, *Prosthennops*, probably restricted their activities to heavily wooded areas near streams where they fed on acorns and other fruits much like their living relatives in the tropical Americas.

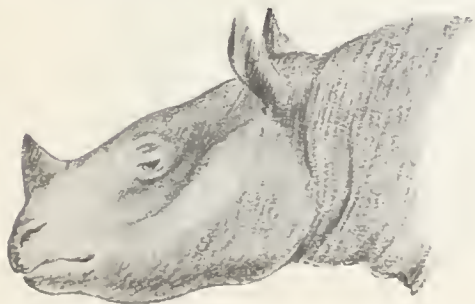
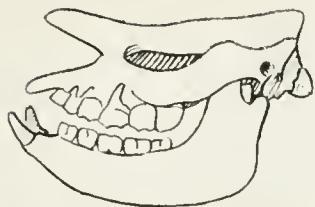


FIG. 4. A rhinoceros from the Pinole tuff. In 1933 a rhinoceros (*Teleoceras*) cranium was discovered in the Pinole tuff near Rodeo, and was removed from the excavation just before the incoming tide of San Pablo Bay swept into the site.

It is not a simple matter for a pair of carnivores to move in on a herd of peccaries and effect a kill. The oreodont, *?Ustatochoerus* was another animal that probably inhabited the stream border association. Fragments found in the Black Hawk quarry represent one of the last stands of a family abundantly represented in the Oligocene and early Miocene faunas.

There were large felines, *Pseudaelurus thinobates* Macdonald, lurking in the brush near the water hole ready to pounce upon the unsuspecting herbivores. These big cats, related to and much like the mountain lion, probably levied primarily on the horses and camels, springing on the shoulders of their prey, and crushing the neck vertebrae with their powerful jaws. Some species of these Pliocene cats were longer limbed than the cougar and were better able to capture a horse or a camel in the open. There is some evidence of sabre-tooth cats in the Black Hawk faunas but the few teeth are too heavily worn for accurate identification.

The marshland around the lakes, with its reeds and tall grass, was thickly populated with a small beaver, *Eucastor lecontei* (Merriam). These rodents were the size of a muskrat, and possibly had habits much like the muskrat. At times they died in large numbers for their teeth and jaws are abundant in the Black Hawk Ranch faunas. Insofar as can be determined, the same species ranged through California during the early Pliocene. Additional evidence for marshland in the bay area is the presence of a crane, *Grus conferta* Miller and Sibley, in the collection. Unfortunately the other bird bones in the fauna were too fragmentary for identification.

Perhaps the most peculiar animals in the Black Hawk Ranch fauna are the hyaenoid-dogs. These carnivores are obviously related to true dogs, but they were adapted much like the modern hyaenas as scavengers. A study of their skeletons indicates a rather slow-running type with heavy teeth and jaws modified for bone crushing. There are two kinds in the Black Hawk deposits—*Aelurodon* cf. *aphobus*, the larger and rarer one, and *Osteoborus diabloensis* Riekey, the smaller and common species. In some respects these carrion eaters probably behaved like the condor and the vulture of today. The *Osteoborus*, possibly owing to their great numbers and smaller size, were more likely to find dead animals; but when *Aelurodon* appeared on the scene the smaller dogs retreated a respectful distance until the king had his fill.

*Middle Pliocene (Hemphillian).* The filling of the Contra Costa basin, probably accompanied by additional local orogenies, continued during Hemphillian time. The sediments are predominantly fine sands and sandy clays, though some conglomerate members are conspicuous ridge markers. There is some suggestion that these gravels, though composed of rocks from the Franciscan (Jurassic) formation, have



FIG. 5. The giant bison and sabre-toothed cats. Caught in a quagmire, the giant bison struggles to extricate himself as his antagonists pounce upon him. At times the cats were injured and trampled into the mud where they became buried with the bones of the bison.



FIG. 6. The Hayward Boy Paleontologists hunting the antilocaprid *Tetrameryx*. Fossil mammal remains were first found in the Irvington gravel pits in 1936. Since that time the Hayward Boy Paleontologists have been persistent in their search for more and better specimens. *Tetrameryx irvingtonensis* Stirton has been one of their most treasured finds. Photo courtesy Time, Inc.

been secondarily deposited from Cenozoic formations. Two gravel members have yielded fragments of *Desmostylus* teeth—an aberrant sirenian normally occurring in the marine Briones (Miocene) formation.

The only early Hemphillian fauna discovered in the San Francisco Bay counties is the Mulholland fauna near Saint Mary's College. Though the known species, and in some examples the genera, differ markedly from those at Black Hawk Ranch, the fauna is nevertheless representative of a continuation of the North American middle Cenozoic faunas. There are two outstanding animals of wide distributional significance. One is a ground sloth whose ancestors found their way through from South America; unfortunately only some limb and foot bones of this animal have been collected. The other is a bear-dog, *Indarctos*, of which a pelvis has been found. *Indarctos* is common in the faunas of Eurasia, but its ancestry is not clearly understood; it may have originated either in the North American continent or in Eurasia.

At the Mulholland quarry jaws and teeth of some small rodents were also found. Such tiny fossils often are overlooked by the collector in his anxiety to secure the large and more spectacular specimens. The Mulholland quarry produced teeth and parts of jaws of a packrat-like animal (*Pliotomodon primitivus* Hoffmeister), deer mice (*Peromyscus*), part of the jaw of a pocket-mouse (?*Cupidinius*), a tooth of a small beaver (*Dipoides*), and even parts of a bat.

Bones of large and small camels are common. Parts of a maxillary and parts of a lower jaw belong to the small *Plianchenia*. Two kinds of horses are represented, a small one, ?*Nannippus*, and a larger one *Pliohippus* cf. *spectans*. The *Pliohippus* is closely related to the type species from the Rattlesnake formation in Oregon. There is one foot-bone of a rhinoceros. The antilocaprids are known from a few isolated teeth and a cannon-bone. The genus cannot be recognized, but it is clearly more advanced than the Black Hawk Ranch *Merycodus*.

Fossil bones and teeth of the mastodonts have been discovered, and on the steep bank near Saint Mary's College their tracks have been



exposed on the ripple-marked bottom of a shallow lake. Recently a Boy Scout in Lafayette found the tarsometatarsus of a flamingo in a road cut. Carnivore remains are rare. Only the limb bones of a small dog have been uncovered. Though the Mulholland fauna is not as representative as the one from the Black Hawk Ranch it fills an important gap in the knowledge of the Pliocene sequence in the San Francisco Bay region.

A more recent Hemphillian mammalian assemblage has been found in the Pinole tuff near Rodeo on the south side of San Pablo Bay. A lower jaw and numerous isolated horse teeth from this formation have been referred to *Pliohippus coalingensis* Merriam. Next in abundance are the teeth of a pronghorn evidently closely related to the genus *Sphenophalos*. In 1933 a rhinoceros (*Telcoecras*) was uncovered and taken out just before the incoming tide swept into the excavation site. Very little is known of the other mammals—a lower jaw of a distant relative of the marten, an upper carnassial of a hyaenoid-dog probably referable to the genus *Ostocoborus*, a molar of a ground sloth, two rabbit teeth, the end of a limb bone and tooth fragments from a camel—have been found. The Oakdale, Jacalitos, Etchegoin, and Mount Eden assemblages in California are closely related to the Pinole assemblage, indicating a distribution of these animals throughout the state in middle Pliocene time.

Four whole teeth and part of a fifth tooth of the Petaluma horse *Neohipparion gidleyi* Merriam were taken from the upper part of the formation above the Tolay volcanics. *Neohipparion gidleyi* was more advanced than *Neohipparion molle* Merriam from the Oakdale and Jacalitos assemblages, and was taller and a much better runner than the horses on the ancient Black Hawk grasslands.

*Late Pliocene (Blanean)*. The Blanean, though sparsely represented in the San Francisco Bay counties, is of unusual interest because at that time many of the Pleistocene and Recent mammalian genera appeared for the first time. Elk, deer, bear, modern dogs, and true beavers spread into North America from Asia. Typical Hemphil-

lian genera like *Pliohippus* and *Ostocoborus* gave rise to *Equus* (with zebra-like characteristics) and to *Borophagus*, one of the largest hyaenoid-dogs. Both of these genera and a giant tortoise have been found in a conglomerate formation near Pittsburg and Willow Pass north of Mount Diablo. Faunas of this age evidently were contemporary with the inception of the first major glacial advances in the northern hemisphere. At this time the Contra Costa basin was well filled with sediments; no beds of undoubted Blanean age have been found in the bay counties south of Mount Diablo or in the Berkeley Hills region, though some remnants should be discovered eventually.

*Early Pleistocene (Irvingtonian)*. During the past 12 years an excellent collection of fossil mammalian remains has been taken from the Irvington gravel pits. The fauna is almost as well represented now as the Black Hawk Ranch assemblage. It is the best early Pleistocene fauna from the Pacific coast and Rocky Mountain states.

The early Pleistocene marks the first appearance of the mammoth from the Old World. Among the artiodactyls there are remains of deer, elk, a form like a musk oxen, camels, and a very peculiar antilocaprid (*Tetrameryx*). True horses, *Equus*, are common. There are many small rodents including gophers, mice, and squirrels. A Canadian goose is also present. The carnivores are common—sabre-tooth cats (*Dinobastis*), the dire wolf, and a primitive coyote.

*Late Pleistocene (Rancholabrean)*. The late Pleistocene faunas are marked by the first appearance of *Bison*, which also came to North America from Asia. The remainder of the fauna varies somewhat from the Irvington particularly in the absence of *Tetrameryx irvingtonensis* Stirton. Perhaps some other difference will be noticed when the species are better understood. Fossils of late Pleistocene age are likely to be encountered almost anywhere. Some of the best material has come from Lone Tree Point near Rodeo, near Mussel Rock southwest of San Francisco, and in Livermore Valley; mammoth teeth and part of a bison jaw have been dredged out of San Francisco Bay.

## INVERTEBRATE FOSSILS AND FOSSIL LOCALITIES IN THE SAN FRANCISCO BAY AREA

BY LEO GEORGE HERTLEIN \*

Invertebrate animals live today in various environments in San Francisco Bay and along the coast adjacent to the open ocean. The habitat of these creatures varies from pure sea-water to brackish water and from a sandy or muddy bottom to a rocky coast. The rivers and lakes are populated by a different group of organisms which cannot tolerate salt water. Evidence that similar animals lived in similar environments millions of years ago is presented by their fossilized remains, found in the rocks today.

Changes in the distribution of land and water in the San Francisco Bay area resulting from past geologic events furnished suitable habitat for a vast assemblage of invertebrate animals. Evidence of these past conditions is revealed by the presence of fossils at many localities. The most abundant fossils in this area are those of mollusks (clams, snails, cephalopods) and echinoids (sand dollars and sea urchins). Most of these lived in comparatively warm and shallow water.

The oldest fossils in the bay area are siliceous skeletons of microscopic forms known as radiolaria, which occur in strongly folded and contorted siliceous marine deposits composed of remarkably evenly and rhythmically bedded red and green cherts, jaspers, and shales. Rocks containing these microscopic organisms can be seen at many localities, one of the best of which is Stow Lake and the adjacent hill surmounted by Prayer Book Cross in Golden Gate Park, San Francisco.

These radiolaria presumably belong to the Jurassic period (Mesozoic era) whose age is estimated to be over 100 million years. Some other animals known to have existed in the Jurassic in other parts of the world include reptiles, many different forms of ammonites, snails, clams, corals, and the first known birds.

The Jurassic period was followed by the Cretaceous period, during which dinosaurs were abundant in some parts of the world; however, they are rare in deposits along the Pacific coast. The warm waters of the Cretaceous teemed with ammonites (relatives of the pearly nautilus and octopus), clams, and snails. An extinct member of the pearl oyster family (*Inoceramus*), whose shell is composed of prismatic layers, occurs at many localities in some portions of the state.

A fossil pearl oyster (*Pteria gregoryi*) has been found in beds of middle Cretaceous age  $1\frac{1}{2}$  miles S.  $10^\circ$  W. of the old settlement of Carnegie, San Joaquin County. About three-quarters of a mile south of the old settlement, from beds presumably of about the same age, a

species of ammonite (*Sonneratia rogersi*) has been described. Upper Cretaceous fossils, including a highly ornamented bivalve (*Pholadomya harrigani*), have been found in black shale in the Western Pacific Railroad cut near Altamont, Alameda County, and an ammonite (*Schloenbachia templetoni*) has been found in the railroad cut between Altamont and Greenway. Specimens of uncoiled ammonites (*Baculites*) occur in beds exposed in the creek south of the aqueduct tunnel in Arroyo del Valle, Alameda County, and on the east side of the same valley in the SE $\frac{1}{4}$  sec. 11, T. 4 S., R. 2 E., M. D., and also on top of a ridge near the road between Marsh Creek and Briones Valley, Contra Costa County. Other localities where Upper Cretaceous invertebrate fossils occur are: under the bridge on State Highway 1, about a mile north of Gualala, Mendocino County; in the sea cliff about 2 miles north of Gualala; on the hillside north of the highway about half a mile west of Muir Station, Contra Costa County.

The Eocene is represented by several thousand feet of sediment, much of it fossiliferous, in the Mount Diablo area. Extinct species of fossil snails, clams, and corals occur abundantly at Muir Station,† Contra Costa County, near the highway in the banks of the stream bed under the railroad trestle. The beds at this locality are generally considered to have been deposited during the middle Eocene Capay stage. Fossils in beds deposited during the following stage (Domengine) may be found in the banks of the railroad cut just east of Muir Station and on the hillside just northeast of the highway intersection at Muir Station. A careful search at this locality will usually reward the collector with specimens of solitary corals, which are quite abundant. Fossils also occur, though rather sparingly, to the north of Mount Diablo 2 to  $2\frac{1}{2}$  miles northeast of Clayton about 100 feet above a seam of coal which was mined nearly a hundred years ago. The climate at the time these fossils were deposited was much warmer than that of today in the same region. The occurrence of fossil palm trees in beds of Eocene age at some localities in this state indicate that at least subtropical climatic conditions existed at that time.

Beds deposited later than the Eocene and referred to the Oligocene outcrop at various localities in the east bay region. One of the most prolific fossil localities is about half a mile southwest of the town of Walnut Creek, in the south side of the creek bed about 100 yards east of the Oakland-Antioch railroad bridge. Here fossil cockles

† Acknowledgment is due Dr. J. Wyatt Durham, Associate Professor, Department of Paleontology, University of California, for advice regarding this and other localities in Contra Costa County, and for the loan of specimens 4 and 5, fig. 1, and specimens 6, 11, 12, 13, fig. 2. Mr. M. V. Kirk, graduate student in the same department, also furnished information regarding certain of the localities in Contra Costa County. Photographs were made by Frank L. Rogers.

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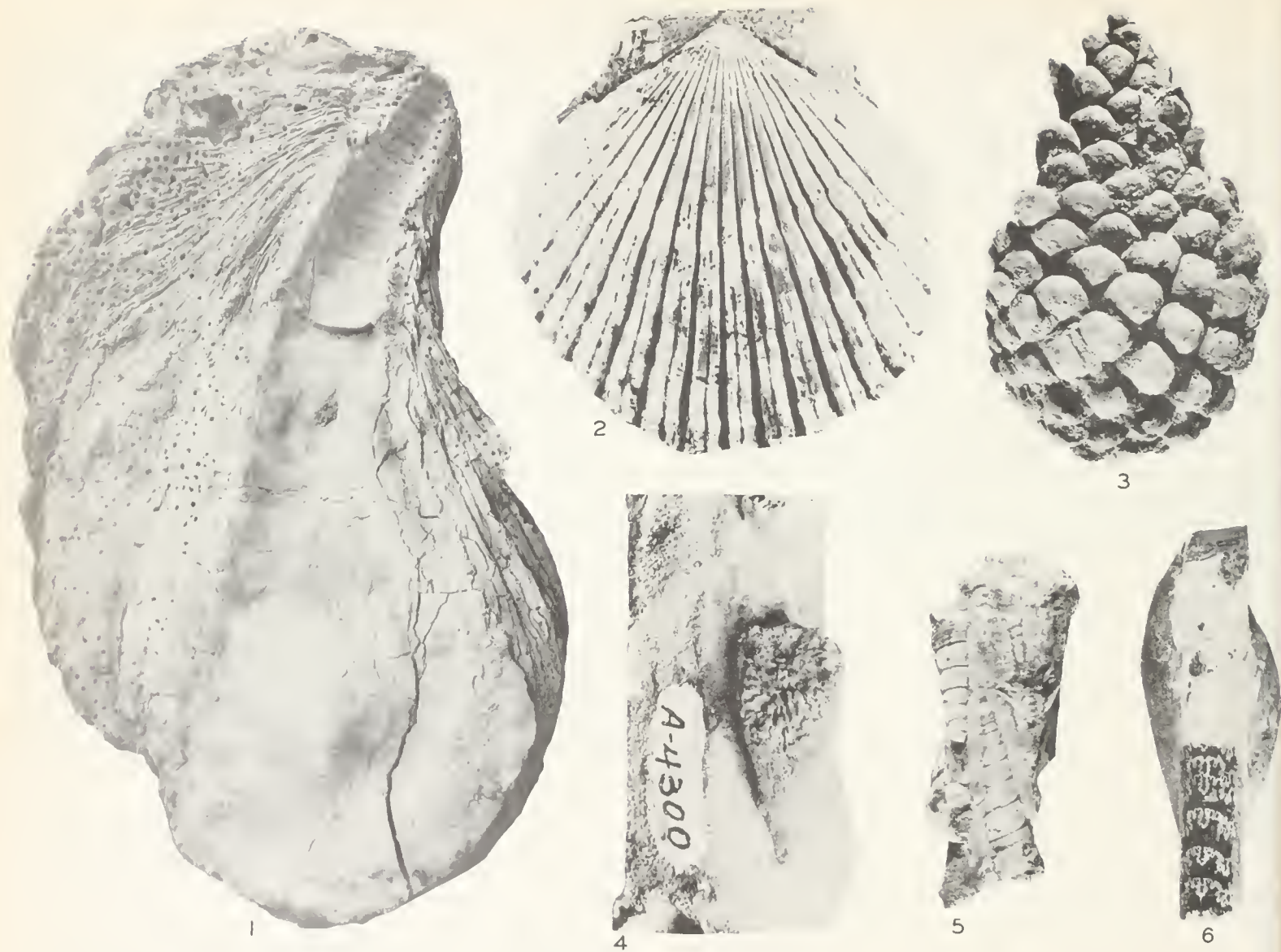


FIG. 1 (See page 189 for description)

FIGURE 1

No. 1. *Ostrea bourgoisii* Rémond. A large oyster about 200 mm. long, from Loc. 2040 (Univ. California), near south edge of NE $\frac{1}{4}$  sec. 33, T. 2 N., R. 1 E., M. D., Kirker's Pass, west side of Markley Canyon, Mount Diablo quadrangle, Contra Costa County, Basal San Pablo (Cierbo), upper Miocene.

No. 2. *Peeten lahri* Hertlein. Scallop shell, height 112.5 mm., from Loc. 28689 (California Acad. Sci.), sea cliffs just north of mouth of first creek south of San Gregorio Creek, San Mateo County, Purisima formation, Pliocene.

No. 3. *Pinus radiata* Don. Cone of Monterey pine, length 110.5 mm. From Loc. 29112 (California Acad. Sci.), beds exposed along beach at very low tide about one mile south of the outlet to Lake Merced, San Francisco County. Probably from base of terrace, Pleistocene.

No. 4. *Balanophyllia variabilis* Nomland. A coral, 19 mm. in length, partially embedded in sandstone. From Loc. A-4300 (Univ. California), Muir Station, Contra Costa County, 10 feet west of spur tracks and 100 feet below in creek bank below trestle. Domengine, upper middle Eocene.

No. 5. *Turritella urasna aedificata* Merriam. Tower-shells embedded in sandstone, from Loc. A-1311 (Univ. California), north of small gully across road from Park Ranger station, about a mile from south entrance inside Mount Diablo State Park, Contra Costa County. Length of rock matrix 59 mm. Domengine, upper middle Eocene.

No. 6. *Baculites* sp. Portion of an uncoiled ammonite, 68 mm. long, partly embedded in a concretion. From Loc. 31245 (California Acad. Sci.), Arroyo del Valle, in creek south of aqueduct tunnel, SE $\frac{1}{4}$  NW $\frac{1}{4}$  sec. 13, T. 4 S., R. 2 E., M. D., Alameda County. Upper Cretaceous. The internal partitions, crinkly where they join the wall of the shell, are well shown on the lower half of this specimen.

(*Cardium*), scallops (*Peeten*), razor clams (*Solen*) and moon shells (*Polinices*) are abundant. Recent construction of residences in this area has made the locality almost inaccessible to collectors. Fossil snails (*Bruclarkia*) and other forms may be found in road cuts on the Arnold Industrial Highway about three-quarters of a mile east of Muir Station, Contra Costa County.

The Miocene epoch, which followed the Oligocene, occurred 10 to 30 million years ago. Many invertebrate mollusks including oysters (*Ostrea*), scallops (*Peeten*), mussels (*Mytilus*), slipper-shells (*Crepidula*), top-shells (*Calliostoma*), and turban-shells (*Tegula*) lived in the shallow warm waters. The fossils of this time include a number of species which are still living off southern and Lower California.

Several well-known localities where fossils of Miocene age occur can be readily found. About 1 $\frac{1}{2}$  miles southwest of Stanford University, under the bridge where Alpine Drive crosses Los Trancos Creek just above its junction with San Francisquito Creek, Santa Clara County, middle Miocene (Temblor) beds are exposed which contain numerous acorn barnacles (*Balanas*). The fossils are so abundant in this general vicinity that these and similar strata are locally known as "barnacle beds."

Beds of upper Miocene age are well represented in Contra Costa County. Large oysters (*Ostrea bourgoisii*) occur at Kirker Pass, about 1 $\frac{1}{2}$  miles northeast of Clayton. In some portions of the state, one species, *Ostrea titan*, attained a length of 18 inches. An easily accessible locality well known to collectors, first described in 1856 and locally known as the "Peeten beds", is on the shore of San Pablo Bay just west of the town of Rodeo and a little south of Lone Tree Point. In these beds fossil shells of a small scallop (*Peeten pabloensis*) occur in profusion. Numerous specimens of the native oyster (*Ostrea lurida*) occur on a low Pleistocene terrace, 8 to 10 feet above sea level, truncating these Miocene beds. Fossil sand dollars belonging to an extinct genus (*Astrodrapsis*) occur in beds exposed in the town of Rodeo at the intersection of Third Street and Pinole Avenue.

Fossil oysters and scallops of the Briones beds, lower upper Miocene, occur in a quarry opposite the Devil's Slide at a sharp turn in the road about 2 miles from the gate to the south entrance of Mount Diablo park. The observation house at the summit of the mountain is built of fossiliferous blocks of rock from this quarry. Farther along this road, just opposite the park ranger's station, a bed outcrops which contains a multitude of Eocene snails of the genus *Turritella*.

Small nonmarine fossil clams (*Pisidium* and *Sphaerium*) and snails (*Lymnaea* and *Planorbis*) have been collected from ancient lake beds deposited during upper Miocene time and exposed in Haggin Creek, about 200 feet below the bridge, a mile east of Penn Grove, Sonoma County.

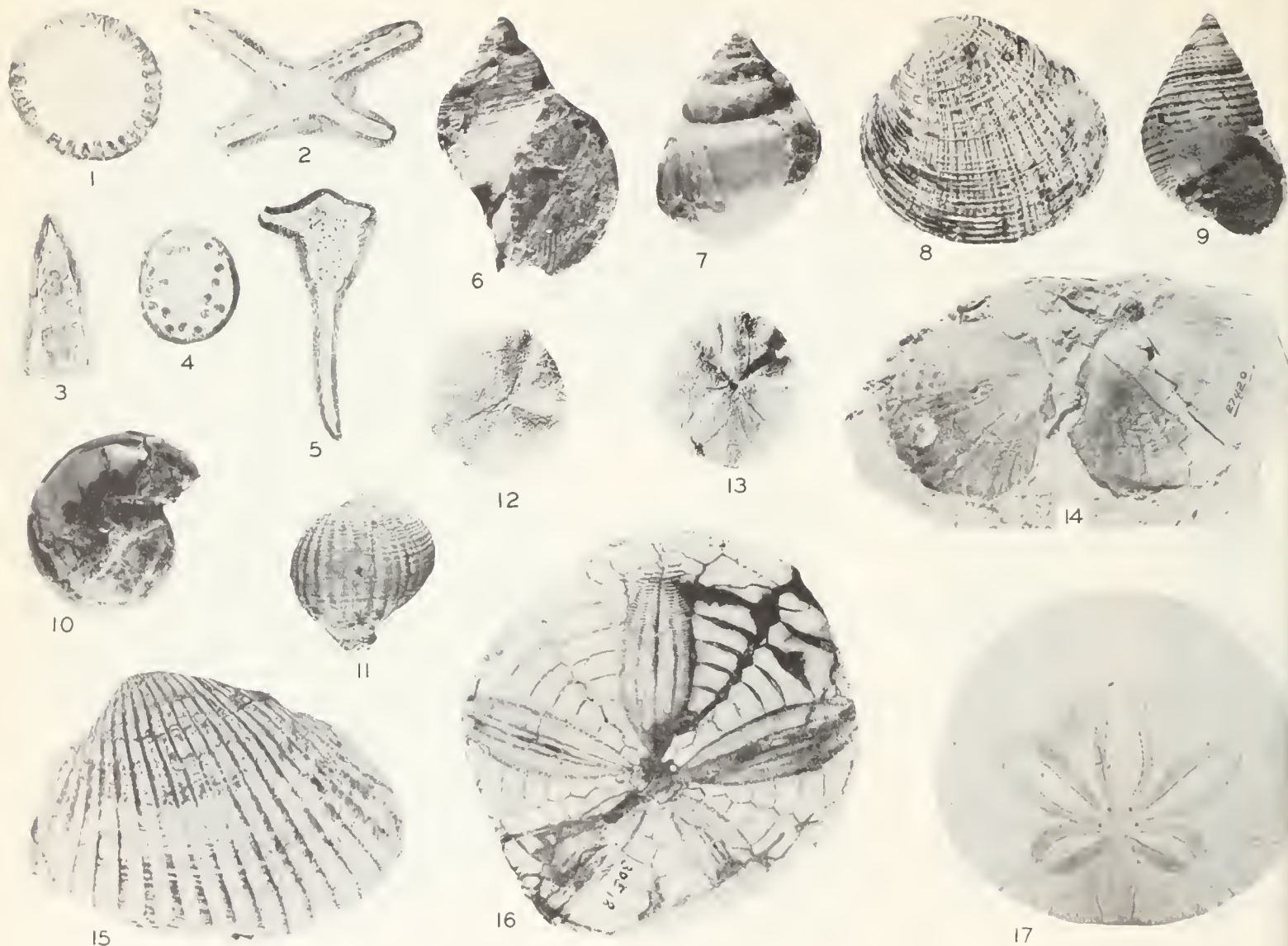


FIG. 2 (See page 191 for description)

## FIGURE 2

Nos. 1-5. Radiolaria. Microscopic animals from chert, Angel Island, Marin County. Probably Upper Jurassic. (1) *Ceospaera* sp.; (2) *Hagiastrium* sp.; (3) *Dictyomitra* sp.; (4) *Cenellipsis* sp. (5) *Tripocyelia* sp. These figures, somewhat reduced, are copied from G. J. Hinde, Univ. California Bull. Dept. Geol., vol. 1, no. 7, 1894, pl. 14, figs. 1, 7, 12, 14, 15. The original illustrations are magnified about X200 natural size. The heavier shading on the outside of the figures is intended to represent the rock matrix in which the forms are embedded.

No. 6. *Bruclarkia gravida* Gabb. Fossil sea snail 21 mm. long, from Loc. A-4661 (Univ. California), on Arnold Industrial highway in road cut three-quarters of a mile east of Muir Station, 1,300 feet due east of north portal of Santa Fe tunnel, Contra Costa County. Oligocene.

No. 7. *Amaurellina clarki* Stewart. Fossil sea snail, 30.5 mm. in altitude, from Loc. 261 (California Acad. Sci.), about a quarter of a mile south of Somersville, Contra Costa County, in sandstone about 100 feet above coal seam. Domengine, upper middle Eocene.

No. 8. *Chione undatella* Sowerby. Wavy *Chione* (also known as hard-shell cockle), 41.5 mm. in altitude, from Loc. 412 (California Acad. Sci.), cliffs along northeast shore of Tomales Bay, about one mile from the ocean. Pleistocene.

No. 9. *Nassarius moraninus* Martin. Fossil basket-shell, height (incomplete) 38 mm., from Loc. 12688 (California State Min. Bur.), Bolinas, Marin County. Pliocene.

No. 10. *Desmoceras* sp. Ammonite, 34 mm. in greater diameter, from Loc. 1467-A (California Acad. Sci.), probably from Enos Canyon, about seven miles west of Winters, Yolo County. Upper Cretaceous.

No. 11. *Brachysphingus mammilatus* Clark and Woodford. Sea snail, height (incomplete) 23 mm., from Loc. A-4785 (Univ. California) in road cut about 100 yards east of the southwest gate to Benicia arsenal, Solano County. Martinez formation, Paleocene or lower Eocene.

No. 12. *Astrodapsis tumidus* Rémond. Fossil sand dollar, greater diameter 22.6 mm., from Loc. A-4786 (California Acad. Sci.), Third Street and Pinole Avenue, Rodeo, Contra Costa County. In a street cut just below Pinole tuff contact. San Pablo formation, upper Miocene.

No. 13. *Astrodapsis tumidus* Rémond. Another specimen of the species shown in No. 12, from the same locality. Greater diameter 23.3 mm.

No. 14. *Pecten pabloensis* Conrad. Fossil scallop shell partially embedded in sandstone. The valve on the right is approximately 55 mm. long. From Loc. 27420 (California Acad. Sci.), rocks exposed at Pecten Point on San Pablo Bay, just west of the town of Rodeo, Contra Costa County. San Pablo formation, upper Miocene. A small fossil barnacle is attached to the middle lower portion of the valve to the left.

No. 15. *Arca (Anadarn) trilineata* Conrad. Fossil ark shell, approximately 65.5 mm. in length, from Loc. 32670 (California Acad. Sci.), quarry about one mile west of Millbrae, San Mateo County. Merced formation, Pliocene.

No. 16. *Anorthoscutum interlineatum* Stimpson. An extinct species of sand dollar from beach south of Fleishhaecker's pool, San Francisco County. Longer diameter, approximately 89 mm. Members of this species are often washed out of the Merced formation, of Pliocene age, which occurs along Seven Mile beach.

No. 17. *Dendroaster excentricus* Eschscholtz. Sand dollar which today lives along the same beach where specimens of the extinct species illustrated in No. 16 are often found. Greater diameter 75 mm. Note the different arrangement of the petals in the two species.

The Pliocene epoch, estimated to have occurred from 2 to 9 million years ago, followed the Miocene. Pliocene beds in the immediate vicinity of San Francisco Bay were deposited in elongate V-shaped indentations, but farther south broad embayments in San Mateo and Santa Cruz Counties were populated by abundant marine invertebrates, many of which occur today in the waters off California. On the whole the temperature was warmer than that at the present time in the same latitude.

Along Seven Mile Beach south of the outlet to Lake Merced in San Francisco, fossil sand dollars are often found where they have been washed out of the upper Pliocene Merced formation, which occurs in the cliffs and along the shore. This extinct sand dollar (*Anorthoscutum interlineatum*) whose petals are only slightly excentric, was originally described from this area in 1856. Sand dollars (*Dendroaster excentricus*) which today live in shallow water along this same strand, also are often washed up on the beach. The differences between the fossil form and the living one may be seen in figure 2, numbers 16 and 17. Many fossil clams and snails can be found in the bluffs between Pillar Point and the top of the marine series about a mile south of the outlet of Lake Merced. The upper, more northern beds are generally considered to be of Pleistocene age. Numerous fossils occur in the cliffs to the south of Halfmoon Bay, San Mateo County, and in beds exposed along the roadside where the highway crosses various ravines, in the cliffs south of the mouth of San Gregorio Creek, and in the cliffs at Capitola south of Santa Cruz. Snails and clams are abundant at these localities. An extinct species of scallop (*Pecten lohri*) is found in the sea cliffs south of the mouth of San Gregorio Creek, San Mateo County. Fossil ark shells (*Arca*) and other forms occur in the Merced formation exposed in a quarry which recently has been opened about a mile west of Millbrae, San Mateo County. Fossils, such as the basketshell (*Nassarius*), also may be found in the bluffs at Bolinas Bay, Marin County, just south of the town of that name. In Sonoma County, marine fossils of Pliocene age have been recorded from about half a mile north of Freestone, 200 feet east of the trestle in the stream, and at other localities in that general region.

The Pleistocene or Glacial epoch, which preceded the present or Recent (Holocene) time, is represented by invertebrate fossils occurring on raised beaches at several localities along the coast. Shells of many species of mollusks, nearly all of which live in marine waters along the coast of California today, occur abundantly on a raised beach at Tomales Bay. Species found there include oysters, hard-shell cockles and spiny cockles (*Cardium quadragenarium*). Fossils of this type may be found in the cliffs along the northeastern shore of Tomales Bay, about half a mile from the ocean; also on a point on the

east side of this bay east of the Inverness Yacht Club. Some of the species such as the hard-shell cockle (*Chione undatella*) are now confined to latitudes south of Morro Bay some 200 miles south of Tomales. This fact suggests that the climate was somewhat warmer at the time they were living on the beaches of middle California.

Today, marine invertebrates, potential fossils of the future, occur abundantly in San Francisco Bay and along the coast, especially in bays or along rocky points. It is an interesting fact that one species of barnacle (*Balanus improvisus*), which occurs abundantly in the waters of San Francisco Bay, ranges to Stockton on the San Joaquin River where the water is virtually fresh. Clams, snails, and sand dollars occur abundantly at such localities as Bolinas Bay, Tomales Bay, Drake's Estero, and Halfmoon Bay, as well as in San Francisco Bay; while forms preferring a rocky habitat occur on Duxbury Reef in Marin County. Several species introduced with oysters from the Atlantic coast and from Japan have established themselves in this region.

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## PREHISTORIC FORESTS OF THE SAN FRANCISCO BAY AREA

BY RALPH W. CHANEY \*

There is, perhaps, no single feature of the natural environment which tells so much about local conditions as its vegetation. One need not be a botanist to recognize marked changes in the plant population as he travels from the Pacific shore eastward across the Coast Ranges into the Great Valley; the oaks and pines of the Sierra foothills, with their understory of manzanita, are different both from the trees of the grassy savannas below and the forests of the mountains beyond; and at the Sierra summit trees disappear altogether, to be replaced by low-growing shrubs and herbs which can survive the snow and wind of a winter at high altitudes. The forests, chaparral, and grasslands of today reflect many characteristics of the landscape and climate where they occur.

When a student of earth history turns to the record of the past, he surveys evidence provided by the rocks of which the earth is made; he searches for indications of ancient land surfaces—the topography of other ages; from layers of ancient sediments he digs out fossils representing successive populations which have spread over sea and land, filling each environmental niche as do the animals and plants of today. With all this evidence collected and wisely interpreted, pictures rise up from remote antiquity like images developing on a photographic film. To understand the world of today and its background, these pictures of yesterday must be clearly drawn and understood.

A fossil is the remains of a once-living thing preserved in the rocks. Although the individual which it represents may have been dead for millions of years, there is still residual in a petrified bone, a shell of a clam, an imprint of a leaf, some evidence of the organic processes which carried it through its life during an earlier geologic period. Studied from the standpoint of these vestiges of its former existence, a fossil becomes more than an object long dead—it comes to represent a symbol of life and living which has fortunately been preserved from earlier ages to offer its testimony in solving the problems of earth history. The fossils of land plants tell much about the past, for their growth and distribution have always been controlled by temperature and rainfall, and by the hills and valleys of former landscapes. Therefore the record of ancient forests is one of the most accurate sources of information regarding the history of the bay area during the late chapters of geologic time.

This discussion will not go back to the beginnings of plant history because there is no record in the bay region of the great forests of ferns, horsetails, and clubmosses which lived in the eastern part of North America during the Carboniferous period. Nor are there any-

where in the bay area fossil examples of the cycads, conifers, and ginkgos, which were so widely distributed during Mesozoic time. No one region has rocks of all ages exposed, and it is necessary, therefore, to piece together the incomplete fragments of earth history from many places. In the vicinity of San Francisco is found one of the most continuous sequences of Pliocene floras known in the world, and the fossils of the Pleistocene are also well represented. These are chapters just preceding the day in which we live, when forests were made up of plants closely resembling those of today. Before turning to this well-known section of plant history, however, the less complete records from the earlier epochs of the Cenozoic era, extending back some 75 million years, will be considered.

The most ancient plant fossils known to occur in the bay area were collected many years ago during coal-mining operations near Tesla in Alameda County. Within recent years additional material has been collected, including leaves of the fan palm (*Sabalites*), magnolia, avocado (*Persea*), sebescia (*Cordia*), and huanchal (*Cupania*). All of these leaves are large and thick as compared with foliage of trees growing in temperate regions, and with few exceptions



FIG. 1. Tropical forest on the Tattare River, Panama, showing the general aspect of Eocene vegetation.

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FIG. 2. Magnolia leaf (*Magnolia dayana*) from the Eocene at Chalk Bluffs (X 3).

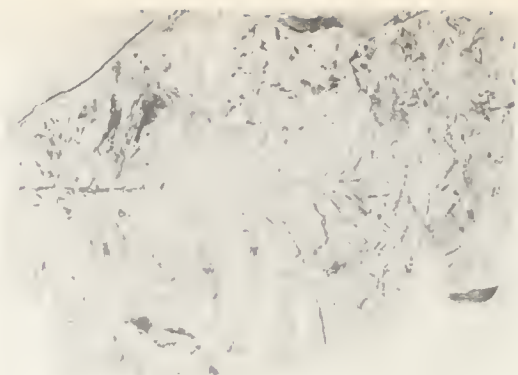


FIG. 3. Leafy shoot of swamp cypress (*Taxodium dubium*) from the Neroly formation at Loma Ranch, near Pittsburgh.

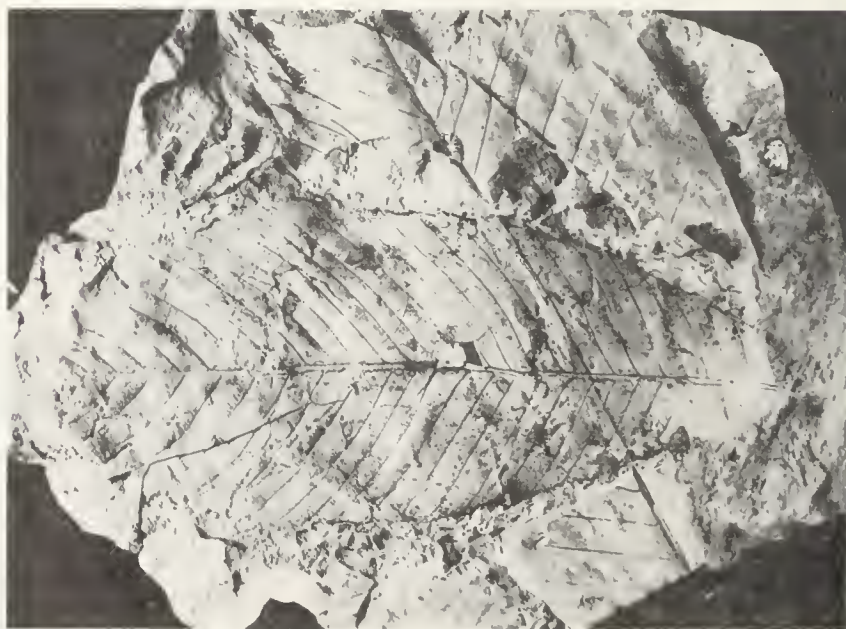


FIG. 4. Chumico leaf (*Tetracera castaneaeifolia*) from the Oligocene at Hay Fork (X 4).



FIG. 5. Swamp cypress and tupelo forest, Varner River, Missouri. The Neroly flora occupied a similar habitat near Pittsburg at the end of the Miocene. Photo by U. S. Forest Service.



FIG. 6. Alder leaf (*Alnus corrallina*) from the Neroly formation at Corral Hollow.



FIG. 7. Fruit of tupelo (*Nyssa knoxltoni*) from the Neroly formation at Loma Ranch, near Pittsburg.



FIG. 8. Poplar leaf (*Populus balsamoides*) from the Neroly formation on Bailey Road, near Pittsburg.

their modern equivalents are found on trees and shrubs growing in the tropics. Close association of the leaf-bearing beds with shales containing marine fossils suggests that the habitat of this forest was on the borders of swamps and lagoons along the shore of the sea. A similar forest, but of a river flood plain type, has been described from Chalk Bluffs and vicinity, on the west slope of the Sierra Nevada. The modern distribution of these forests in Mexico and Central America, in areas without frost, emphasizes the extent of climatic change in the bay area since the Eocene epoch.

During the remainder of the Eocene, and in the Oligocene and Miocene epochs which followed, shallow seas continued to cover wide areas in west-central California. The sediments deposited in the bays and along the shores of these seas contain the remains of animals of sorts that today live only in salt water. The presence of a coral in Oligocene deposits near Walnut Creek, and of mollusks like those now living as far south as the Gulf of California, suggests that the sea of this epoch was much warmer than the present waters of San Francisco Bay. During the Miocene epoch which followed, there is evidence of gradual reduction in water temperatures, though even at this time the life of the sea was like that now found in warmer waters along the coast of southern California. In these marine deposits there are included only fragments of plants which lived along adjacent shores. A few pieces of driftwood have been found, now petrified. And in the Kirker formation north of Pittsburg there are incomplete leaves which may have been blown into the sea from nearby headlands. Although the forests of the bay counties can scarcely be reconstructed from this meagre record, a brief survey of the fossil plants found elsewhere in California during Oligocene and Miocene time will suggest the probably aspect of the vegetation during these epochs.

Specimens of leaves, fruits and wood, laid down in beds of fine sediment deposited with gold-bearing gravels, are found in Trinity County in the Weaverville flora of Oligocene age. The forest which has been reconstructed from these fossils contained trees whose living equivalents inhabit humid, warm-temperate areas such as the Gulf States, Mexico, and Central America, as well as central and southern China. A tree like the living swamp cypress (*Taxodium distichum*) of the Gulf States was the most prolific, as judged by abundance of its leafy shoots. Walnut (*Juglans*) and laurels (including the red bay, *Persea*, to which genus belongs the avocado) were other common trees, and vines of sumac (*Rhus*) and chumico (*Tetracera*) are represented by many leaves. In this mixture of temperate and tropical plants is found the first California record of *Metasequoia*, a deciduous redwood recently found living in central China. In most of its Tertiary occurrences, this conifer is associated with *Taxodium*, though it appears to have occupied somewhat less swampy habitats.

Farther to the south, near Boulder Creek in Santa Cruz County, a few leaves have been found in the San Lorenzo formation of Oligocene age; these are also suggestive of trees which live today in regions with heavy rainfall and mild climate. Although not so subtropical as those of the Eocene, the Oligocene forests of California appear to have required a much warmer and rainier climate than that of today.

This is much less true of the Mioocene floras of California, all of which are found in the interior where the moderating effects of the ocean are less pronounced. The upper Cedarville flora in northeastern California and adjacent Nevada represents a typically temperate forest made up of alder (*Alnus*), chestnut (*Castanea*), hickory (*Carya*), maple (*Acer*), oak (*Quercus*), pine (*Pinus*), and poplar (*Populus*). Many of the living equivalents of these Mioocene trees now occupy regions where much of the rainfall comes during the summer season, in contrast to the present regime of dry summers and light winter rains. This forest, known as the Arcto-Tertiary flora, had its origin in Alaska and other northern regions during the Cretaceous and Eocene, and in subsequent ages migrated southward across North America, and down into Eurasia as well. The term forest migration carries no suggestion that individual trees travelled from Alaska into California; such movements of vegetation involve the wide scattering of seeds around the centers of origin, and their best germination and development in areas where climate, topography, and soil are most favorable to their establishment. In this case, with slow changes toward lower temperature and reduced rainfall, members of the northern forest found superior growing conditions in regions south of Alaska. Gradually they became extinct in their original home, and during millions of years of geologic time they spread southward across most of the United States. The proof of this southward movement is to be found in the fossil occurrence of members of the Arcto-Tertiary flora at successively more southern localities from Eocene time to the present. These favorable conditions have persisted in eastern North America, where the Arcto-Tertiary flora has survived with relatively little modification. But in the western United States, a trend toward wider extremes of temperature and dryer summers was apparent during the Miocene, and most of the Arcto-Tertiary flora has disappeared from this region since that epoch. The upper Cedarville flora is the last in which this forest from the north is fully represented.

A Mioocene flora from Kern County, on the western border of the Mojave Desert, gives evidence of a semiarid climate. Over half the specimens collected are oak leaves resembling those of live oaks now living in the dryer parts of California and Mexico. Most of the others represent trees and shrubs similar to those now found along waterways east of the Coast Ranges, where the climate is continental. Almost no members of the Arcto-Tertiary flora penetrated as far south as



FIG. 9. The Monarch (Tunnel Tree), a petrified log of redwood (*Sequoia langsdorfi*) at the Petrified Forest.

this region in California, where even 20 million years ago the vegetation was largely of a type now living in northern Mexico and the southwestern United States. During the Pliocene epoch which followed, many members of this semi-arid southern flora moved northward into central California.

In the bay area, a flora transitional in age between Miocene and Pliocene occupied the region from San Pablo Bay east to Pittsburg, and southward around Mount Diablo to the region of Altamont Pass and Corral Hollow. The record of this forest is found in sandstones and shales which make up the Neroly formation. These sediments were laid down along the shore at the north, for in outcrops near Pittsburg are shells of marine mollusks and other invertebrates which lived in a shallow sea. Interbedded with these marine sediments are layers of rhyolitic ash which were deposited upon a land surface, for they contain the leaves and stems of terrestrial plants. It is evident that earth movements were taking place, which at some times lowered the continent, bringing an advance of the sea and its shellfish popula-

tion, and at other times raised it to permit the growth of trees along the shore. Like the Weaverville flora, the coastal phase of the Neroly flora contains swamp cypress and tupelo, with bordering trees of red bay, sycamore, and willow; but growing conditions appear to have been much less favorable, as judged by the smaller size of the Neroly leaves. In the Altamont region to the south, the sea appears to have been wholly withdrawn at this time. There are no marine invertebrates in the sediments here, nor is evidence found of coastal swamp vegetation like that near Pittsburg. Instead there is a record of forests including such trees, as alder, cherry (*Prunus*), poplar, sycamore, and willow, which still live in the valleys of this region; birch (*Betula*) which is found in the Sierra; and chumico and magnolia which now grow largely at lower latitudes. While some resemblances to modern California trees are apparent, the Neroly flora as a whole shows its closest relationship to the forests now living along the Gulf Coast and on the shores of the Atlantic from the Carolinas southward. Here are coastal swamps occupied by swamp cypress and tupelo, with birch,

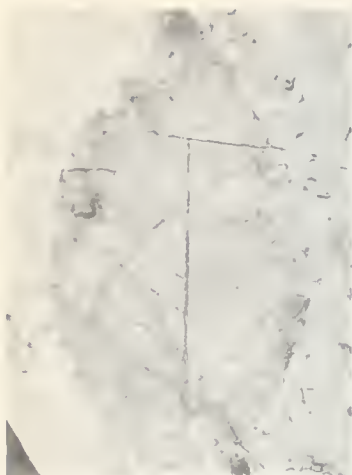


FIG. 10. Elm leaf (*Ulmus californica*) from the lower Pliocene on the southwest side of Mount Diablo.



FIG. 11. Valley oak leaf (*Quercus moragensis*) from the middle Pliocene of the Oakland-Berkeley Hills near St. Mary's College.

magnolia, red bay, sycamore, walnut, and willow growing on the margins and along the streams which come down from adjacent hills. All of these trees are represented in the Neroly flora.

The disappearance, since Neroly time, of the swamp cypress, tupelo, and other trees may be explained by a brief comparison of the summer climate of central California with that of coastal Louisiana and Georgia. Unlike the dry summers of coastal California, there is heavy rainfall in the southeastern United States. During Neroly time, some 15 million years ago, there was a similar regime of precipitation in the bay area; with a gradual change toward dry summer climate, many of the members of the Neroly flora disappeared from the bay region, though they have survived in the southeastern United States where adequate rain continues to fall during the summer months. Alder, poplar, sycamore, and willow have lingered on here in valleys where there are permanent streams, but for the most part the aspect of the existing vegetation has been greatly changed.

The Black Hawk Ranch flora from the southwestern flank of Mount Diablo gives further evidence of a gradual trend toward reduced rainfall in the bay area during the first half of the Pliocene epoch. A study of this and most of the other Pliocene floras of California has shown that they include abundant leaf impressions of poplar, willow, elm (*Ulmus*), and sycamore, trees of kinds now living on the borders of streams. Leaves of live oak, sumac, and mountain mahogany (*Cercocarpus*) are less numerous, probably because the

trees on which they grew occupied slopes, as do their modern descendants. In most fossil floras, the species which lived near streams or lakes are more abundantly represented than those of the slopes and hills, for trees growing beside bodies of water are in a better position to add their leaves and seeds to the sediments there accumulating. The four floodplain trees all are common in Miocene floras of western North America, and two of them, sycamore and willow, have modern relatives still living in valleys on the sides of Mount Diablo. One of the oaks, a relative of the coast live oak, *Quercus agrifolia*, and the mountain mahogany are also represented locally in the modern vegetation. Altogether, the Black Hawk Ranch flora shows a much closer resemblance to the vegetation around Mount Diablo today than the Neroly flora with its swamp cypress, tupelo, and other eastern trees. Only the elm is no longer found native in California, and even it grows well under cultivation.

By middle Pliocene time, the forests of the bay area were almost wholly modern in aspect. Oaks, sycamore, poplar, and willow are the most abundant trees of the Mulholland flora from the eastern side of the Oakland-Berkeley Hills. A large group of typical California shrubs and small trees is recorded, including bush poppy (*Dendromecon*), flannel bush (*Fremontia*), desert sweet (*Chamaebatiaria*), Catalina ironwood (*Lyonothamnus*), christmas berry (*Photinia*), California lilac (*Ceanothus*), coffee berry (*Rhamnus*), dogwood (*Cornus*), and manzanita (*Arctostaphylos*). There are no redwoods or other trees which today require high rainfall. In fact, the Mulholland flora indicates climatic conditions with slightly less rainfall than is found in this region at the present time. Unlike the older floras, in which many or most of the species had their origin at the north, a majority of the Mulholland plants appear to have come up from the southwest, and are assigned to the Madro-Tertiary flora because of their supposed migration from the Sierra Madre of Mexico.

Nearer the coast there is a record of a much more humid type of vegetation during the closing days of the Pliocene epoch. The Sonoma formation was deposited during a series of volcanic eruptions which scattered volcanic ash over a large part of Napa County and into Sonoma and Lake Counties. Deposits of this sort are highly favorable for the preservation of the life record. So, at the Petrified Forest, on the road from Santa Rosa to Calistoga, one of the finest examples of an ancient forest in all the world is preserved. Here are enormous trunks of redwoods (*Sequoia*) lying where they fell when they were blown down, perhaps by explosions, or by winds rushing down the slopes of an adjacent volcano. In fine layers of volcanic sediment are found, in addition to redwood, the winged seeds of four other conifers, fir (*Abies*), spruce (*Picea*), Douglas fir (*Pseudotsuga*), and hemlock (*Tsuga*). Various associates of the redwood in living forests are also represented, including wax myrtle (*Myrica*), red alder,

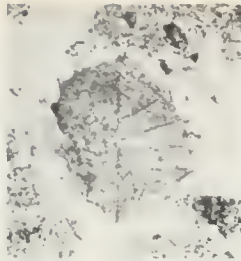


FIG. 12. Live oak leaf (*Quercus wislizenoides*) from the middle Pliocene of the Oakland-Berkeley Hills near St. Mary's College.

chinquapin (*Castanopsis*), tan oak (*Lithocarpus*), pepperwood (*Umbellularia*), rhododendron, and huckleberry (*Vaccinium*). The remains of these plants indicate that climatic conditions much like those of today were present north of the bay during upper Pliocene time, and that the forest was similar to the one which now extends from Point Sur along the coast to the Oregon line. A few survivors from earlier days remained, including chestnut, elm, and red bay, all of which now live in the eastern United States, and the water chestnut (*Trapa*), an aquatic plant which is now native only in China; but the forest as a whole is typically western and coastal.

On the east side of the Santa Clara Valley a similar flora of upper Pliocene age has been studied. Conifers include redwood, pine, Douglas fir, and incense cedar (*Libocedrus*), and there were other trees such as alder, madrone (*Arbutus*), oak, and poplar whose living relatives occupy stream borders and valley slopes in the bay area. The Santa Clara flora suggests conditions somewhat less humid than the Sonoma, as might be expected from its interior situation; both these floras are interpreted to indicate forests essentially like those of today in corresponding habitats.

None of the direct evidence of glaciation which characterizes deposits of Pleistocene age in many parts of North America is found in the bay area; but the effects of lowered temperature are apparent in the nature and distribution of Pleistocene forests along the California coast. In one of these forests in the Tomales Bay region of Marin County, 12 species of trees have been found, which are in no way different from those living. These species have been identified as California nutmeg (*Torreya californica*), tideland spruce (*Picea sitchensis*), Douglas fir (*Pseudotsuga taxifolia*), Bishop pine (*Pinus muricata*), Monterey pine (*Pinus radiata*), Gowen eypress (*Cupressus goveniana*), red alder (*Alnus rubra*), coast live oak (*Quercus agri-*

*folia*), wax myrtle (*Myrica californica*), pepperwood (*Umbellularia californica*), big-leaf maple (*Acer macrophyllum*), and madrone (*Arbutus menziesii*). Judging from the numbers of fossil cones, needles, and wood specimens, conifers were conspicuous trees in this forest, Monterey pine being the most abundant species. Common shrubs were thimbleberry (*Rubus parviflorus*), California hazel (*Corylus rostrata*, var. *californica*), California blackberry (*Rubus vitifolius*), a manzanita resembling *Arctostaphylos columbiana*, and Creek dogwood (*Cornus californica*). Unlike most older fossil floras, the Tomales flora contains many remains of herbs, represented largely by seeds and flowers. Most abundant of these is a close relative of the pine mistletoe (*Arceuthobium campylopodum*); ditch-grass (*Ruppia maritima*), an immersed aquatic inhabitant of modern coastal swamps, bedstraw (*Galium californicum*) and durango root (*Datisco glomerata*) are other abundant herbs. More than half of the species represented in the Tomales flora now range northward to Puget Sound, and a third of them are not found south of Monterey. The modern forest lives in a region characterized by frequent summer fogs, and an annual rainfall of 20 inches or more.

Another Pleistocene flora from a locality near San Bruno has also been studied. A high ridge lies to the west of this region at the present time, and an inland habitat during the Pleistocene is also indicated. A log of Douglas fir over 6 feet in diameter, together with seeds and

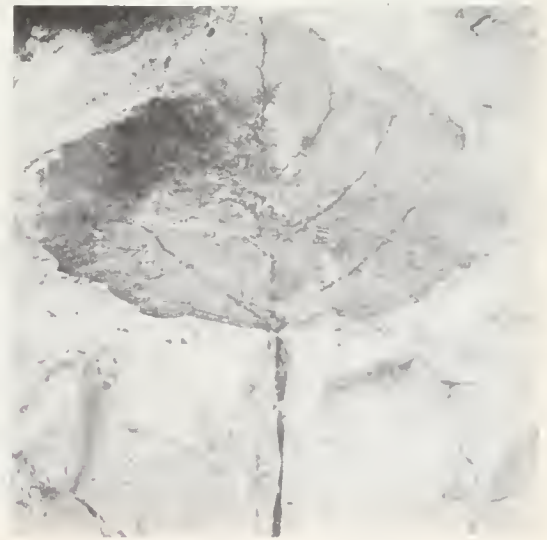


FIG. 13. Cottonwood leaf (*Populus fremontii*) from the middle Pliocene of the Oakland-Berkeley Hills near St. Mary's College.



FIG. 14. Water-chestnut fruit (*Trapa americana*) from the upper Pliocene north of Santa Rosa.



FIG. 15. Pine forest above Carmel, showing the general aspect of Pleistocene vegetation.



FIG. 16. Cone of Gowen cypress (*Cupressus goreniana*) from Pleistocene asphalt deposits near Carpinteria (X6).



FIG. 17. Cone of Monterey pine (*Pinus radiata*) from Pleistocene asphalt deposits near Carpinteria (X $\frac{3}{2}$ ).



FIG. 18. Fruit of manzanita (*Arctostaphylos glauca*) from Pleistocene asphalt deposits near Carpinteria (X3).

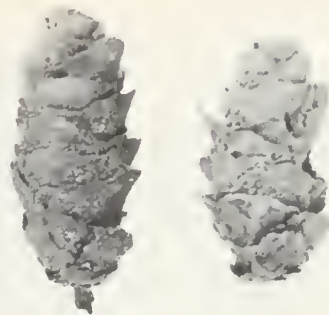


FIG. 19. Cones of Douglas fir (*Pseudotsuga taxifolia*) from Pleistocene deposits near San Bruno.



FIG. 20. A partly buried log of Douglas fir (*Pseudotsuga taxifolia*) from Pleistocene deposits near San Bruno.



needles, suggests that this species lived near at hand, probably in a ravine with a small stream. Various shrubs and herbs now common in the chaparral of the Coast Ranges appear to have occupied exposed slopes where there was less available moisture. Similar vegetation is to be found on the east slopes of Inverness Ridge in Marin County.

Remains of coast redwood (*Sequoia sempervirens*) and other northern trees in Pleistocene deposits at Carpinteria are worthy of brief comment, even though this area is outside the bay region. This is the farthest southward extension which has been recorded for the redwood. To a lesser degree the Tomales and San Bruno floras also were shifted down the coast during this epoch of reduced temperature. Return to the milder climate of the present day has brought about the disappearance of many northern species from Carpinteria and elsewhere in southern California, and they are now to be found largely between the Monterey peninsula and Puget Sound.

During the long span of geologic time, measured in scores of millions of years, many kinds of trees lived in the bay area which are no longer native in California. The forests of the Eocene, including palm, fig, and avocado, gradually disappeared as the climate became colder, but survived in Mexico and Central America in regions not touched by frost. With their departure there came down from Alaska the trees of the Arcto-Tertiary flora. This temperate forest, not represented in the bay area until the end of the Miocene epoch, contained many species whose living descendants require summer rainfall. With the change in climate toward winter rainfall and summer drought, most of the members of the Arcto-Tertiary flora disappeared, although the redwood survived along the coast in a belt covered by summer fog; and the alder, big-leaf maple, sycamore, and rhododendron still thrive along streams. By middle Pliocene time the small-leafed evergreen oaks which make up such an important part of the present woodland, and the shrubs which are members of the existing chaparral, had come up from the southwest. The modern character of the vegetation in the bay area became established when the Coast Ranges had been raised up as barriers to ocean winds, and when long-term climatic trends brought lessened rainfall, dryer summers, and colder winters.

Forests of today are the result of long ages of change. The forests of the future will unquestionably respond to further earth changes—as mountain ranges and continents are built up or worn down, and as rainfall and temperature are altered by forces which are so far only partly understood. A survey of the history of vegetation in the bay area, as judged by the record of plants buried in the sediments of other ages, gives a clearer picture than could otherwise be obtained of an earth before man came to live upon it, and suggests the nature of the changes which lie ahead in ages to come.

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PART V  
MINERAL INDUSTRY

**Editorial Note:**

PART FIVE describes man's utilization of the rocks and minerals of the San Francisco Bay area. As the population has grown in this region, demand for useful products has rapidly expanded, resulting in the development of a great market center for minerals. Industries must be provided with raw mineral materials to make all manner of goods; building stone, limestone, clay, sand and gravel for building construction; various minerals needed in the manufacture of metals and metallic equipment; the so-called nonmetallic minerals for the manufacture of chemicals, fertilizers, and various products useful to agriculture; and the mineral fuels—coal, oil, and gas—which provide energy and reducing agents for various industries. Though the San Francisco Bay area has provided large amounts of minerals and rocks to its growing industry, the State of California as a whole has contributed generously to the industrial needs. In addition, many raw mineral products have been imported from other states and other countries, some of which could just as well have been mined in California. As we look beyond this lively, growing metropolitan area and the farm and home land which adjoins it, we see immense tonnages of minerals and rocks flowing into it. On the other hand, we see enormous shipments of finished products coming from the area for distribution to all parts of the country. It is hoped that the significance of our background study may now be better realized and enjoyed, since the entire economic picture as we see it today is shown to have grown out of the historical past, the natural environment, and the natural resources provided by this natural gathering center of materials made from the products of the earth.

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## CALIFORNIA'S CONTRIBUTION OF MINERAL RAW MATERIAL TO SAN FRANCISCO INDUSTRIES

By LAUREN A. WRIGHT \*

Even as the San Francisco of 100 years ago drew its youthful vigor from the Sierran gold fields, so today do the expanding economies of the San Francisco Bay cities depend on many additional, though perhaps less romantic, mineral substances produced in California. The region within a 300-mile radius of San Francisco has yielded a mineral wealth that, in diversity and total value, probably can be matched by no other area of comparable size. To meet the requirements of industrial growth and an increased population even greater future demands will be placed on the mineral resources of this area and of the entire state.

During the last few decades the most noteworthy trends in California's mining industry have been marked increases in the output of mineral fuels and nonmetallic substances, and a decline in metallic mineral production. The combined mineral output of the state has steadily risen, however, and in 1948 its annual value for the first time exceeded one billion dollars. The rise in the consumption and output of petroleum and natural gas and the significance of these materials to the state's economy are well known. Perhaps less obvious, but of comparable significance in the every-day life of the average Californian are the nonmetallic materials upon which the building construction and ceramic industries, agriculture, chemical plants, foundries, and even the oil industry depend so heavily.

Foremost among the state's nonmetallic products are cement, sand and gravel, clay, stone, and boron minerals. The annual output of each of these is valued at more than 10 million dollars. Other California nonmetals that are produced in yearly amounts valued at more than a million dollars are calcium chloride, diatomite, gypsum, lime, magnesium compounds, potassium salts, pumice, salt (sodium chloride), sodium carbonate, and talc. Nonmetals that are produced in smaller quantity include asbestos, barite, bromine, feldspar, fluor spar, garnet, gem stones, iodine, lithium minerals, magnesite, scrap mica, peat, pebbles for grinding, perlite, slate, sulfur, and pyrophyllite. Deposits of andalusite, kyanite, optical calcite, strontium minerals, and quartz crystals have been operated in the past but are currently inactive.

The production of metallic minerals, though now overshadowed by the nonmetal output, is still significant. California, with a 1949 gold output valued at 14½ million dollars, ranked second among the states as a source of this metal. Also valued at more than a million dollars each are the annual lead, zinc, iron, and tungsten yields. Recently,

however, California's yearly output of copper, silver, and quicksilver has slipped below one million dollars in value for each.

Chromite and manganese deposits in California have been operated profitably in wartime, but are generally inactive when unstimulated by emergency prices. The production of metallic magnesium in the state began during World War II, but has since been discontinued. Antimony and ilmenite deposits in the state have yielded a small and sporadic output. Two or three hundred ounces of platinum minerals are being obtained each year as a by-product of certain gold-placer operations, and a relatively small quantity of by-product molybdenum is recovered in tungsten mining.

Notwithstanding the great variety and relatively large volume of both the metallic and nonmetallic mineral commodities produced in California, they are dwarfed in value by the state's natural gas and petroleum output. Of the more than one billion dollar value placed upon California mineral production in 1949, more than four-fifths was assigned to these mineral fuels. From 1850 to the early nineteenth century, coal mined in California was also a significant mineral fuel; but in the last few decades coal has been produced in the state only sporadically and in very small amounts. Large deposits of natural asphalt and bituminous rock that are known to exist remain relatively undeveloped, but may become important sources of fuel in the future.

The geologic and geographic occurrences of California's mineral commodities that either directly or indirectly enter into the commerce of the San Francisco Bay area are very diverse. Some of the deposits formed early in geologic time; others are forming today. Some of the commodities must be obtained close to the localities at which they are used, others are transported long distances to manufacturing and marketing centers in California and in other parts of the United States and the world. Some are removed at great expense from hundreds or thousands of feet underground; others are obtained inexpensively in large surface operations; still others are won from sea water or the brines of inland saline lakes.

The deposits of none of the state's mineral commodities, however, are distributed haphazardly. Instead their distribution patterns ordinarily outline distinct belts that reflect conditions of order and uniformity in the geologic history of a given region. It is part of the work of the economic and petroleum geologists to study such belts, to reconstruct the events that led to the accumulation of useful mineral substances, to determine the extent of the known deposits, and on the basis of such data to guide the exploration for hitherto undis-

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covered deposits. Geologic studies of this type have been carried on for many years in California, and the interested reader is referred to an extensive literature on the state's mineral resources. Much, however, remains to be learned of the nature, extent, and useful application of these materials. In this brief discussion, it is possible to present merely a glimpse of the known broad geological and distributional features and uses of the more important of California's mineral commodities.

Nearly all of the petroleum and most of the natural gas produced in California originated in marine sediments of the Tertiary period. These rocks, which were deposited relatively late in the state's geologic history, record the former presence of oscillating seas that once invaded large parts of the areas now occupied by the southern Coast Ranges, the central valley, the Transverse Ranges, and the Los Angeles basin. The vast amounts of organic matter deposited in the more shaly beds are believed to have been the source of the petroleum and natural gas which have later migrated to relatively permeable strata. In many places such migration has been halted beneath impervious sediments in stratigraphic or structural traps, and in this manner commercial accumulations have formed. Of greatest significance to the San Francisco Bay counties are the oil and gas fields of the central valley, for these supply much of the region's industrial and domestic fuel requirements.

Most of California's coal production has been obtained from within a 50-mile radius of San Francisco, at localities on the northeast slope of Mount Diablo and near Livermore. Here and at other points in the state vegetal matter grew under warm, moist conditions in early Tertiary to mid-Tertiary time and accumulated in shallow, fresh-water bodies. It was later changed to lignite or sub-bituminous coal. In the late eighteen-hundreds San Francisco depended on these deposits for most of her fuel requirements. During the past 50 years coal production has been negligible, but in recent years lignite mined near Lone has been used in the production of montan wax.

The cement industry in northern California owes its existence mostly to the availability of large bodies of usable limestone. Such bodies have been economically developed in the Coast Ranges between San Francisco and Santa Cruz and in the foothills of the Sierra Nevada. Additional and unusual raw materials for cement manufacture are the large tonnages of sea shells and silt dredged from San Francisco Bay itself. The limestone bodies of the Coast Ranges and Sierra Nevada form parts of metamorphosed sedimentary rock sequences of pre-Tertiary age, and are commonly highly deformed and difficult to exploit. Nevertheless, the cement industry of this region supplies not only northern California, but exports its products to such distant points as Seattle, Washington, and Hawaii. Limestone

from northern California sources is also consumed in the manufacture of lime used by the construction, chemical, and agricultural industries.

Most of the sand and gravel produced in northern California is aggregate material for the heavy construction and building industries; but the state also yields a wide variety of specialty sands that support a glass industry, provide valuable molding materials for foundries, and supply sand-blasting material to shipyards and other consumers. Recent stream-laid deposits are generally the most readily available and easily worked sources of aggregate material, but large tonnages are also obtained from beach and dune sands and from Tertiary sedimentary beds. Because transportation costs figure heavily in the marketing of such low-cost, high-tonnage material, most sand and gravel pits must be located close to centers of consumption. Many pits are active only for the life of a single project; others are long-continuing operations. Of considerable importance are the high-quality sands obtained from the beaches and dunes of the Monterey peninsula. These deposits are the only current source of glass sand in northern California, and are the principal foundry sand source in the state.

The San Francisco Bay counties are particularly favored in their nearness to large deposits of high-quality clays, of which the principal centers of production are near Lincoln and Lone. The clays in these areas and at other localities, both in northern and southern California, were formed in early Tertiary time when warm, moist climate prevailed and the land surface was deeply weathered. Much of the clay produced by such weathering was transported and deposited in lagoons and deltas of an early Tertiary sea. Deposits of high-silica sand and coal commonly accompany the clay and were formed at nearly the same time. Clays of this origin in northern California are used in the manufacture of refractory brick, a wide variety of high-quality heavy clay products and pottery, and in the preparation of foundry molds. Clays for use in the manufacture of building brick and other heavy clay products are obtained mostly from deposits of Recent alluvium close to marketing centers. Large quantities of clay and clay-rich substances are consumed as cement material and are generally obtained from sources close to the manufacturing localities. Much of the clay used in California for such special purposes as filters for mineral, animal, and vegetable oils, as fillers, and as constituents in drilling muds is obtained from altered volcanic deposits in the desert regions of the state.

Stone has long been one of northern California's principal mineral products; but during the last 50 years the demand for dimension stone (produced in specified shapes) has dropped sharply, while the demand for crushed stone has correspondingly increased. This trend has been caused chiefly by the widespread acceptance of concrete as



FIG. 1. Silica-sand loading platform at the site of the old coal mining town of Nortonville northeast of Mount Diablo, Contra Costa County. Eocene rocks of the Nortonville-Somersville area, important in the 1880s for their coal veins, have since been mined intermittently for quartz sand for use in glass or refractories. Neither the sandstone nor the coal veins have been exhausted, but remain as potential sources of mineral wealth. *Photo by Bob Campbell, April 1947, reproduced courtesy San Francisco Chronicle.*

a material in paving and heavy construction work. Most of the deposits that were formerly operated as dimension stone sources cannot be profitably worked for crushed stone, but some are still producing stone for use as architectural decorative materials and monuments. In northern California dimension stone has been obtained principally from granite quarries in the Sierra Nevada; from basalt quarries in Napa, Sonoma, Solano, and Santa Clara Counties; from limestone quarries in El Dorado, Santa Cruz, and Tuolumne Counties; and from sandstone quarries in Colusa and Santa Clara Counties.

Most of the crushed stone produced in northern California, as elsewhere, is used as aggregate material; but certain types are also used as riprap, furnace flux, refractory stone, agricultural stone, poultry grit, roofing granules, and numerous other chemical and industrial materials. Sources of crushed stone are widespread in the San Francisco Bay region. The locations of quarries are determined as much by the cost of removal and transportation as by the quality of material.

The first borax produced in California was obtained in 1864 from lake deposits in Lake County; but in the following years borate mineral production shifted to the phenomenally large deposits of the Death Valley and Mojave Desert regions. Here the borate minerals

were first removed from the surface of playa lakes. Later they were obtained at several localities from bedded deposits in folded Tertiary sediments. Since 1926, however, the principal borate mineral sources have been the large and unusually rich deposits near Kramer, San Bernardino County. The Kramer deposits are in gently folded Tertiary sediments and lie several hundred feet beneath the surface of a topographic basin. Borate minerals are also obtained from the brines of Searles and Owens Lakes, and in small amounts from folded Tertiary deposits. These present sources supply about nine-tenths of the world's borate requirements. The boron of the deposits in the Death Valley and Mojave Desert regions is believed to have been derived from Tertiary volcanism. The borate minerals have formed under arid conditions as preprecipitates or efflorescences. The steel, glass, and soap industries are the principal consumers of the state's borate production.

The brines of saline lakes in the desert areas of California also yield large quantities of potassium salts, sodium carbonate, and sodium sulfate; and smaller, but significant amounts of bromine, calcium chloride, lithium, and sodium chloride (common salt). Most of the state's output of potassium salts is shipped to the eastern states for use in fertilizers; but the salts are also extensively used in the manufacture of soap, special types of glass, explosives, and matches. The state's production of sodium carbonate is consumed mainly by the glass and cleanser industries on the west coast. The kraft paper, glass, and chemical industries use most of California's production of sodium sulfate. Bromine is used in making antiknock gasoline. Calcium chloride is a drying agent, a dust settler, and a constituent of refrigeration brines. Lithium compounds have many uses, particularly in the ceramic industry.

The salt industry of California is centered mainly along the southeast shore of San Francisco Bay where, at Newark, large tonnages of the material are obtained by solar evaporation of sea water. Similar operations are located on Monterey Bay and in southern California. Only a small fraction of the total output of this mineral is consumed in the familiar form of table salt. Much of it is marketed in unrefined form to chemical industries. Semi-refined salt is extensively used as a preservative. Refined salt is used in the industrial preparation of foodstuffs.

Sea water and dolomite are the principal raw materials used in the production of magnesium compounds, a California mineral industry that also centers about San Francisco and Monterey Bays. A plant at Newark uses bittern rejected from the nearby salt operations. Other plants at South San Francisco and at Moss Landing on Monterey Bay use unconcentrated sea water. Most of the dolomite used in these operations is obtained from a series of old sedimentary rocks exposed in the Gabilan Range of San Benito and Monterey Counties.



FIG. 2. Entrance to one of the stops at Nortonville from which siliceous sand was taken. The nearly pure white quartz sandstone seen in the picture is weakly cemented and rather easily reduced to loose sand by blasting and simple crushing. Photo by Bob Campbell, courtesy San Francisco Chronicle.

The production of magnesia, the chief magnesian compound, involves the precipitation of magnesium hydroxide by the addition of calcined dolomite to the saline solutions. The hydroxide is then calcined to magnesia. Most of the magnesia thus produced is used in the manufacture of refractories, and much is shipped to eastern markets. Some of the metallic magnesium produced in California during World War II was obtained by the reduction of magnesia. The rest was obtained by a process that involves reduction of the metal from a ferrosilicon-calcined dolomite mix.

In the past, magnesia has been obtained in California by calcining magnesite (magnesium carbonate), a mineral formerly mined in relatively large quantities in the Coast Ranges north and south of San Francisco Bay and near Porterville in Tulare County. These deposits

have formed as fissure fillings and nodular replacements in ultrabasic rocks. Deposits of the Red Mountain district on the border of Santa Clara and Stanislaus Counties have been the principal source of magnesite in the state; but since 1945 this and the other districts have been inactive.

Gypsum in the San Francisco Bay area is obtained as a by-product of magnesia manufactured from salt plant bittern. Gypsum mining in California, however, centers about the southern part of the state where large deposits of the mineral occur in Quaternary lake beds, Tertiary sedimentary deposits of which many have been folded and faulted, and highly deformed beds in much older sedimentary rocks. These rocks are believed to have formed by the evaporation of saline waters. Large quantities of gypsum (gypsum mixed with clay or sand) have formed in efflorescent deposits along the southwest margin of the San Joaquin Valley and at other localities in central and southern California.

In spite of the abundance of gypsum in California, large amounts are obtained from out-of-state sources. Most of the gypsum consumed in California is used in the conditioning of soils and the manufacture of plaster. The cement industry also requires relatively large quantities of the mineral.

In recent years the increased use of pumice as a lightweight aggregate has led to the development of large deposits of this material in northern California. Pumice, a very cellular glassy rock, is found in areas of Tertiary or Recent volcanism. The principal sources of pumice in California lie east of the Sierra Nevada in Mono and Inyo Counties, but large quantities are also obtained in Napa, Siskiyou, and Stanislaus Counties.

Of California's mineral commodities, the rock perlite is one of the latest to become economically significant. Perlite is also a glassy volcanic material. When heated it expands to several times its original volume. It is used mostly as lightweight plaster aggregate, but is also valued as insulating, filtering, and abrasive material. The perlite deposits nearest the San Francisco Bay markets are in Lake, Napa, and Sonoma Counties.

Talc mining in California, also has increased rapidly in recent years. The state's principal high-quality talc deposits lie along a 200-mile belt in the desert regions near the Nevada line. Here talc deposits occur in a variety of geologic settings; but most have formed by the alteration of sedimentary carbonate rocks. Most of the talc obtained in this region is consumed by the ceramic industry of southern California; but large amounts of talc are marketed in the San Francisco Bay area, to the ceramic and paint industries. Talcose rock, obtained from deposits in serpentine and talc schist bodies in the Sierran foothills, is marketed in northern California as insecticide dust.

Pyrophyllite deposits that occur in ancient metamorphic rocks in Mono County also contribute material for use as insecticide dust.

Among the other nonmetallic commodities produced in northern California are asbestos in deposits in serpentine bodies of the Coast Ranges and Sierran foothills; barite in replacement and vein deposits in metasedimentary rocks of the Sierran foothills; slate, also in Sierran foothill metasedimentary rocks; and peat in Recent deposits in the delta of the lower San Joaquin and Sacramento Rivers.

The preeminence of gold among the metallic mineral commodities of California is the best-known fact of the state's history. Virtually every Californian is aware of the great wealth yielded by the vein quartz and placer deposits of the Sierra foothills and of their significance to the early development of the state and of San Francisco in particular. Large quantities of gold have also been obtained from vein quartz and placer deposits in Shasta, Trinity, and Siskiyou Counties in northern California and from other districts scattered throughout the state. The value of the total recorded gold output of California now stands at about  $2\frac{1}{3}$  billion dollars. With the curtailment of gold mining by government order early in World War II, however, the state's annual gold output dropped from nearly  $1\frac{1}{2}$  million ounces to about 117,000 ounces. Increased operating costs and the lack of a corresponding increase in the price of gold have greatly hindered the post-war revival of the industry. Production now stands at about one-third of the pre-war level.

For many years copper mining was a significant industry in northern California, the total copper output of the state ranking second to gold in value. More than half of the 635,000 tons of copper produced in California during the period 1860-1948 has been obtained from a belt of deposits in Shasta County. Relatively large amounts of copper also have been obtained from Plumas County and from the Sierran foothill counties. Almost all of the primary copper deposits in the state have formed as veins or replacement deposits in igneous or metamorphic rocks.

A price slump in the period 1931-36, together with a depletion of the known reserves of several of the state's large copper deposits, caused a sharp drop in copper production. In 1948 most of the state's copper output was obtained as a by-product of a tungsten mine in Inyo County. Most of the copper produced in California previous to 1919 was smelted in the state; but since then the ore has been sent to out-of-state smelters.

Nearly nine-tenths of the nation's total mercury production has been obtained from deposits scattered along a 350-mile belt in the Coast Ranges north and south of San Francisco Bay. Total production was  $2\frac{2}{3}$  million flasks, valued at about 150 million dollars. Mercury ranks third in value, behind gold and copper, among California's

metallic commodities. Most of the state's mercury deposits have formed in the interstices of porous or brecciated rocks. Serpentine and Jurassic sandstones are the most common host rocks. Although California supplied more than 70 percent of the domestic mercury output during World War II, production has dwindled in the post-war period. The decline has been caused by depletion of proved reserves, and by competition from imported mercury. Much of the early production of mercury in California was used in the amalgamation of gold mined in this and other western states. In later years, however, it has been used mainly in the manufacture of chemicals and in industrial and scientific instruments.

The lead-mining industry in California, which is currently producing from 10 to 20 million pounds of lead each year, is centered in the desert region east of the Sierra. Most of the deposits are veins or replacement bodies in Paleozoic carbonate sediments. These ores also are shipped to out-of-state smelters.

Zinc in California has been obtained from the copper-bearing deposits of the northern and central parts of the state, and from the lead-bearing deposits of the eastern desert region. About half of the nearly 2 million ton total zinc output of the state was mined during World Wars I and II when high prices prevailed. Because zinc and copper minerals commonly occur together in California, the decline in zinc production in recent years is largely attributed to the decreased activity in copper mining. Zinc ores from California sources, like those of lead and copper, are treated at out-of-state smelters.

California's silver yield, which now totals well over 100 million ounces, has been obtained in large part from the lead-zinc and copper-zinc deposits described above. Deposits in the Randsburg and Calico districts of southern California, however, have been mined principally for silver. Silver has also been recovered in appreciable amounts from lode gold mines.

California tungsten deposits, most of which are in the desert areas of the eastern part of the state, have contributed about one-third of the nation's total tungsten output. Most of the large deposits have formed at the contacts of Jurassic granitic rocks with carbonate sediments; but some are vein deposits in granitic rocks. A relatively large output has also been obtained from placer deposits. Nearly 45 percent of the nation's tungsten yield during World War II was supplied by California deposits. Although production was curtailed after the war, prices have continued high, and the industry remains active. Tungsten is used principally as a steel alloy.

As early as the mid-eighteen hundreds small amounts of iron ore from deposits in northern California were used in the production of iron and steel in the San Francisco Bay area. The first large-scale development of the state's iron resources, however, was begun in 1912



when a deposit in San Bernardino County was opened to supply a newly constructed steel plant at Fontana in southern California. A deposit in Riverside County now serves as the source of ore for this plant. These two are members of a group of deposits in the southeastern part of the state that have formed as contact-metamorphic bodies in carbonate strata. Iron ore from similar deposits in Shasta County has been used as ship ballast. Relatively large iron deposits are also known to exist in Sierra and Madera Counties, but as yet none of the northern California deposits have contributed to a large-scale production of iron or steel.

Chromite has been mined at numerous localities in California, and occurs in deposits that are confined to three serpentine-bearing belts: one in the Coast Ranges, another in the Sierra foothills, and a third in the Klamath Mountains. The deposits are segregations of chromite in ultramafic rock. The total chromite production of California (approximately 435,000 tons) is the greatest of any state, but most of it was obtained during World Wars I and II when prices were high. The state's current production of the metal is very low, and all but a very small part of the nation's supply is imported. Chromite is consumed principally in the production of steel alloys and refractory bricks.

Manganese is another of California's commodities produced principally in war-time. Manganese deposits are widespread in the state, but most commercial concentrations occur in chert of the Franciscan (Jurassic) formation which is extensively exposed in the Coast Ranges north and south of the San Francisco Bay area. A property in San Joaquin County has been the largest single source of manganese in the state.

Nearly all of the mineral commodities mentioned above enter in varying degrees into the economic pattern of the San Francisco Bay counties, and therefore become real, though often unrealized, factors in the life of each bay-county resident. As all mining men know, however, the mere presence of useful mineral materials in comparatively

large deposits does not assure their immediate profitable exploitation. Of primary concern to the metal miner is the quoted market price of his particular metal or group of metals, against which he must charge the costs of mining, milling, refining, and transportation. There are, for example, many gold deposits in the gold-bearing belts of the Sierran foothills and northwestern California that are inactive, not because they are worked out, but because the present price of gold will not permit their profitable operation. If suitably stimulated by increased prices or lower operating costs, the output of most of the state's metallic commodities would undoubtedly also increase; but even such stimulation will not permit the reconditioning of many of the larger inactive mines, and their reserves at present must be considered virtually lost to the commerce of California. In many metal-mining districts the proved ore reserves are clearly depleted. The rejuvenation of such districts must depend on exploration guided by careful geologic study.

Although the operator of a nonmetallic property generally is not faced with an acute problem of reserves, he is concerned with other problems of comparable importance. The prices for his product are generally not fixed, but he must operate in open competition with other sources of the same commodity, or with other commodities with uses similar to his. A rapidly changing nonmetallic technology may, with a single development, greatly decrease the demand for one commodity and raise another commodity to much greater importance than it previously had.

It is obvious that the problems of the mineral industry of the San Francisco Bay counties will multiply in the face of heightened demands and the lowering of irreplaceable reserves. But as such problems increase, so will the geologist, the mining engineer, and the mineral technologist become more effective in the techniques of their professions. New mineral reserves will be discovered; new operating techniques will permit profitable removal of hitherto uneconomic materials; and new and better uses will be found for the commodities that California has in abundance.

## UTILIZATION OF MINERALS IN INDUSTRIES OF THE SAN FRANCISCO BAY COUNTIES

By CHARLES VOLNEY AVERILL \*

The year 1949 was the 100th anniversary of the gold rush, and the year 1950 was the centennial of the admission of California to the Union. This brings to mind the difference in living conditions 100 years ago and now—the contrast between the log cabin of those days and the modern dwelling. A log cabin equipped with modern conveniences is a very comfortable dwelling, and many such cabins exist in the mountains of California today. These conveniences are largely the result of the better utilization of mineral raw materials. The bathtub, kitchen range, and refrigerator are all made of enameled steel; the enamel on the steel is a mineral product made, in part, from a mineral with which California is now supplying practically the entire world—borax. Other accessories in the bathroom, including the tile on the walls and floor, and part of the plumbing, are made of ceramic materials; clay is the principal ceramic raw material, but a number of other minerals are also needed, such as feldspar, silica, and talc. Both enameled steel and ceramic products are made on a large scale in the San Francisco Bay area, at Richmond and elsewhere.

The modern fireproof building and the skyscraper are made almost entirely of mineral raw materials. The steel frame is derived from iron ore. The concrete of the walls and floor is made with a mineral aggregate combined with portland cement, which is manufactured from limestone, clay, and gypsum. The aggregate is mined either from a rock quarry or a gravel pit. The plaster on the walls is made from gypsum, a mineral mined extensively in California. The decorative stone, tile, or brick facings are all mineral products. Even the paint is likely to contain both mineral pigments and mineral oils.

The automobile is also made predominantly of mineral raw materials. The body and frame are steel derived from iron ore; many other metals, such as manganese, chromium, copper, lead, zinc, and tin, are used in various parts. The ores of all of these metals are being produced in California with the exception of tin, which has been produced in the past and may be produced again. However, many of these metallic ores are being sent to the east for processing and refining, and parts made from the refined metals or alloys are returned from the east to California for assembling into automobiles in assembly plants in the San Francisco Bay area. Even the tires of an automobile are partly of mineral origin if they are of the synthetic variety. The raw material may be several minerals, including petroleum; and, of course, the fuel for their operation comes from petroleum also.

*Petroleum Processing and Products.* Petroleum is by far the most important mineral product in California, and its refining is one of the most important industries of the San Francisco Bay area. Crude oil is brought in by pipe lines from the oil fields to refineries at Richmond, Martinez, Avon, and Oleum, where it is refined and manufactured into a great variety of useful products. As many as 1100 products are made at a single refinery. Most of these are the familiar greases, lubricating oils, fuel oils, asphalts, and gasolines. Other products include the highly refined white oils, which are sold in small bottles at drug stores, and several grades of waxes for milk cartons, waxed papers, and candles. The waxes are removed from the oil by treating with solvents, first to dissolve out asphaltic impurities, then to dissolve the wax. To remove the wax from the solvent, the mixture is chilled well below the freezing point of water by means of liquid ammonia, then the wax is removed in large rotary-drum filters, which are enclosed to maintain the low temperature. This calls for many tons of ammonia, which is made in chemical plants of the bay area.

Early oil refineries depended on straight distillation for the separation of gasoline and other fractions from the crude. Greatly increased yields of the desirable products such as gasoline are now obtained by processes called cracking. Early methods of cracking depended on high temperatures and high pressures, and in some plants these processes are still in use. Temperatures of 850° to 950° Fahrenheit and pressures of as much as 1,000 pounds per square inch are necessary. A more recent development is catalytic cracking. A catalyst is a substance that speeds up a chemical reaction without actually entering into the reaction. In one of the processes in common use the catalyst is in the form of silica-gel beads, which may be used over and over again; however the beads accumulate a coating of carbon, which must from time to time be burned off at a controlled temperature. This process yields gasoline of high anti-knock properties. A plant that was built during the war for the manufacture of aviation gasoline is now producing gasoline for automobiles.

Oil refineries are now producing a great variety of chemicals in addition to the commonly known oils, greases, gasolines, and asphalts. For instance, a plant that was built during the war for the production of toluene for T.N.T. explosives is now producing phthalic anhydride, a chemical from which paints and plastics are made. Other products include cresylic acid used in the flotation of metallic sulfide ores; cobalt, lead, and manganese naphthenates used as paint

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FIG. 1. Sheet and tin-plate mill of Columbia Steel Corporation at Pittsburg, Contra Costa County. Photo by U. S. Steel Corporation, courtesy San Francisco Chamber of Commerce.

dryers; paint thinners; sulfonated oils used as detergents or "soapless soaps"; and a great variety of insecticides and germicides.

As catalysts in the manufacture of many of these chemicals, other chemicals made from mineral raw materials are used. Several of them are manufactured in the San Francisco Bay area, for example, pelletized molybdenum oxide and alumina, and metallic nickel on a carrier. Other chemicals of mineral origin and raw minerals used in oil refineries include sulfuric acid, liquid sulfur dioxide, caustic soda, diatomite as an aid to filtration, and large quantities of clays for decolorizing and bleaching such products as white oil and waxes.

*Steel Industry.* Although the feed for the open-hearth steel furnaces of the San Francisco Bay area is from 90 to 95 percent steel scrap, large quantities of mineral raw materials are also fed to the furnaces, mainly as fluxes. Thousands of tons of both calcined limestone and raw limestone are used for this purpose each year, as well as smaller quantities of fluorspar. Thousands of tons of dolomite are needed for repairing the furnace linings, and similar amounts of iron ore (magnetite) are fed to the furnaces. Chrome ore in earload lots is needed as a refractory for furnace linings. Ferromanganese, silicomanganese, and ferrosilicon are added to the furnaces to control the quality of the steel; also some coke, part of which is California petroleum coke, the residue from cracking petroleum. With the exception of this coke and the lime, limestone, and dolomite, all of the minerals and mineral products are imported into California from other states and countries. The steel in the furnaces originates to the amount of 5 to 10 percent from pig iron, and this is now available in southern California; but most of that used around San Francisco is imported from other states. Fuel for the furnace is natural gas or oil.

At a cost of many millions of dollars, one of the steel mills has added, since the war, a plant for rolling the thin steel that is used for making the familiar "tin can", so much in demand in California for canning fruits and vegetables. Although the steel fed to this plant has been rolled hot and coiled in other plants of the company, the final reduction in thickness is accomplished by cold rolling. The machine in which this is done is called a five-stand, tandem, four-high cold-reduction mill, and it weighs 3500 tons. The strips can be rolled by this mill at the rate of 4000 feet per minute. One line handles steel 38 inches wide for tin plate, the other handles steel 54 inches wide for other purposes. The thin steel in coils several feet in diameter must next be annealed in furnaces containing a controlled atmosphere to prevent oxidation; then the steel goes through a tempering process. The tin coating may be put on by either of two processes. One of these is a hot-dipping process, for which the coil of steel is cut into plates. The other is a continuous electrolytic process, through which the steel passes in long strips. This tinning line is about 250 feet long.



FIG. 2. Removing slag from a 90-ton ladle of molten steel at the Pittsburg, California, plant of Columbia Steel Corporation. Photo by U. S. Steel Corporation, courtesy San Francisco Chamber of Commerce.

After passing through the plating tanks, the strips go through a furnace, which melts the tin coating and causes it to spread uniformly. The tin-plated steel is then cut into sheets of proper size for the can factories. The new plate mill contains also a galvanizing plant for coating steel with zinc.

*Sugar Refining.* Sugar refineries, a number of which are located in the San Francisco Bay industrial district, are large consumers of minerals, especially limestone. Even a small refinery uses thousands

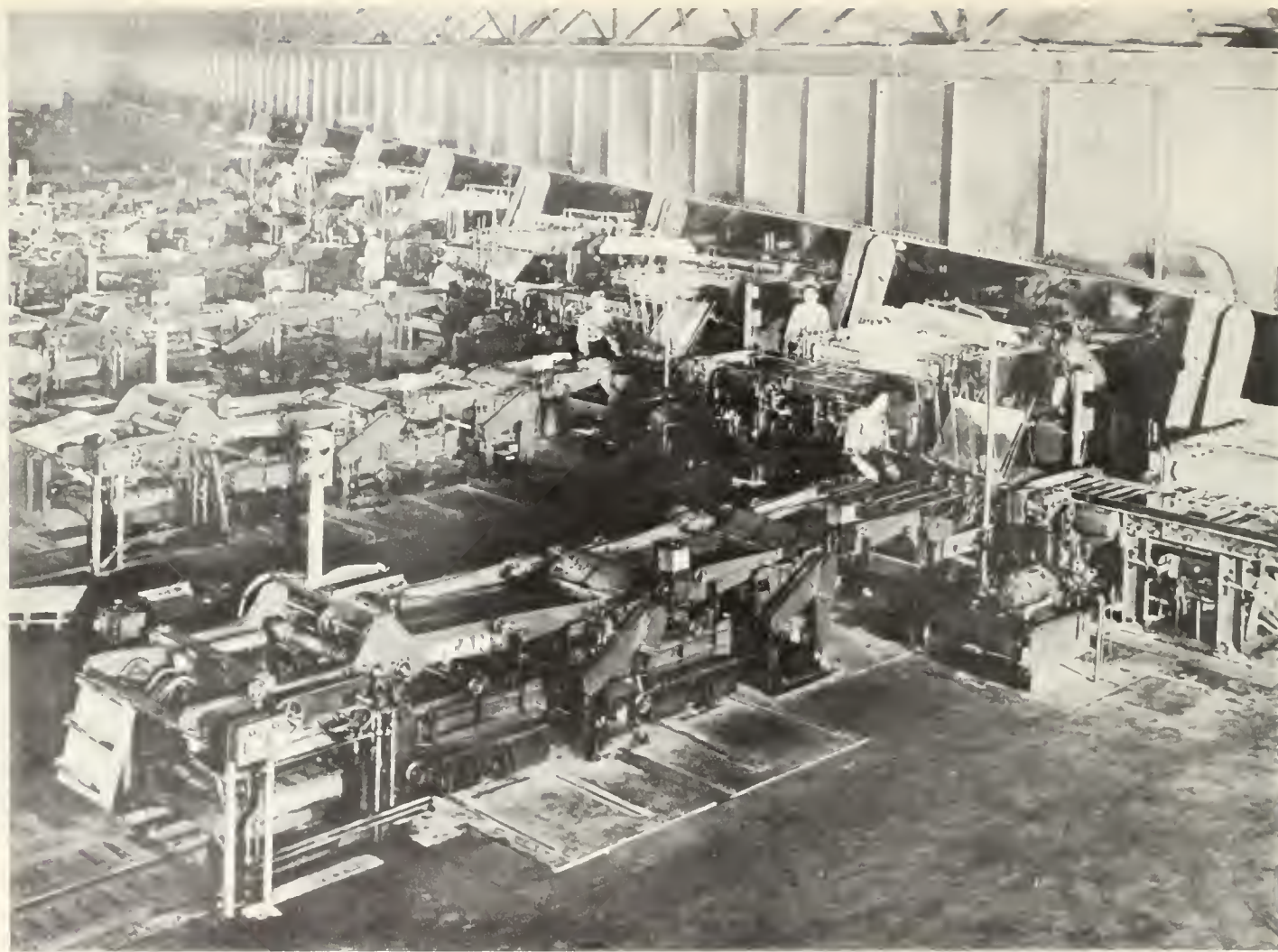


FIG. 3. Hot-dip tin-plating department of the Columbia Steel Corporation sheet and tin-plate mill at Pittsburg, California. The mill is also equipped with a continuous electrolytic tinning line. Tin plate is used mostly in manufacture of food containers. Photo by U. S. Steel Corporation, courtesy San Francisco Chronicle.

of tons of limestone each year, and the stone must be the dense, high-calcium variety. The limestone is separated into two chemicals, lime and carbon dioxide, by heating in kilns; both of these chemicals are used in the refining process. The lime is converted to milk of lime when it is added to water; it is then mixed with the juices containing the sugar to remove impurities. Most of the lime is later precipitated by adding carbon-dioxide gas, and is removed with filters. Diatomite is added to aid in the filtration, and carload lots of this mineral substance are required at each refinery every year. The lime is removed on the filters as a chalk-like material and, in some parts of the bay area, is used on beet-sugar fields as a soil conditioner. The sugar refineries also require many tons of sulfur dioxide each year. This enters the process both as a precipitant for part of the lime and as a bleaching agent. Sulfur dioxide may be purchased at some refineries in the San Francisco area where it is purified, and compressed to the liquid phase; it is then sold in cylinders or tank cars. Other refineries purchase sulfur and burn it in air to sulfur dioxide. Other chemicals used in ton lots at sugar refineries include soda ash, which is produced from natural sources in southern California, and caustic soda, which is manufactured from common salt in the San Francisco Bay area.

*Industrial Chemicals.* Common salt (sodium chloride) is produced on a large scale by solar evaporation of San Francisco Bay water at the south end of the bay, and this salt is also consumed on a large scale in the industries of the area. Crude salt scraped from the evaporating ponds is taken to Pittsburg, where electrolysis is used on a strong brine to separate the salt into sodium and chlorine. The sodium immediately reacts with the water of the brine to form caustic soda and hydrogen. Hence three products come from the electrolytic cells: caustic soda, chlorine, and hydrogen. One plant where this is done consumes about as much electricity as the whole city of Berkeley.

Before entering the electrolytic cells the salt must be highly purified. All mud from the evaporating ponds, and the elements calcium and magnesium must be removed. This is accomplished in a series of precipitating tanks and thickeners; from these, impurities are withdrawn at the bottom as a sludge, and clear brine overflows at the top.

The caustic soda from the electrolytic cells is concentrated and marketed as caustic. Part of the hydrogen is used to remove oxygen from air by burning to form water. The remainder of the hydrogen is caused, by means of a catalyst, to react with the residual atmospheric nitrogen at high temperature and pressure to form ammonia, which is cooled and compressed to liquid ammonia and marketed in that form.

The chlorine receives more extensive treatment and yields a large number of products. Part of it is marketed as liquid chlorine in pressure cylinders for such uses as purification of domestic water supplies.

The remainder is caused to react with purified natural gas or methane, a compound of carbon and hydrogen. The various chemical compounds which result must be separated by fractional distillation. They include chloroform, carbon tetrachloride, hydrochloric acid, and a number of other organic chlorine compounds. As the raw materials have been very highly purified, the resulting chloroform is pure enough for the drug trade. The carbon tetrachloride and other similar compounds are marketed as a liquid dry-cleaner which will not burn: on the contrary—carbon tetrachloride forms part of the liquid in the familiar one-quart fire extinguishers that are carried in automobiles. Numerous other chemicals are prepared for the market by combining some of those already mentioned with other substances. These include a series of xanthates, widely used in the flotation of sulfide ores of various metals.

*Magnesia Insulation.* A plant at Emeryville produces, on a large scale, the familiar insulation seen on steam-pipes and known as "85 percent magnesia". The magnesia arrives at the plant in tank-trucks as a thick slurry of magnesium hydroxide and is handled with pumps. The source of the magnesium hydroxide is the bittern produced as a by-product of the evaporation of San Francisco Bay water for salt at the south end of the bay. The first step in manufacturing the insulation is to change the magnesium hydroxide to carbonate by forcing carbon-dioxide gas through the slurry. The carbon dioxide is contained in flue gases piped from a large steam-boiler plant. To the slurry of magnesium carbonate, asbestos fiber is added in such an amount that the final product contains 12 percent asbestos. The asbestos is a mixture of two types, one imported from Africa, the other from Canada. Long, strong fibers are needed to bind the insulation together. The slurry of magnesium carbonate and asbestos is next filtered on a rotary-drum filter, both to thicken it and to remove impurities in solution. A thick slurry is then fed to cylindrical molds, in amounts regulated by an automatic weighing machine, and is cooked for 15 minutes at 180° fahrenheit. The magnesium carbonate hydrates and hardens in a similar way to plaster of paris. After drying, the cylinders are trimmed and squared on the ends, then slit lengthwise through the middle with band-saws. A cloth wrapping with an adhesive is put around the cylinders, and they are ready for packing in cartons for shipment.

*Gypsum Products.* In San Mateo County near the south end of San Francisco Bay is a plant for the manufacture of gypsum wall board, which is used in the construction industry as a substitute for plaster on walls and ceilings. Such wall board is a sandwich in which the plaster of paris core represents the filling, and sheets of specially manufactured paper represent the two slices of bread. The plaster of paris filling is of much the same composition as ordinary wall plaster.

Both are made from gypsum by heating to drive off most of the water of crystallization. When the resulting white powder is mixed with water, recrystallization proceeds as water is absorbed again, and the formation of the crystals results in hardening or setting.

Although gypsum for wall plaster is usually calcined in kettles by means of a batch method, a continuous method has been developed in the wall-board industry. The gypsum, in lumps as large as  $1\frac{1}{2}$  inches, is fed to a hammer-mill, which is constructed in such a way that hot gases from a furnace carry the pulverized gypsum away from the hammers and calcine it at the same time. The temperature is carefully controlled at the proper point for calcining, about  $350^{\circ}$  fahrenheit, by automatic devices attached to a recording thermometer. The hot gases carry the calcined gypsum to cyclone separators, where the white powder drops free from the gases, and is conveyed to bins near the machine that manufactures the board.

Before entering this machine the calcined gypsum is mixed with some filler such as sawdust, and a little soap to form bubbles and make the board porous. Starch or corn meal is used to help stick the plaster to the paper. Enough water is added to make a rather thin slurry, which is fed to the lower sheet of paper as it moves through the machine. The top layer of paper is then fed to the machine, and the sandwich is ready for the forming-rolls, which fold the bottom layer of paper over in such a way that the edges are made square with the face of the board. The wet board is carried on a belt for a short distance, but has soon set enough so that it may be automatically cut to desired length; then it travels on rollers to the drying-machine. This consists of six to eight decks of rollers in a housing containing steam coils for heating. The machine is equipped with devices which select the proper deck and feed the board through entirely automatically. The board passes through the dryer very slowly, and when it emerges is ready for loading in box cars for shipment.

*Glass.* Glass bottles and jars are made on a large scale in Alameda and Contra Costa Counties, entirely from mineral raw materials. Ordinary glass is made from limestone, silica, and soda, all of which must be practically free of minerals containing iron if the glass is to be colorless. Borax, which is abundant in California, is used to a considerable extent in heat-resistant glass and laboratory ware, but is not considered in ordinary container glass; although it is coming into use as a minor ingredient even in this type of glass to improve the quality.

Limestone suitable for glass-making is available in California, but a careful selection must be made in order to obtain the desired purity, especially freedom from iron compounds. Part of the limestone may be calcined to lime before it is fed to the glass furnaces. Soda ash is available in California from natural sources, although in most other industrial areas it is manufactured from salt. In California

soda ash is produced from the brines of desert lakes such as Searles and Owens.

The silica sand used for glass-making in the San Francisco Bay area comes largely from ocean beaches. It contains considerable feldspar, an ingredient that is often added purposely to batches of glass; hence it is not particularly objectionable for container glass. The beach sands must be rather extensively processed for removal of impurities, such as minerals containing iron. First, all heavy impurities are removed from the sand by means of shaking tables which discard minerals of high specific gravity. After drying, the sand is put through high-intensity magnetic machines for removal of iron compounds, chiefly dark-brown to black mica.

*Cement.* In Santa Clara County is a group of industries, including the largest portland cement plant in the world, all located together, and all dependent entirely on mineral raw materials or metals derived from mineral raw materials. The limestone deposit upon which the portland cement plant depends for one of its principal raw materials was found to contain silica in the form of chert, which is difficult to grind to the fine sizes needed. Experiments were made with a process similar to the flotation process for extracting the sulfides of copper, lead, and zinc from certain ores; also for extracting iron sulfide containing gold from quartz ores. In treating these metallic ores, oils and other chemicals are used to form a froth to float the heavy sulfide minerals to the surface of a vessel, where they are skimmed off. The waste material, which is usually much larger in volume, drops to the bottom and is drawn off. In treating the limestone, the bulk of the material was floated, and the undesirable silica or chert was drawn off at the bottom as waste. The chemical used in this flotation process is similar to soap. Although the process was not used commercially here, it has interesting possibilities for many other minerals.

*Fertilizer and By-Products of the Fertilizer Industry.* Another in this group of Santa Clara County industries is the manufacture of phosphate fertilizer by fusion in electric furnaces of phosphate rock (impure calcium phosphate) with serpentine. The resulting product, fused calcium-magnesium phosphate, is marketed in several grades and is registered with the Bureau of Chemistry of the California Department of Agriculture as containing 18 to 19 percent of available phosphoric acid "determined as citric acid soluble phosphoric acid." Ordinary superphosphate is made by treating phosphate rock with sulfuric acid. All such phosphate rock used in California must be imported from other states or countries, as no deposits have been found in California. The serpentine used in the fusion is a California product, and all such serpentine contains water as a constituent of the mineral. The water must be driven off at considerable expense

Hence a possible market exists here for a high-magnesian olivine such as forsterite, which contains no water. However, the deposit would have to be close enough to the plant so that cost of transportation would be low.

Another product of this same electric-furnace plant is ferrosilicon made in the furnaces from quartz, scrap iron, and coke. The product is an alloy of iron and silicon containing 75 percent silicon. Ferrosilicon is used for de-oxidizing steel and for improving the resistance of cast iron to corrosion. The fume from these electric furnaces passes through bag-houses for the recovery of "volatilized silica," a silica in extremely fine micron sizes.

*Aluminum Foil.* The latest addition to the group of industries in Santa Clara County is a plant for making aluminum foil. The plant was bought in Germany from the Foreign Liquidation Commission, shipped to this country, re-designed, rebuilt to double its capacity, and installed in a building that housed a plant for making metallic magnesium during the war. Although metallic aluminum was made in California during the war in two plants, both of these are now shut down, and aluminum sheets for rolling into foil must be imported from other states. The sheets are rolled in the new plant until they are only 0.00035 of an inch thick. The foil is used in packing cigarettes, fruit, flowers, and frozen foods; also for ornamental purposes and in electrical condensers.

*Smelting of Ores.* The Selby lead smelter located on the shore of San Francisco Bay about 25 miles by road north of San Francisco is one of the most important outlets for mineral raw materials in the region. Lead ores have been smelted on this site since 1885. Although the lead ores are delivered by ocean-going ships from all parts of the world rather than from California, many other minerals are also used. Gold and silver ores and concentrates produced in California are smelted with the lead ores, and furnish part of the flux needed. The precious metals form alloys with the lead, and are separated in elaborate refineries adjoining the smelter, so that both gold bullion and silver bullion are produced. California limestone is purchased as flux, and petroleum coke as fuel; but most of the coke is imported. The smelter is equipped to produce antimonial lead as well as ordinary lead, and in this connection about 1000 tons of junk storage-battery plates are purchased each month. Facilities are provided at the smelter for rolling the lead into sheets, and an affiliated company in San Francisco manufactures finished articles for the wholesale and retail trade. A number of by-products are produced at the smelter, such as copper-bearing residues, which are shipped for recovery of the copper, and bag-house dust recovered from the fumes.

Both the Selby smelter and the oil refineries recover sulfur-bearing gases. At the smelter, it is sulfur dioxide, part of which is com-

pressed to a liquid and shipped in tank cars to a nearby chemical plant for purification. This liquid is used in many household refrigerators, in many chemical processes such as the treatment of wood-pulp for making paper, and for bleaching and disinfecting. Still larger quantities of the gas are converted to sulfuric acid at the smelter. At oil refineries, the sulfur may be recovered as hydrogen sulfide, which is piped to chemical plants for conversion to sulfuric acid, one of the most widely used heavy chemicals. The largest use is in the manufacture of superphosphate fertilizer, but oil refineries also use large quantities.

*Industrial Research.* Although research is not itself an industry, it is of high value in the expanding usefulness and efficiency of all industrial activities. In the San Francisco Bay area the two great educational institutions, University of California at Berkeley and Stanford University near Palo Alto, maintain large laboratories, which are used partly for research and partly for teaching. Research achievements at both of these universities have been of wide significance; the development of the cyclotron at the radiation laboratory at Berkeley, and the development of the klystron tube, a generator of very short radio waves used in radar at Stanford, are only two instances. In addition to these universities, six other universities and colleges in the area have research facilities.

However, industrial research laboratories far outnumber all others in this area, amounting to 53. There are also eight commercial laboratories, four government laboratories, and several research institutes or foundations.

In industrial research, the petroleum industry is by far the most active and has achieved excellent results. Examples are a commercial method of producing synthetic glycerine, production of solvents and fertilizers, development of additives for lubricating oil, and production of synthetic detergents. As a result of these developments and other similar ones, oil refineries now produce a great variety of chemicals, many of which have little resemblance to the familiar oils and greases.

Next in importance from the standpoint of research activity is the chemical industry, including paint manufacturers. A considerable overlap exists between the chemical industry and the petroleum industry. One chemical plant (not petroleum) in the area with 800 persons employed has 100 of these occupied on research, but this is higher than the average ratio. Some achievements of this research have been the development of improved insecticides and weed killers, improvements in sugar refining, improved process for chlorination of hydrocarbons for solvents, development of improved reagents for the flotation of metallic minerals from ores, and development of magnesia for re-





FIG. 4. Standard Sanitary Manufacturing Company plant at Richmond, Contra Costa County, manufacturers of all types of sanitary ware. *Photo by Commercial Photo and View Company, courtesy San Francisco Chronicle.*

fractories. Other research has resulted in improvements in the canning of foods, production of penicillin, and the use of synthetic resins in floor coverings.

With all this research activity, California is still somewhat behind the United States as a whole in research. This is due partly to the fact that California has not yet developed as high a ratio of industrial activity to population as the country as a whole. In 1947, all of northern California had 3.15 percent of the population of the United States

but only 2.28 percent of the manufacturing value, and only 2.16 percent of the industrial research expenditure in dollars. In the mineral industries other than petroleum, research could probably be expanded with considerable profit. New ways can doubtless be found for using some of California's 60 or more mineral products in industry; and ways can be found to raise the quality of many California minerals that are not now utilized, so that they meet the demands of present industries, or may form the basis for new industries.

## SALINES IN THE BAY AREA

By W. E. VER PLANCK \*

Salines in the bay area are derived entirely from sea water. Common salt, magnesium compounds, artificial gypsum, and bromine valued at over three million dollars were produced in 1947. The salt refineries of the Morton Salt Company and the Leslie Salt Company are located at Newark, and the ponds for harvesting the crude salt cover the marshes from Mulford to Alviso. Westvaco Chemical Division of the Food Machinery and Chemical Company also operates a plant in Newark in which are recovered magnesium compounds, gypsum, and bromine from bittern, the waste product of salt recovery. Across the bay at South San Francisco is the plant of the Marine Magnesium Products Company, the first in the United States to successfully manufacture magnesium compounds directly from sea water. These mineral products of the sea are sold throughout the northwest.

Salt has been produced from sea water since the dawn of history, but San Francisco Bay is one of the few places where age-old methods have been perfected. Sea water contains on the average 3.72 percent salts. San Francisco Bay is slightly diluted with fresh water and contains only about 3.4 percent salts. These salts are, in grams per liter: sodium chloride, 27.317; magnesium chloride, 4.176; magnesium sulfate, 1.668; calcium sulfate, 1.268; potassium sulfate, 0.869; calcium bicarbonate, 0.178; and magnesium bromide, 0.076.

The great problem is to extract sodium chloride with a minimum of other salts. Magnesium salts have a bitter taste; they are highly deliquescent, as are calcium salts, tending to stay wet.

If a quantity of sea water is evaporated the least soluble salts will, in general, be precipitated first. When the volume has been reduced to one half, calcium carbonate, magnesium carbonate, and ferric oxide begin to precipitate. At 20 percent of the original volume these materials are completely removed from solution, and gypsum begins to form. When the volume reaches 15 percent of the original most of the gypsum has precipitated, but it continues to come out down to 3 percent. Salt begins at 10 percent and continues to 1.6 percent. Magnesium sulfate and chloride come down in the same range but much faster than salt at the lower limit. There then remains a bittern containing magnesium, potassium, and sodium chloride, sodium bromide, and magnesium sulfate.

Throughout the world it has been found more practical to make the best grades of salt from rock salt and artificial brines, and solar salt manufacture has been abandoned except for local use in the less industrialized regions. In San Francisco Bay, however, three factors

favorable to rapid solar evaporation are combined so that this age-old method has been perfected and modernized. First, the dry climate, lack of rain during the summer, and summer winds cause high evaporation. Second, the thousands of acres of salt marsh provide low-lying land on which the necessarily large acreage of evaporating ponds may be built. The marshes are at or close to sea level which minimizes pumping, and the clay soil provides natural water-tight bottoms which minimize leakage. Finally, the industries of the bay area constitute a ready market.

The earliest white settlers gathered salt that formed natural deposits as much as 8 inches thick in tidal lagoons among the marshes. By 1860 the natural deposits were practically exhausted, and it was but a slight step to the construction of the first crude salt works that consisted of little more than a dam with a gate across the entrance to a lagoon. Later the interior portion was subdivided into smaller ponds by means of dikes. One of the earliest producers on record is John Quigley, who in 1862 built a plant at Alvarado. Six years later the salt pans of 17 companies lined the southeastern shore of San Francisco Bay from San Leandro Creek to Centerville. Their capacity was 17,000 tons a year, much of which was cleaned and ground at San Francisco.

The salt produced in those days contained a high percentage of bittern salts and was of such poor quality that the bay region inhabitants accepted it with reluctance. They much preferred salt imported from Liverpool, but salt from Carmen Island in the Gulf of Mexico also found a ready market at San Francisco. Local salt was considered unfit for table and dairy use, or even for meat packing, and as late as 1880 bay salt sold for a dollar or two less a ton than imported salt.

Gradually local salt-making technique improved. By 1880 the process had become more or less standardized and was on its way to becoming the present highly perfected process that is distinctive enough to be called the California process.

Typical of the salt works in 1882 was that of the Union Pacific Company, the largest at the time. The salt pans covered over 1200 acres of marsh land, most of it on a flat, low-lying island divided by dikes into ponds of 100 to 300 acres. Bay water was admitted through small gates into the first of five concentrating ponds, where it remained for 3 or 4 weeks. It was passed to a second pond where evaporation continued, then to a third, fourth, and finally a fifth. Calcium and magnesium salts precipitated in the fourth and fifth ponds. From the last pond concentrated brine was drawn into small crystallizing vats, many of them floored with boards where the salt formed. The bittern

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FIG. 1. Newark, Alameda County, plant of Leslie Salt Company. Bay water is concentrated by solar evaporation in the large irregular ponds in the distance and then run into small rectangular ponds in the middle distance where salt precipitates. The crude salt is then scraped up, washed with brine to remove some impurities and stock piled in the long stacks seen in the right middle ground. The washing plant is behind the stock piles. Crude salt then passes through the processing plant to the left of the stock piles where it is either loaded directly into railroad cars or trucks for outside delivery or ground, sized, and sacked. A portion of the crude salt is refined by re-solution and vacuum evaporation in the building in center of the picture. Part of the Morton Salt Company refinery is visible at the extreme right of the picture. Crude salt refined in this plant is purchased from Leslie Salt Company. *Photo by Clyde Sunderland, Oakland.*

was then drained off, and the salt was piled into stacks on dry ground where it remained through one rainy season. This weathering hardened and whitened the salt and washed away traces of the magnesium salts which contaminated it. Table salt was made from clean brine evaporated in wooden tanks. Some of the salt made in 1880 contained as much as 99.4 percent sodium chloride.

The later history of the San Francisco Bay salt industry is one of consolidation of producers. In 1901 the California Salt Company was formed and gradually acquired competing plants, some of which consisted of less than 50 acres of evaporating ponds operated by a single man. In the same year the Leslie Salt Refining Company began operations near Redwood City, San Mateo County. In contrast to Alameda County, only three or four companies have operated there, and the last shut down in 1940.

The Leslie-California Salt Company was incorporated in 1924 as a consolidation of the Leslie Salt Refining Company, the California Salt Company, and the Continental Salt and Chemical Company whose works adjoined the California Salt Company near Alvarado. In 1931, Leslie-California gathered in the Oliver Salt Company, an operation which was begun in 1872. The company was reincorporated in 1936 as the Leslie Salt Company when it absorbed the Arden Salt Company and with it the Union Pacific Salt Company which the Arden Company had acquired in 1926. Thus all the original producers, with the exception of the American Salt Company, founded in 1865, have been absorbed. The third Alameda County producer, Oliver Brothers Salt Company, is a newcomer which began producing in 1938.

Concurrent with this consolidation has been a steady evolution in technique and improvement in the quality of the salt produced. Perhaps the most important step was the control of brine concentration to prevent contamination with bittern salts. In contrast with foreign practice the bittern is discarded before more than a trace of magnesium salts forms, although much salt still remains in the bittern.

Mechanization has played an important part in the development of the industry. Pumping, which cannot be entirely eliminated, was first done with windmills. The Union Pacific works in 1880 used a windmill-driven paddle wheel running in an inclined wooden trough. Later Archimedes-screw windmills were universally adopted; these have been displaced by gasoline and electric pumps only within the past 25 years, and their remains may still be seen. The larger plants now use electrically driven centrifugal pumps.

For the harvesting of the crude salt, tram cars running on temporary track were used as early as 1880. Small gasoline locomotives were in use in 1920. Conveyor belts were tried in the twenties, but the last installation was abandoned in 1940. The first loading machines

were built about 1915 but were not perfected for another 15 years. Hand shoveling, however, is still practiced at small plants.

The first vacuum pans were installed in 1910 at the Leslie Salt Refining Company's Plant at San Mateo. Here brine made by dissolving crude salt in fresh water was treated with sodium carbonate to precipitate magnesium salts, filtered, and evaporated. A little later the California Salt Company was evaporating brine from the concentrating ponds in vacuum pans at the Alvarado refinery.

The first modern refinery was that of the Morton Salt Company, built in 1926 at Newark. The Morton Salt Company, which never has produced crude salt in California, obtained crude salt first from the Arden Salt Company and then from the Leslie Salt Company. The present refinery of the Leslie Salt Company was built in 1941.

The Leslie Salt Company now evaporates bay water in ponds covering 25,000 acres. Bay water which contains between 3.0 and 3.5 percent salt, is admitted through tidal gates into the first of a series of 10 concentrating ponds. Brine in the last concentrating pond contains about 26.5 percent salt. After the winter rains the concentrated brine is run through a series of crystallizing ponds where continued evaporation causes salt to form and fall to the bottom. Bittern is drawn from the last pond and sent to the bittern storage. An attempt is made to adjust the rate of flow of the brine through the crystallizing ponds so that the brine remains unsaturated with bittern salts. Occasionally, however, in order to prevent the formation of bittern salts, it is necessary to drain the crystallizing ponds and refill them with fresh concentrated brine. From 4 to 6 inches of salt forms during the evaporation season.

Crude salt is harvested from September to late December. At the end of the evaporating season the crystallizing ponds are drained, and the crude salt that has formed on the bottom is broken up and loaded into cars by machines mounted on caterpillar treads. The crude salt is washed first with concentrated brine and then with fresh water before it is stock piled.

Much salt is sold in bulk directly from the stock pile. It contains 99.30 percent NaCl. Semi-refined salt containing 99.80 percent NaCl is rewashed, kiln-dried, and screened. For making refined salt, crude material is dissolved in fresh water, treated chemically, and evaporated in a triple-effect evaporator. The crystals formed are dewatered, dried, screened, and packed. Vacuum-refined salt contains 99.9 percent NaCl.

No important use of the discarded bittern was made until World War I, although in 1880 the Union Pacific Salt Company was recovering magnesium carbonate for sale to the Hercules Powder Company. It has been estimated that the bittern produced in making 100,000 tons of salt contains 2,800 tons of potassium chloride, 27,300 tons of magnesium chloride, 16,000 tons of magnesium sulfate, and 240 tons of

elemental bromine. The shortage of chemicals, especially of potassium salts during World War I, created a new interest in bittern salts. The Oliver Salt Company, an affiliate of the Leslie Salt Refining Company, the Arden Company, and others built plants which produced potassium chloride of fertilizer grade, and magnesium salts. In these plants the bittern was further concentrated in open pans to remove the remaining sodium chloride. Then sodium sulfate and artificial carnallite ( $KCl \cdot MgCl_2 \cdot 6H_2O$ ) were recovered by chilling, leaving a mother liquor high in magnesium chloride, or fractional crystallization and cooling was practiced in vacuum pans to recover sodium chloride, magnesium sulfate, carnallite, and magnesium chloride. The carnallite was dissolved again and the potassium chloride separated from it.

When chemicals again became plentiful after the end of the war these plants operated at a disadvantage. The last one was closed in 1926, and the salt companies have played no further part in the recovery of bittern salts.

The magnesia industry took the next step when in 1923 the California Chemical Corporation, a subsidiary of the National Kellstone Company, built a plant at San Diego for the recovery of magnesium chloride used in the manufacture of oxychloride cement. Bromine was recovered at this plant in 1926, the first time bromine was recovered in California. Later the same year a second bromine plant was built at San Mateo, and this also treated bittern. The California Chemical Corporation then arranged long-term contracts for bittern with the salt companies and began the construction of a much larger plant at Newark to recover bromine and magnesium chloride. The first step was the recovery of bromine, which changed the character of the bittern very little and had no effect on the following steps. The bromine-free bittern was then further concentrated in a triple-effect evaporator. Salt crystallized while the liquor was hot, and cooling caused magnesium sulfate and synthetic carnallite to crystallize, leaving a liquor containing magnesium chloride. Magnesium chloride ( $MgCl_2 \cdot 6H_2O$ ) was obtained by further evaporation in open pans.

As the market for magnesium chloride was limited, research was initiated on the problem of recovering other magnesium compounds. A pilot plant was built in which lime made from oyster shells was used to precipitate magnesium hydroxide which could be carbonated to make basic magnesium carbonate or calcined to make magnesium oxide. Perhaps the most critical problem was the formation of a granular precipitate which could be easily washed and filtered, but another problem to be solved was the preparation of quicklime from oyster shells. These problems were eventually solved and a new plant was completed late in 1937. In the same year the California Chemical Corporation passed into the hands of the Westvaco Chlorine Products Corporation.

The process begins with the collection and storage of bittern. Storage ponds large enough to hold a year's supply are connected with the salt works by pipe lines. The removal of bromine by a modified Kubierschky process is the first step in the treatment of the bittern.

Bittern is neutralized with concentrated sulfuric acid and run into concrete storage tanks before treatment in the bromine towers, which are square hollow columns built of stone and loosely packed with ceramic ware. Preheated bittern is fed in at the top, steam at the bottom, and chlorine gas at an intermediate point. From the top of the tower comes a vapor containing bromine, a little chlorine, and water. Bromine is recovered from this in a stoneware condenser. Hot bromine-free liquid comes from the base of the tower.

Before further treatment sulfate must be removed. This is done by the addition of calcium chloride formed at a later step in the process. Synthetic gypsum is precipitated and sold to a San Francisco Bay company for use as a retarder in portland cement. It is also sold for agricultural purposes.

The sulfate-free bittern is then reacted with lime. Originally quicklime made by calcining oyster shells in a rotary kiln was used, but now calcined dolomite is added. Conditions are maintained which cause a granular precipitate of magnesium hydroxide to form. The sludge is washed with fresh water and thickened in five Dorr thickeners. It is dewatered on a rotary vacuum filter. The magnesium hydroxide filter cake is calcined in rotary kilns. About half of the output is periclase, and the remaining products are various grades of light-burned caustic calcined magnesia.

The first recovery in the United States of magnesium compounds directly from sea water was made by Marine Chemical Company in 1927 at South San Francisco. The Marine Magnesium Products Corporation, originally the Marine Chemical Company, now produces relatively small quantities of high-priced compounds such as milk of magnesia, basic magnesium carbonate for coating salt, and magnesium oxide for the pharmaceutical industry.

Raw sea water, which contains 0.01 of a pound of magnesium per gallon must be purified before treatment so that impurities in the raw sea water will not appear in the final product. Purification is accomplished by treating the water with chlorine and lime and filtering.

Magnesium hydroxide is precipitated with a slurry of slaked lime. The precipitate is a gummy slime which requires special and elaborate handling in order to be dewatered and freed of sodium and displaced calcium salts. Originally, the magnesium hydroxide was precipitated with calcined shells, but now calcined dolomite is used. The magnesium hydroxide may be dried, carbonated, or calcined, depending on the product desired.

## MINERAL FUELS OF THE SAN FRANCISCO BAY COUNTIES

By GORDON B. OAKESHOTT \*

The growth and development of any great modern industrial area and population center is dependent to a very considerable extent on sources of energy and power which may be obtained at reasonable cost. The phenomenal growth of the San Francisco Bay area and nearby counties has been possible because this region has been particularly favored with respect to raw materials which may be utilized as energy sources. There has been an extremely large per capita increase in energy requirements of the bay area since the last war, dependent on the rapid rise of population, the expansion of industry, and the increased use of machines in farm and factory.

The major sources of industrial, commercial, and domestic energy are coal, petroleum, natural gas, and water-power developed as electrical energy. California has been favored in having all these sources of energy, although at various times in the history of the state one or more has been the dominant source of energy used. In the early history of the state, coal was most important; petroleum and natural gas were undiscovered and undeveloped, and the development of electrical power was yet to come. The period of rising importance of petroleum and natural gas, early in the twentieth century, coincided with the time of decline in importance of coal as a raw material for fuel and energy in California. Late years have seen the increasing use of electrical power, both water-based and fuel-based.

*Coal.* The history of industrial development in California in the second half of the nineteenth century is closely tied in with the development of low-grade lignite and sub-bituminous coal in the state. Coal was first mined in California in 1855, and the peak annual output of 236,950 tons was reached in the year 1880. Since 1910, competition from petroleum has almost completely eliminated California coal as a fuel for industrial use. For the past few years, the annual production of coal in California has not exceeded a few hundred tons. Compared to total United States production, which in 1948 was over 650 million tons, California's yield is thus of little significance. However, the California coal industry is of considerable interest historically and, as indicated by certain recent developments in the extraction of waxes and pigments from high-volatile coals and lignites, and by possibilities of in-place gasification of coal, may see an eventual revival in the state.

Most commercial coal deposits in the United States were formed in the geological periods known as the Carboniferous and Cretaceous; but California coal deposits were formed much later in geologic time, largely in the Paleocene, Eocene, and Miocene epochs of the Tertiary

period. At each California locality, coal seams are interbedded with sandstone, shale, or clay; carbonaceous matter, deposited along with the sands, muds, and clays of lagoons, swamps, and shallow lakes marginal to ancient seas, underwent partial decay and decomposition through many millions of years, and was gradually transformed into lignite and sub-bituminous varieties of coal.

In 1852 the Contra Costa County mines, destined to become the largest producers of coal in California, were discovered on the north-eastern slope of Mount Diablo, 5 years after the first recorded discovery of coal in California near San Luis Obispo. They were first worked in a small way in 1855. By 1859 these mines were supplying a fair proportion of the domestic coal used in San Francisco. Greatest activity of the Mount Diablo coal mines was in the period 1867-88. By 1902, when coal mining in the Mount Diablo district ceased, about 3,000,000 tons valued at \$15,000,000 had been produced. Six coal-mining towns, of which little trace now remains, were in existence while the mines were being worked: Nortonville, present population 900, Somersville, Stewartsville, Judsonville, West Hartley, and Empire. In 1870 over 1000 men were employed at the mines.

Operation of the mines in their heyday was interrupted by frequent disaster. Ventilation was poor, fire-damp explosions were common, and surface fires and floods added to the difficulties. The earthquake of 1868, due to movement along the Hayward fault a few miles west, damaged mine workings.

In the Mount Diablo district the coal was mined underground, loaded in cars which were pulled by donkeys to chutes at the opening of each mine, and then was moved by gravity railroad cars down to the mouth of the San Joaquin River at New York Landing (now Pittsburg). Today, from some of these same mines, sand is mined and transported by trucks to Pittsburg for use in the foundries. In the early days, the coal was carried from this port by boat down the river to San Francisco, and up to Stockton, or up the Sacramento River to Sacramento. It was also commonly used as fuel to operate the river steamers. Production of the Mount Diablo properties fell off rapidly about the turn of the century, and there has been virtually no production since 1902.

Coal measures in the Mount Diablo district are in formations deposited in the middle of the Eocene epoch, beginning possibly 50 million years ago. They crop out a few miles from the northern slopes of Mount Diablo. Beds of sandstone, shale, clay, and coal dip northward at angles ranging from a few degrees to 35 degrees. The steep dip

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FIG. 1. Oil storage and dock-loading facilities at Point San Pablo near Richmond, California, part of the transportation facilities serving the Richmond oil refinery shown in Figure 2. *Photo by Commercial Photo and View Company, courtesy San Francisco Chamber of Commerce.*

of coal strata, so commonly found in California, is a distinct disadvantage in mining because the rapidly increasing depth very soon raises costs above the economic level. In general, the surface coal in the Mount Diablo region was found to be deeply weathered, but its quality improved 200 feet below the surface.

Two principal coal seams were mined in the area. They were known as the Clarke vein and the Black Diamond vein. Coal from both these seams is classed by the United States Bureau of Mines as sub-bituminous. The Clarke vein ranges from  $1\frac{1}{2}$  to  $4\frac{1}{2}$  feet in thickness, and is generally free of interstratified slate, or other undesirable material. The Black Diamond vein, which occurs about 375 feet stratigraphically below the Clarke vein, varies in thickness from 6 to 18 feet, but contains much interstratified clay, slate, and bone (a miner's term for an impure slaty coal). At some areas in the district, small coal seams that occur between the Clarke and Black Diamond seams have been mined.

About 1857, deposits of coal were discovered at Corral Hollow near Tesla in Alameda County. For a few years, beginning in 1897, these deposits were intensively developed. By 1898, the Tesla mines were the largest producers in the state, but the same factors that caused the economic collapse of the Mount Diablo coal fields also forced the Tesla mines to shut down a few years later; last production was in 1902. Total production at Tesla was about 404,000 tons valued at \$1,200,000.

Coal beds at Corral Hollow, like those at Mount Diablo, are in middle Eocene sediments, probably formed on the landward margin of seas which extended to the west. There are several coal horizons at Corral Hollow, but only two seams have been found thick enough to be worked. Thickness of individual seams is from a few inches to about 5 feet. These coal beds dip as steeply as 70 degrees and are cut by numerous faults and zones of crushed rock. The coal is classified as sub-bituminous. Clay, glass sands, and foundry sands were later produced from beds just above the coal seams.

*Asphalt and Bituminous Rock.* Asphalt and bituminous rock in the bay counties consists of sandstones which have become soaked with petroleum from subsurface sources. The lighter fractions in oil seepages evaporate and leave the sands cemented with the heavy asphaltic residue. Small amounts of such material were quarried intermittently during the years 1899-1910 in Alameda, Contra Costa, San Francisco, San Joaquin, San Mateo, and Santa Clara Counties. The material was used mainly for road covering but in later years the natural asphalt has been supplanted by refinery products.

Although of little commercial importance in itself, this wide occurrence of bituminous rock in the bay area is a significant indication of the presence of petroleum and was responsible for the drilling of many of the early day oil wells.

*Petroleum.* The great bulk of California's oil is found in rock formations in the southern half of the state. Such counties as Kern, Los Angeles, Orange, Ventura, Santa Barbara, and San Luis Obispo are important producers. The amount of petroleum actually produced from wells in the San Francisco Bay counties is quite small in comparison with the great production in the southern half of the state. However, transportation of oil is now efficiently and cheaply accomplished through pipeline systems. An extensive system of pipelines brings oil, primarily from the San Joaquin Valley, to San Francisco Bay area refineries. Five principal refineries, located at Emeryville, Martinez, Richmond, Avon, and Oleum, have an output capacity of approximately 330,000 barrels of refined petroleum products per day. This amounts to about one-third of the refinery output in California, a proportion approximating the relative populations of the San Francisco Bay region and the Los Angeles metropolitan area. The San Francisco area has at its back door, therefore, the petroleum resources of all California, the state ranking second only to Texas in total petroleum production in the United States.

The accumulation of petroleum, including both oil and gas, involves formation of the hydrocarbons which constitute petroleum, migration of the oil and gas from their source rocks into a reservoir rock, and finally the formation of some sort of natural trap to prevent loss of the migrating petroleum.

Petroleum is certainly of organic origin, forming by natural distillation processes that take place below the surface of the earth and affect the plant and animal remains which were deposited with muds and sands of past geologic ages. The most favorable source rocks for petroleum are some of the highly organic marine shales and limestones. One of the most important source rocks in California has been the Miocene diatomaceous shale, although a wide variety of organic matter in the sediments has no doubt contributed to the formation of petroleum.

Because of the physical characteristics of oil, gas, and water, the lighter oil and gas have a tendency to move upward in rock formations from their source sediments, if more porous and permeable rocks lie above. Most of this more or less porous and permeable reservoir rock in California is sandstone, but in some fields oil in commercial quantities has come from fractured shale and chert, and even from fractured schist and gneiss. If there were nothing to prevent, the upward migration of oil and gas would result in the loss of its lighter fractions to the atmosphere and the leaving of nothing but a tarry residue. This in itself sometimes serves as a seal or trap for remaining oil and gas below, but much more favorable traps may be formed through folding and faulting. The chief structural trap for petroleum in California's oil fields has been the anticline or dome, usually faulted.



## Oil fields and pools in the bay counties.\*

County	Field	Year discovered	Depth of wells (feet)	Initial barrels per well per day	Geologic formation, age, and structure	Production in 1948 (barrels)	Total cumulative production (barrels)	Status in 1949
Santa Clara	Moody Gulch.....	1880	1000-1250....	10-40 40-45° gravity	San Lorenzo formation, Oligocene; narrow faulted structure	638	62,039	1 producing well
	Sargent.....	1886	1000-2000....	11-19° gravity.....	Basal Pliocene sand; faulted plunging syncline	0	784,000	Abandoned 1948
Sonoma	Petaluma.....	April 1948	1200±.....	Trico disc. well 32 bbls. 19.7° gravity	Lower Pliocene Tolay volcanics and shales; fault blocks	2,363	5,667	Abandoned 1948
San Mateo	Halfmoon Bay....	1867	Shallow.....	25-200 bbls. high gravity....	Lower Pliocene and upper Miocene Purisima formation. Four areas on Purisima anticline and minor structures	0	41,330	Abandoned 1948

\* Data from California Div. Mines, Bull. 118, 1943, and Div. Oil and Gas.

Other structures commonly responsible for the commercial accumulation of petroleum have been faulted anticlinal noses, homoclines, monoclines, thrust-fault and normal-fault blocks, and unconformities and overlaps; stratigraphic changes, such as lensing, and changes updip in thickness and texture of sandstone beds have assisted in the formation of commercial accumulations. Extremely complex folding and faulting have made the search for petroleum increasingly difficult in California, as most of the more obvious structures have already been developed.

The age of the reservoir rock in California oil fields ranges from pre-Cretaceous to Pleistocene. Some fields produce from stratified rocks of several geologic epochs, some from only one horizon. The early production of California oil was largely from Pliocene formations, but in late years production from the Miocene has become greater. A large part of the folding and faulting, and consequently the formation of structural traps, occurred near the close of the Pliocene and during Pleistocene time; much of the migration of petroleum into its present reservoir rocks must therefore have taken place at a later time.

The geologist, in his search for petroleum in California, maps the distribution of all marine sedimentary formations of Tertiary and Jurassic-Cretaceous age and looks for favorable structural and stratigraphic conditions for the accumulation of petroleum. In the San Francisco Bay counties, possible source rocks and reservoir rocks are widely distributed and many favorable structures have been mapped; numerous seeps of both oil and gas have been known for many years. However, in spite of these apparently favorable conditions, exploration for petroleum in the bay area has so far met with just enough success to indicate that the region is a potential producer of oil.

California's oil industry began early in the history of petroleum developments in the United States. A definite oil boom began in California as early as 1865, just 6 years after Drake's famous discovery of petroleum in Pennsylvania; the Drake well was the first successful well drilled for petroleum in the United States. The rapidly growing City of San Francisco, after the discovery of gold in California in 1848, was in great need of a source of fuel. Beginning in 1854, this need was supplied largely from gas manufactured from coal which cost between \$36 and \$40 per ton. The gas itself sold at about \$15 per thousand cubic feet. The need for light was partly supplied by the manufacture of illuminating oils (particularly camphene) in the early 1850's in San Francisco. Increasing need and market for such oils was one factor in the beginning of the oil boom in the northern part of the state. Interest was attracted first of all to light-oil seepages in Santa Clara, San Mateo, Humboldt, and Colusa Counties, and to seepages of asphaltic and bituminous materials in Mendocino, Marin, Contra Costa, and Santa Cruz Counties. At first these were exploited by the digging of trenches, pits, tunnels, and shafts; many of the latter were drilled with spring poles.

Possibly the earliest account of the occurrence of oil in San Mateo County was in the *Mining and Scientific Press* of May 6, 1865, which indicated that there was a report of the discovery of oil on a ranch about 15 miles south of Halfmoon Bay on Purisima Creek. About that time a tunnel was run in the vicinity of Purisima Creek and some light oil was encountered, but not in commercial amounts. The earliest serious attempts to produce oil in the Halfmoon Bay area were in 1867, when wells were drilled close to seepages of rather light oil from Pliocene-Miocene rocks belonging to the Purisima formation. The first wells about this date produced from 25 to 200 barrels per day of high gravity oil. Production since has come from four distinct structures

in the region, of which the best known is the Purisima anticline. Cumulative production had reached over 41,000 barrels when the Halfmoon Bay field was abandoned in 1948. Because of its high gasoline content, much of the oil was refined locally.

The *Mining and Scientific Press* of November 30, 1861, carries notice of the discovery of oil springs near Moody's Mill. Nothing much was done about the light oil found until about 1865. In that year the Santa Clara Petroleum Company and the Shaw and Weldon Petroleum Company found oil in a 30-foot shaft. A newspaper in the San Jose area in October 1865 carried an item that the newly developed well in the Moody Gulch area shipped 120 gallons of light oil to New York. The first real drilling at Moody Gulch took place in 1880. The early wells produced between 10 and 40 barrels per day of 40- to 45-degree gravity oil from the Oligocene San Lorenzo formation. Moody Gulch has continued to produce high gravity oil to the present day; the one well producing at Moody Gulch is the only one currently producing petroleum on a commercial scale in the San Francisco Bay counties. The Moody Gulch oil field, about 2 miles south of the town of Alma, is in the San Andreas fault zone; the oil production comes from narrow, contorted, faulted structures.

At Sargent in Santa Clara County, seepages of asphaltic oil near the contact of shales and serpentine attracted interest as early as 1864. A number of pits were dug and the oil obtained was refined locally to furnish kerosene. The first serious drilling at Sargent took place in 1886. Production of a few barrels a day of 11- to 19-degree gravity oil was obtained from basal Pliocene sandstone. From a complex structure, probably essentially a faulted, plunging syncline, cumulative production of the Sargent oil field to its abandonment in 1948 was over 780,000 barrels, by far the largest production of any oil field within the limits of the San Francisco Bay counties.

Search for oil in the Petaluma area in Sonoma County began in 1909, as the result of observation of outcrops of oil sands. Oil of 19-degree gravity was found at a depth of 1900 feet in a well drilled near Petaluma in 1925; the initial flow was 20 barrels per day. The well produced a total of about 5000 barrels, but was abandoned when salt water was encountered on deepening. Shell Oil Company in 1927-28-29, drilled five unsuccessful wells in the region, which encountered some flow of gas. Little exploration was done until 1941 when Trico Oil and Gas Company developed a gas well at 1214 feet; it produced a small flow of nearly pure methane.

The most recent discovery of petroleum in the San Francisco Bay counties was that of the Petaluma oil field about 4 miles east of the town of Petaluma in Sonoma County. Trico Oil and Gas Company Petaluma Community 5-2, the discovery well, was brought in for 32 barrels a day of 20-degree gravity oil. Three wells were completed in 1948

and produced a total of about 2000 barrels. The field was abandoned as noncommercial in late 1948. Production in the Petaluma area came from lower Pliocene sediments interbedded with the Tolay volcanics in an area broken by faults.

A number of wells have been drilled, all of them noncommercial, near oil seeps in the other San Francisco Bay counties. Among these was a well drilled to a depth of 87 feet in 1862 on the west bank of San Pablo Creek about 4 miles southeast of the town of San Pablo in Contra Costa County. This may have been the first well actually drilled in the bay counties, but in northern California was probably antedated by a well drilled in Humboldt County in 1861. In Marin County in 1865, a well was drilled to a depth of more than 60 feet near seepages near the entrance to Bolinas Bay. Oil and gas seepages at Duxbury Point in Marin County were responsible for the drilling of shallow wells there. A number of wells have been drilled in Alameda and Contra Costa Counties, some of which encountered oil, none of which has been commercial. A number of wells in the Tesla region, Alameda County, obtained showings of oil.

The most interesting and important conclusion to be drawn from accounts of the results of exploration for oil in the San Francisco Bay counties is that it has been proved that the source rocks for petroleum exist, petroleum of various gravities is actually present in suitable reservoir rocks, and favorable structures have been found. At the present time, intensive exploration of a number of the more favorable areas in the bay counties is being carried on by oil companies. Possibility of an oil field of commercial importance in the bay counties has by no means been exhausted.

*Natural Gas.* The use of natural gas in the United States, and particularly in California, has grown tremendously the last few years. This rapid increase in the use of natural gas, for both industrial and domestic purposes, is expected to continue for the next several years and pipeline facilities are being made available for transmission of the gas from fields to major centers of consumption, such as the San Francisco Bay area. For the United States as a whole, proving of new reserves of natural gas has been notably widespread in the past few years, but the still greater consumption of gas in California has necessitated importation, chiefly from Texas and New Mexico. At the beginning of 1948, the proven reserves of natural gas in California amounted to 10 trillion cubic feet, about 6 percent of the United States' reserves of 165 trillion cubic feet.

Two types of natural gas, exclusive of carbon dioxide, are of commercial importance in California. The first is dry gas, or marsh gas, most of which occurs separately from petroleum. The second is oil-well, petroleum, or wet gas, which occurs in the same formation as petroleum and is produced with it. Dry gas is a mixture composed of several



FIG. 2. Richmond oil refinery of Standard Oil Company of California, showing the numerous storage tanks which serve the refinery. Point San Pablo is to the left of the area shown in the photograph; City of Richmond to the right. *Photo by Commercial Photo and View Company, courtesy Contra Costa County Development Association and San Francisco Chamber of Commerce.*

## Gas fields and pools in the bay counties: discovery, geologic and production data.\*

County	Field	Year discovered	Company	Well	Depth in feet	Initial M. cu. ft.	Geologic age and structure	Net gas withdrawn Jan. to Dec. 1948 M. cu. ft.	Gas reserves Jan. 1, 1948 M. cu. ft.	Gas reserves Jan. 1, 1949 M. cu. ft.
Contra Costa	Rio Vista <sup>1</sup>	(See Solano	County)							
Sacramento	Rio Vista	(See Solano	County)							
	Thornton	1943	Amerada Petroleum	Capital Land 1	3,380	6,800	Eocene; anticline	3,410,823	24,372,916	20,962,093
San Joaquin	Lodi	1943	Amerada Petroleum	Lodi Comm. 9-1	2,270	7,200	Eocene; anticline	1,143,072	2,197,818	1,054,746
	McDonald Island	1936	Standard	McDonald 1	5,227	26,647	Eocene; dome	5,579,652	94,136,604	88,556,952
	Roberts Island	1942	Standard	Woods Comm. 1	5,254	5,613	Eocene; anticline	304,852	0	0
	Tracy	1935	Amerada Petroleum	F.D.L. 2	4,063	35,000	Cretaceous; anticline	262,724	10,672,789	10,410,065
	Vernalis <sup>2</sup>	1941	Standard	Blewett 1	3,872	10,000	Cretaceous; anticline	935,059	7,028,092	6,093,033
Solano	Cache Slough	1945	Standard	Cal. Pack 2	4,840	14,867	Eocene; anticline	2,558,328	0	0
	Denverton	1948	Honolulu	McCormick Est. 1	3,010	7,000	Eocene; anticline	33,373		0
	Honker	1944	Standard	Honker Comm. 1-A	7,246	3,200	Eocene; faulted anticline	2,799	0	0
	Kirby Hill							3,237,021	0	35,165,774
	Lambie	1945	Shell	Lambie 1-A	2,320	3,980	Eocene; faulted anticline			
	Lambie 5	1948	Shell	Lambie 5	4,232	4,720	Cretaceous; faulted anticline			
	Maine Prairie	1945	Amerada Petroleum	Wineman 1	4,790	18,997	Eocene; faulted anticline	1,957,236	0	0
	Maine Prairie North	1946	Amerada Petroleum	Winship 1-A	4,805	7,210	Eocene; anticline			
	Millar	1944	Amerada Petroleum	Starkey Fee 1	4,620	22,750	Eocene; anticline	2,843,601	0	0
	Potrero Hills	1938	Richfield	Potrero Hills 1	3,625	5,000	Cretaceous; anticline			
	Rio Vista	(Also in S	acramento and Contra C	osta Counties)				138,977,851	2,155,458,154	2,016,480,303
	Anderson sd.	1944	Standard	Perry Anderson H-6	5,795	15,704	Eocene; faulted dome			
	Emigh sd.	1936	Amerada Petroleum	Emigh 1	4,485	50,000				
	Hamilton sd.	1936	Amerada Petroleum	Hamilton 1	5,600	4,350				
	Midland sd.	1943	Standard	Midland Fee 5	5,082	13,337				
	Suisun	1944	Standard	Suisun Comm. 3	3,978	7,350	Eocene; faulted anticline	2,971,397	0	0
Sonoma	Petaluma	1941	Trico	Miller 1	1,214	8,000	Pliocene; anticline	4,382		0
Yolo	Dunnigan Hills	1946	Texas	Hermle 1	2,620	3,030	Eocene; anticline	1,379	0	0
	Fairfield Knolls	1937	Standard	Hooper 1	3,700	7,340	Cretaceous; anticline	222,237	0	0
	Pleasant Creek	1948	Shell	Unit 3-1	3,000	9,500	Paleocene; anticline			
	Winters	1946	Shell	McCune 1	5,240	11,000	Cretaceous; anticline	520	0	0

\* Data modified from Petroleum World Annual Review '49 and California Div. Oil and Gas.

<sup>1</sup> Largest production from Sacramento county but large production also from Solano and Contra Costa Counties.<sup>2</sup> Extends into Stanislaus County, but larger production is from San Joaquin County.

hydrocarbons, methane being the chief among them, plus small percentages of impurities such as carbon dioxide and nitrogen. Wet gas, after the removal of liquid petroleum, is similar in composition to dry gas but most of it contains less methane.

Geologic factors necessary for the formation and accumulation of natural gas are very similar to those for petroleum, namely, a source rock high in organic matter, and a structural or stratigraphic trap adequate to prevent the loss of the highly mobile gases. The organic source rocks, ranging in geologic age from Upper Jurassic to Pliocene, are common in the Sacramento and San Joaquin Valleys and in the San Francisco Bay area. Nearly all gas production in the state is from closed anticlinal structures, including faulted domes and anticlines.

A large proportion of the natural gas marketed is consumed near the field from which it is produced, although long-distance pipeline transmission is becoming more general. About 75 percent of the natural gas sold by utility companies in the San Francisco Bay area is dry gas from the great Rio Vista gas field in Sacramento, Solano, and Contra Costa Counties. In southern California, about 90 percent of the gas utilized is wet gas, produced in connection with the great oil fields of the southern counties.

In contrast with Texas and other gas-producing states, California uses little natural gas as a raw material for the chemical industries; the largest use is for fuel and heating purposes. Approximately three-fourths of all heated dwellings in California use gas. It is also very widely used in industry, particularly in such industries as ceramics, glass, cement, power generation, food processing, and metal fabrication. Cheapness and constant availability are prime factors in these uses in the bay area. The importance of petroleum and natural gas in the economy of California is indicated in the fact that, together, they supply close to 97 percent of the total energy requirements of the state; this is in comparison to about 50 percent for the United States as a whole.

The first useful natural gas produced in California was from the famous Courthouse Well at Stockton, drilled to a depth of 1003 feet

between 1854 and 1858. Many wells in the area have since encountered gas in drilling for water. Gas discovered in water wells in 1891 near Sacramento was used. In 1901 a well was completed in Solano County which supplied gas to the towns of Suisun and Fairfield. The first high-pressure gas well brought in, in northern California, was at Marysville Buttes in Sutter County in 1933, just outside the 12 bay counties proper.

The Rio Vista gas field was bought in June 1936 by Amerada Petroleum Corporation. The discovery well produced 50,000 M cu. ft. per day of gas from Eocene sand at a depth of 4485 feet. Rio Vista is now the largest gas-producing field in California; it produced more gas in 1948 than the next two largest fields (Kettleman North Dome and Wilmington) combined. Rio Vista had 143 wells which were producing in August 1948. Discovery and early development were in Solano County, but development spread southeastward across the Sacramento River into Sacramento County and recently across the San Joaquin River into Contra Costa County. Sacramento County production has exceeded that of Solano County since 1941. Discovery of two deeper gas sands in 1943 and 1944 added appreciably to the reserves of the state.

An intensive search for gas, which has gone on in northern California in the past few years, has resulted in a number of new field discoveries since Rio Vista. A complete list of these, with their production and reserves, is in the accompanying table. The majority of these new fields have proved disappointingly small and are rated as adding almost nothing to reserves in the state. Of those named, Thornton, Lodi, Vernalis, and Kirby Hill are successful small dry gas fields. McDonald Island, discovered in 1936, is second in importance to Rio Vista, but only has 4 or 5 percent of Rio Vista's reserves.

It is significant that, in spite of intensive exploration and numerous discoveries, no major gas fields have been found in California since Rio Vista, discovered in 1936. Additions to reserves have come mainly from extensions and from new pools in known fields. Total natural gas reserves in the state declined from 10,232,980,306 M cu. ft. on January 1, 1948, to 9,669,647,936 M cu. ft. on January 1, 1949.

# LIMESTONE AND THE CEMENT INDUSTRY OF THE SAN FRANCISCO BAY COUNTIES

BY OLIVER E. BOWEN, JR. \*

Few mineral resources are more important to metropolitan development in the San Francisco Bay area than the limestone and shell-lime deposits in and adjacent to the bay. If one considers the essential materials utilized in erection of any building, he will realize that mortar, lime-plaster, and portland cement are three items without which construction would be both difficult and prohibitively expensive. In all three of these building materials lime is an essential constituent. Not only is the construction industry almost wholly dependent upon lime as a raw material but so also are dozens of other ventures. Lime itself is one of the most important industrial chemicals, and it is used in the manufacture of myriads of other compounds.

Industries in the vicinity of San Francisco make use of two types of natural lime-bearing raw materials. The first, seashells, have been calcined to lime for as long as the process has been known to the human race. It is exceedingly uncommon, however, to find seashells in sufficient concentration to form source material upon which to justify erection of a modern industrial plant. Nevertheless, the Pacific Portland Cement Company's mill at Redwood City, which produces cement far in excess of a million barrels annually, utilizes seashell accumulations from San Francisco Bay as its sole source of lime. There are shell deposits on certain parts of the bay floor large enough to support such a plant for many decades.

The second natural source of industrial lime lies in the limestone deposits scattered through the Coast Ranges. The most extensive quarries now in use are developed along Permanente Creek near Los Altos by Permanente Cement Company. Sufficient limestone is mined there annually to produce more than 5,000,000 barrels of cement. Two other localities have limestone deposits of major proportions which are now being exploited; and, though these are outside the group of 12 San Francisco Bay counties, they are located closely adjacent thereto and the bulk of rock taken from them goes into cement marketed in cities bordering the bay. One is located in the Santa Cruz mountains near Davenport; the other is at the edge of the Gabilan Range southwest of San Juan Bautista. Both support cement plants.

A third type of raw material formerly important to cement manufacturers in the bay region is shell marl, a rock made up of fragments of seashells in a matrix of calcite and clay. A deposit of this material near Benicia, Solano County, was utilized for hydraulic cement intermittently between 1860 and 1880. Another deposit of shell marl located near Napa, Napa County, was quarried between 1902 and 1922 for portland cement by the Standard Portland Cement Com-

pany. Other smaller occurrences of shell marl and shell limestone have been mined and burned to lime for local use at various times.

Although precise records dealing with the burning of lime and with the nature and source of the raw materials from which it was made are few, various lime mortars and cements were used in the construction of many of the missions, asistencias, and other public buildings during the Spanish period. Captain George Vancouver stopped at Monterey and Yerba Buena (as San Francisco was then called) in 1792 and his mention of the burning of seashells to lime is one of the earliest records of lime manufacture in California. Shell limestone was quarried near El Toro, Orange County, and burned in the lime kilns of Mission San Juan Capistrano during its construction. Many of the missions were whitewashed both inside and out, and large quantities of lime were used for this purpose as well as for making mortars and cements. It is generally agreed that most of the lime used during the early Spanish period was made from seashells, most commonly from the well-known abalone.

One of the first records of utilization of limestone during the American period may be seen in the lime kilns located a few miles south of the town of Olema in Marin County. These date from the gold rush period, more precisely from 1850. Largely because of fire hazard, brick construction, requiring large quantities of lime mortar, became increasingly popular from the 1850's to well toward the turn of the century. Both lime and hydraulic cement were used in early-day brick mortars and for the first decade of the American era these materials were largely imported. By 1868, more than one third of all lime marketed in San Francisco came from the quarries and kilns of Santa Cruz County, and a substantial part of the remaining consumption was produced in other parts of northern California. In spite of the rise of California lime production, lime was still imported in large amounts until the use of portland cement became widespread.

The rise of portland cement concrete as a structural material revolutionized limestone quarrying in California as well as in other parts of the United States. In 1894, when cement production amounted to only 8000 barrels, the total limestone quarried in California amounted to only 92,760 tons. At the end of 1904, by which time three cement mills had come into production, the annual output of California limestone quarries had risen to more than 474,000 tons. Present consumption is in excess of 8,250,000 tons, of which more than 90 percent goes into portland cement. Although manufacture of quicklime and hydrated lime for use in the construction industry has decreased with expanded use of portland cement, the use of lime

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FIG. 1. Pacific Portland Cement Company's Redwood City plant, the only one in California using oyster shells and bay mud as the basic raw materials for cement manufacture. Photo by Fred Mac Acro Photos, courtesy San Francisco Chamber of Commerce.

as an industrial chemical and as a soil conditioner in agriculture has risen tremendously. Consequently, lime production as well as cement production has substantially increased.

Quantity production of portland cement in California began with the opening of the California Portland Cement plant at Colton, San Bernardino County, in 1894. Prior to that date a small annual production of cement had been recorded from the Jamul Ranch in San Diego County beginning in 1891. There has been some discussion as to whether or not the Jamul product was a true portland cement or merely a hydraulic cement. Portland cement differs from most other early hydraulic cements in that the ingredients are heated to incipient fusion to form a clinker whereas calcining of most early hydraulic cements was accomplished in an ordinary lime kiln at temperatures somewhat less than that maintained for clinkering as now practiced. In any event, the Jamul cement was near a portland cement and probably should be so classified.

Portland cement manufacturing in the San Francisco Bay region dates from the period 1902-03. During this interval Standard Portland Cement Company opened plants at Napa Junction, Napa County, and Davenport, Santa Cruz County. A third plant was opened at this time by Pacific Portland Cement Company at Cement, Solano County. Depletion of limestone reserves and other economic considerations caused cessation of the Napa enterprise in 1918, and the Solano County operation in 1928. The Davenport plant was taken over by the Santa Cruz Portland Cement Company in 1907.

In 1908, a plant was put into production near Mount Diablo at Cowell, Contra Costa County, by the Henry Cowell Lime and Cement Company. This operated until 1946 at which time depletion of local limestone reserves and loss of rail facilities forced a permanent shut-down.

Old Mission Portland Cement Company began marketing cement in the San Francisco Bay area in 1918 from a plant located at San Juan Bautista, San Benito County. In 1927 the plant was taken over by Pacific Portland Cement Company, which has operated it intermittently every since. The brand name "Old Mission" has been retained. Pacific Portland Cement Company also operates the well-known Redwood City plant which utilizes oyster shells from San Francisco Bay.

In 1927, Yosemite Portland Cement Company commenced production at Merced, Merced County; much of the company's output was marketed in the San Francisco Bay area. Limestone was shipped to the plant from Jenkins Hill, Mariposa County, via the Yosemite Valley Railroad. The plant operated until 1944 at which time the Yosemite Valley Railroad was abandoned. The increased cost of truck haulage over rail freight from the quarry to the plant was deemed sufficiently serious to warrant liquidation of the plant. It

was sold to the Kaiser interests which dismantled and shipped the equipment to South America.

Largest and most recently completed of the cement plants now operating in the bay region is that of Permanente Cement Company near Los Altos, Santa Clara County. Opened in 1940 to supply the gigantic Shasta dam construction project, Permanente has since developed an organization which helps supply not only the bay area and environs but the Pacific islands as well. In addition to its truck fleet which delivers bulk and bagged stocks to bay industries, Permanente operates its own seagoing vessel, the Silver Bow, into which cement for foreign markets is loaded and unloaded by compressed air blowers. The Permanente plant has many unique features which make it the show place of the California cement industry.

The only other cement plant in northern California is located near San Andreas in Calaveras County and is operated by Calaveras Cement Company. This enterprise came into active production in 1926. It supplies the central valley counties and the east-central part of the state, Nevada, and, to a lesser extent, projects in the San Francisco Bay area. With the decline of gold mining, this cement plant has become of major importance to the economy of the foothill region in which it is located.

Almost everyone has observed the setting of a sloppy, water-soaked mixture of rock, sand, and gray portland cement powder into the hard, lithified material which is concrete. Not so many, however, know what happens during solidification of a concrete mix. Portland cement is made up of a group of chemical compounds which have the property of recrystallizing in the presence of and by chemical interaction with water. It is a crisscross of these hydrous crystals which bind the rock and sand together to form concrete. As crystallization of the cementitious compounds is often too fast to allow for efficient handling of the concrete mix, gypsum is added to retard crystallization. Some of the chemical compounds in portland cement crystallize quickly to give an early strength to the concrete, but final crystallization of all ingredients may take days, weeks, or even many months. Maximum strength is reached at various times by different types of cement. Late crystallizing cements often have desirable properties which offset their slowness in producing maximum strength in concrete, so that completeness of crystallization at an early time is not always a gauge of the quality of the cement.

The three most important cementitious compounds in portland cement are tricalcium silicate ( $3\text{CaO}\cdot\text{SiO}_2$ ), dicalcium silicate ( $2\text{CaO}\cdot\text{SiO}_2$ ), and tetracalcium aluminoferrate ( $4\text{CaO}\cdot\text{Al}_2\text{O}_3\cdot\text{Fe}_2\text{O}_2$ ). Small amounts of tricalcium aluminate ( $3\text{CaO}\cdot\text{Al}_2\text{O}_3$ ), magnesium oxide ( $\text{MgO}$ ), and calcium oxide ( $\text{CaO}$ ) commonly are present. Free lime ( $\text{CaO}$ ) is often undesirable as it may react latently with



minerals in some kinds of crushed rock to produce new compounds of increased volume which cause failure of the concrete. It has become common practice to add opaline silica to many cements in order to eliminate the potential danger of free-lime-aggregate reactions. Opaline silica has an affinity for free lime over most minerals of reactive aggregates, and the crystals formed by the combination of lime and opaline silica do not disrupt the previously formed structure of the concrete.

Although the two calcium silicates are the most important cementing compounds, the calcium aluminates and ferrates are important in special kinds of cement. For instance, iron cannot be present in the raw materials for use in white cement as it causes discoloration during calcining; on the other hand, high-iron cements are necessary where structures are in contact with salt water. Some compounds in portland cement give off more heat during crystallization than others. Hence, in massive structures cements having low heat producing components are desirable. Dicalcium silicate and tetracalcium aluminoferrate are two compounds which evolve relatively little heat during hydration and low-heat cements are formed predominantly of these two compounds.

In some structures, high early strength is necessary and for such usage portland cement is made to contain a high percentage of tricalcium aluminate, and a low percentage of iron. High-iron cements, although very resistant to corrosion by sulfate waters, are notoriously slow in hardening. Thus, by varying the chemical content of portland cement, it can be made to satisfy the wide variety of requirements demanded by the construction industry.

Conversion of raw materials to portland cement is an interesting but involved procedure. Briefly, the process consists of pulverization of raw materials; thorough mixing to give the desired uniformity after firing; calcining the powder or slurry formed from it to clinker made up of new chemical compounds; grinding of the clinker with addition of gypsum retarder; and classification of ground clinker to give a uniform, finely divided finished product.

In addition to one of the several lime-bearing materials described in the opening paragraphs, sufficient aluminous and siliceous rock must be blended and mixed with the lime to give the desired lime-silica-alumina ratio in the finished product. Many rock types are utilized for this purpose, but most of them consist predominantly of clay

minerals or their metamorphosed equivalents. Clays contain silica, alumina, and iron in varying proportions and usually are available in quantity; clay shale is perhaps the most widely used. Limestone and clay commonly are coarse-crushed in jaw crushers and then pulverized in ball mills.

After pulverization two slightly different procedures are followed at different mills. In the "wet" method of manufacture the powdered rock is made into a slurry by addition of water. Mixing and blending then takes place in open silos, usually by compressed air agitation. Transportation to the kiln is accomplished by pumping the slurry through pipes. In the "dry" method mixing takes place in closed silos also by compressed air agitation and transportation is accomplished by pipes or airslides and blowers.

Calcining takes place in long, gently inclined, rotating, tubular kilns. Pulverized raw materials are fed in at one end of the kiln and drop out in walnut-sized nodules of red-hot clinker at the other. After going through an air-draft cooling device the clinker nodules are pulverized in ball mills together with two or three percent of gypsum.

After being finish-ground, the cement is made very fine and uniform by air separation. Air separators are complicated devices in which particles of desired size are removed in air suspension and collected on air filters while the heavier over-sized particles drop out by force of gravity and are sent back through the ball mills for regrinding.

Although much cement is retailed in the familiar bags weighing 90 pounds each, by far the largest percentage of the total production (about 80 percent) is not sold in packaged lots but is delivered to the consumer in bulk form. Many elaborate devices have been developed for handling and storing bulk cement. Loading is commonly accomplished by suction blowers connected to flexible pipe lines. Huge bottom-dump cement trucks are a common sight on the road, their funnel-shaped or inclined design making them unique among trucking units. Permanente Cement Company has a specially designed ocean-going vessel which is loaded and unloaded by air-draft methods. The old railroad box car is rapidly being replaced by bottom-dump cement cars designed somewhat like cement trucks, but there is still a shortage of railroad cars designed to handle powdered material which must be kept dry. Current shortages in cement are expected to be alleviated in the near future by increases in mill capacity now well along toward realization.

# THE BUILDING STONE AND AGGREGATE INDUSTRY OF THE SAN FRANCISCO BAY COUNTIES

BY MORT D. TURNER \*

California has the largest commercial output of rock products of any of the 48 states. It is far ahead of any other state in production of sand and gravel, and ranks near the top in production of crushed and broken stone. Of the total rock products produced in the state about one-third comes from the San Francisco Bay counties.

The term stone, in commercial usage, is applied to material quarried from larger masses of rock. The same material in place before being quarried, broken, or cut is called rock. In the industry, rock products have been divided by custom and usage into several categories based on size and shape of the particles and the nature of the processing they have undergone. Sand and gravel are natural detrital stone materials which usually require only sizing and washing before marketing; crushed stone is made from rock or gravel; dimension stones are blocks shaped to various degrees; aggregate is crushed stone, sand, or gravel used in such materials as concrete, macadam, plaster, terrazzo, road metal, and railroad ballast.

Prior to 1850 very little stone was used for construction purposes in California. Owing to the great increase in population after 1850, however, permanent bridges, public buildings, and all-weather streets became more desirable, and a building-stone industry developed. Sandstone, basalt, granite, and marble were extensively mined for construction or paving purposes at various places in the bay counties prior to 1900. With the decline of the building-stone industry in the early nineteen hundreds, there was a contemporary rise of the production of aggregate because of the great increase in the use of concrete in construction and road building. At the present time, the stone industry is centered around the production of aggregate in its various forms.

Sedimentary, igneous, and metamorphic rocks are all mined and used by the building-stone and aggregate industry of the San Francisco Bay counties. Hardness, coherence, workability, chemical stability and color are the principal characteristics which govern the choice of a rock for a given purpose. The principal rock types quarried in the bay region are sandstone and crystalline limestone from the Franciscan formation of the Coast Ranges; basalt, andesite, and rhyolite from the Berkeley Hills; and granite from the Sierra Nevada foothills of Sacramento County. In addition, there are imports of slate from El Dorado County and the eastern United States; granite from Fresno County, Georgia, and New England; marble from the eastern United States; and sandstone from Arizona.

Because most rock products are low-cost commodities there must be a local source of supply. Short-haul traffic in aggregate in the bay

area is the rule; long hauls are uncommon. Dimension stone, on the other hand, is shipped in from points as distant as New England, Georgia, and Europe largely because of long-established trade practices. Although many of the mining operations are large, continuous, and serve an extensive area, others are relatively small and operate intermittently to supply local needs. Some deposits have been worked only during the life of a single project, such as the construction of a large building, dam, or bridge.

Building stone and aggregate are almost always mined by open-pit or quarry. Great care and intimate knowledge of the rock are necessary for efficient quarrying of building stone. After quarrying the stone is dressed to size and shape, and may be polished to enhance the beauty.

The mining of aggregate must necessarily be simple to hold the cost down. Crushed stone is generally produced by running an open cut into a face of suitable rock. The rock is blasted down and transferred to large crushers by trucks, scrapers, or conveyor belts. After crushing it is usually screened, sometimes washed, and commonly stockpiled according to size. Sand and gravel are taken in much the same way except that most gravel banks are sufficiently unconsolidated to be dug with power excavators without blasting. In many plants oversize gravel is crushed and either sold separately or mixed with uncrushed material of the same size range.

The construction industry in the San Francisco Bay counties has available an adequate supply of aggregate of various types. Aggregate is produced in all of the counties, and in more than half of them it has been the most valuable mineral product marketed during recent years.

The first recorded development of the stone resources of California following the Gold Rush was in the foothills of the Sierra Nevada at Folsom, where granite was quarried for building purposes in 1856. The area remained one of the state's centers of granite production, and is still intermittently active. The heaviest and steadiest producer has been the Folsom State Prison where granite dimension stone, riprap, and crushed granite have been produced by prison labor for many years. Much of the granite dimension stone has gone into prison construction, but from 1888-90 Folsom Prison furnished the rock for the construction at Folsom of a dam, canal, and the first electric-power plant in central California. Riprap, rubble, and ballast from the prison quarry once were used extensively by the Southern Pacific Railroad. Sandstone from the Eocene Ione formation was quarried north of the Cosumnes River near Michigan Bar at an early date.

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FIG. 1. Pacific Coast Aggregates Company operation near Livermore, Alameda County. Rock, sand, and gravel are scraped from surface deposits by heavy earth-moving equipment, each unit carrying 20 tons. Material is gathered in a sub-surface hopper, fed onto a conveyor belt, and run through a washing, screening, and crushing plant. Sized material is then sent to stock piles via conveyor belts. Belt conveyors also connect the rail and truck-loading hoppers with the stock piles. In the background is the gravel pit and plant of Henry J. Kaiser Company. *Photo by Clyde Sunderland, Oakland.*



FIG. 2. An old photograph of the Healy-Tibbetts rock quarry crushing plant and loading dock near Winehaven, west of Richmond, Contra Costa County. Crushed rock once was shipped by barge in large open boxes as shown in the left middle ground. Quarry was in sandstone of the Franciscan formation. Site is now occupied by installations connected with the Standard Oil Company refinery at Richmond. Photo courtesy Pacific Gas and Electric Company.



FIG. 3. Colusa sandstone quarry near Sites, Colusa County, from which building stone for such San Francisco structures as the Ferry Building, St. Francis Hotel, and Flood Building was taken. Sandstone beds of Upper Cretaceous age range from 18 inches to 35 feet in thickness. Photo courtesy Pacific Gas and Electric Company.

The building stone from this deposit was used in construction in Sacramento, but production ceased before 1890.

Except for granite, quarried occasionally at Folsom prison, and some sand and gravel taken from the American River, there is no current production of dimension stone or aggregate from that part of the San Francisco Bay region that is within the Sierra Nevada province.

Because of the lack of rock exposures in the Great Valley, that area is largely dependent for aggregate upon extensive deposits of alluvial sand and gravel. The need for crushed stone is supplied primarily by crushing gravel obtained locally, and in part by crushing stone obtained from quarries in the Coast Ranges. Large-scale production of aggregate in this area did not begin until about 1900. In 1904 the total sand and gravel production for all of California was only 23,000 tons as compared with over 1,500,000 tons produced in Sacramento County alone in 1947.

Sand and gravel obviously may consist of a wide variety of abrasion-resistant rock types. The first sources were pits dug in

recently formed bar and channel deposits along streams flowing down from the Sierra Nevada. Gravel was removed by scrapers and drag lines. Older terrace gravels, which cover a large part of the valley, later became sources of sand and gravel, and still furnish most of the present production.

One of the largest operations in the Great Valley is at Fair Oaks, Sacramento County, where coarse dredge tailings are washed, crushed, and graded. In 1920 the plant was leased to the Coast Rock and Gravel Company. In 1929 that company was consolidated with Pacific Coast Aggregates, Inc., which now operates the plant. Pacific Coast Aggregates at that time also absorbed the Pratt Building Materials Company at Mayhew and Rhodes, Jamieson and Company, both in Sacramento County, and the Associated Gravel Company at Riverbank, San Joaquin County. What is probably a unique method of recovering sand and gravel is the large-installed suction pump operated by Robert Powell and Company. The rig operates along the American River, lifting gravel from the river bed.

Some of the large gravel pits most easily seen from the highway in the Great Valley are those of the Perkins Gravel Company on State Highway 16, near Perkins; the large plants and pits just south of the American River between Citrus and Fair Oaks; and two large gravel plants outside of Tracy on the Corral Hollow road.

Widespread exposures in the Coast Ranges of rock suitable for aggregate, together with gravel deposits of various sizes in the adjacent valleys, furnish an almost inexhaustible supply of stone for construction projects along San Francisco Bay. The greatest production comes from Alameda County where over 4,000,000 tons of aggregate are produced every year. Most of this is sand and gravel from the large pits around Pleasanton in the Livermore Valley.

The earliest use of stone in the Coast Ranges was by the Indians. They quarried obsidian, soapstone, red ochre, and chert in Sonoma County and red ochre and schist in Contra Costa County.

During the late eighteenth century and early nineteenth century, quarried stone and field stone were used in the construction of the missions and some ranch buildings. The principal building materials then used were wood and adobe, but stone entered into almost all of the structures to some extent. Commonly, stone was used in columns and foundations, and for trim.

The earliest stone building in San Francisco was constructed in 1854; dressed granite from China was used. Soon after this, granite from Folsom came on the market. In the sixties quarries were opened, on Angel Island in San Francisco Bay to furnish a bluish sandstone, and near Petaluma in Sonoma County for the production of basalt. During the eighties and nineties light-brown sandstone was quarried at Benicia in Solano County, and near San Jose in Santa Clara County. Sandstone of other colors was marketed from quarries near Alameda, Livermore, and Hayward in Alameda County during the same period, and some stone was imported. The Old Mint at Fifth and Mission Streets in San Francisco was constructed in the eighties of sandstone from New Castle Island in British Columbia.

Two of the most extensive and recent building programs using stone were at the University of California at Berkeley and Stanford University at Palo Alto. The University of California used gray granite from Raymond, Madera County. Stanford University used a local, light-brown sandstone from the Graystone quarries south of San Jose in Santa Clara County.

As macadam roads and concrete construction became more common, large quarries for production of macadam and crushed stone were opened in the hills around San Francisco Bay. Locations such as Angel Island and Point San Pedro in Marin County and Point Richmond in Contra Costa County were especially favorable because of the availability of satisfactory stone and cheap water transportation. The rock

at these localities is sandstone of the Franciscan formation. Basalt, limestone, chert, and sandstone from the Franciscan formation have been quarried intermittently at various other places on the San Francisco peninsula and in parts of Marin, Contra Costa, and Alameda Counties.

The gravel deposits of the valleys in the Coast Ranges have been most fully developed around San Jose in the Santa Clara Valley, at Pleasanton in the Livermore Valley, and on the Niles alluvial cone in southern Alameda County.

The best gravel operations to be seen from the highway in this area are the large Kaiser and Pacific Coast Aggregates gravel pits and plants about a mile east of Pleasanton on the road to Livermore. Rock quarries and crushing plants can be seen about 1½ miles south of San Rafael, and near Rockaway Beach on the coast highway in San Mateo County.

Glass sand and foundry sand, often considered to be kinds of aggregate, have been produced at various times in the vicinity of San Francisco Bay since 1920.

Glass sand was processed for the market for some years from a belt of Eocene sandstone south of Pittsburg and Antioch. The sands were washed to remove clay, and the remaining high-silica sand was used for making glass. At present the washed sand is used only as foundry sand. Foundry sand with a natural clay bond is mined from the Eocene Tesla formation at the old Tesla coal mine in Corral Hollow. This operation represents what is probably the only underground mining of aggregate material in the bay counties.

Foundry sand is also marketed from dune deposits in San Francisco and alluvial and marine sands in San Francisco County and northern San Mateo County.

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## VOLCANIC ROCKS USEFUL IN THE SAN FRANCISCO BAY AREA

By C. W. CHESTERMAN \*

Volcanic rocks in the San Francisco Bay area—lava flows, beds of tuff, agglomerate, and breccia—range in age from late Jurassic to late Tertiary. They are well exposed in almost all of the bay counties and cover extensive areas in Alameda, Contra Costa, Napa, Solano, and Sonoma Counties.

Numerous quarries in Marin, Napa, Solano, and Sonoma Counties that formerly furnished paving and building blocks now supply huge quantities of crushed stone for concrete aggregate and road metal. The demand for lightweight aggregate has increased the output of pumice from the tuffs, which formerly were quarried for building blocks. The rapid growth in the use and demand for expanded perlite as an industrial material, especially in the fields of lightweight aggregate, has developed much interest in this glassy volcanic rock.

Various volcanic rocks, especially the rhyolites which have the property of splitting readily along well-defined parting planes, are quarried at several places and sold as flagstone and colored building stone.

*Types of Volcanic Rocks.* There are several varieties of volcanic rocks in the San Francisco Bay area, ranging from basalt to rhyolite. Large areas are underlain by the older basaltic rocks of the Upper Jurassic Franciscan formation. Still larger areas are underlain by Tertiary and Quaternary volcanic rocks comprising a varied assortment of rhyolites, andesites, basalts, tuffs, agglomerates, breccias, and glasses. These rocks are described briefly in order of their decreasing silica content.

Perlite is a glassy volcanic rock, characterized by a so-called onion-skin fracture, and capable of breaking down into spherical fragments, many of which have a pearly luster. For a volcanic rock, a rather large amount of water enters into its composition. Perlite ranges in color from light to dark gray; some of it is reddish. When rapidly heated, perlite as well as many other volcanic glasses, expands into a frothy, white, pumice-like material which is of value as a lightweight aggregate in the building industry.

Obsidian is a glassy volcanic rock having a conchoidal fracture and the luster of common glass. Although usually black in color, obsidian may be red, brown, gray, or even greenish. Some of it is banded, owing to the concentration in layers of very small magnetite particles and embryonic crystals. An obsidian that contains appreciable amounts of quartz and feldspar usually is referred to as a vitrophyre.

Another variety of volcanic glass, pitchstone, differs from obsidian in that it has a pitchy luster, a subconchoidal fracture, and contains considerably more water (2 to 8 percent) than obsidian.

Pumice is a cellular volcanic glass formed by rapid expansion of gas contained in solidifying acidic lava. Most of it is light gray to white in color and occurs in tuffs or other pyroclastic rocks. The latter are made up of fragmental volcanic materials expelled from volcanic vents and deposited upon a land surface or in standing water.

Rhyolite is a common type of acidic volcanic rock in the San Francisco Bay area. It is multi-colored, normally has a porphyritic texture, and generally is characterized by phenocrysts or crystals of quartz, sanidine (a glassy variety of orthoclase), and biotite in a groundmass of minute crystals and volcanic glass. Many of the rhyolites show well-developed banding or flow structure, which developed while the rock was in a molten condition.

Trachyte, which occurs rarely in the San Francisco Bay area, is a light-colored rock resembling rhyolite. It has a porphyritic texture and contains phenocrysts of sanidine enclosed in a groundmass of small feldspar crystals. Quartz is normally absent. Hornblende and biotite are present and usually occur in well-developed phenocrysts.

Most dacite is light colored, ranging from gray through yellowish-brown to pink. Dacite is porphyritic and contains phenocrysts of plagioclase, hornblende, biotite, quartz, and sometimes hypersthene, enclosed in a groundmass of small crystals and glass.

Andesite is one of the most abundant volcanic rocks in the bay area. It differs slightly from dacite in containing little or no quartz. Most andesites are either dense and compact or else porphyritic. The porphyritic varieties contain phenocrysts of plagioclase, hornblende, and biotite enclosed in a fine-grained ground-mass of needle-like crystals of feldspar, with or without glass. Most of the rock is dark gray and may easily be mistaken in the field for basalt.

Basalt is also common in the bay area. It is a dark, dense rock ranging in color from greenish gray or brown to black. Porphyritic varieties are common, though the phenocrysts may be masked by the dark groundmass. With the aid of a hand lens, the constituent minerals can be recognized. Most of the phenocrysts are green and greenish-black olivine, black prismatic crystals of hornblende and augite, black platy crystals of biotite, and dark-appearing crystals of plagioclase set in a fine-grained aggregate of lath-shaped feldspar crystals and tiny prismatic crystals of augite. Jointing in many basalt flows is platy or columnar. Flow structures are common, as are cavities more or less filled with calcite, chaledony, or some variety of zeolite.

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FIG. 1. St. Helena Church, St. Helena, Napa County. Constructed in 1879 of rhyolite, andesite, and dacite.



FIG. 2. Cresta Blanca Winery, north of St. Helena, Napa County. Constructed in 1889 of dacite and rhyolite blocks.



FIG. 3. Cresta Blanca Winery, north of St. Helena, Napa County. Gate is made of field boulders of andesite and basalt.



FIG. 4. Stone fence on Silverado Trail, east of Yountville, Napa County. Built of field boulders of andesite, rhyolite, and basalt.

Tuff is a fine-grained, fragmental volcanic rock. It is made up of various types of volcanic material such as pumice, pumieite, rhyolite, andesite, and basalt, which have been expelled in the air from volcanic vents and deposited upon a land surface or in standing water. Tuffs may be either loosely consolidated or compact. In places they contain sufficient amounts of pumice to warrant mining as light-weight aggregate. Several of the more compact varieties of tuff in Napa and Sonoma Counties were formerly quarried for building blocks.

Fragmental volcanic rocks expelled from volcanic vents, but coarser than tuff, are called breccia or agglomerate. If the fragments are predominantly angular the rock is called a breccia; if the fragments are rounded it is called an agglomerate. In both types, however, the fragments consist essentially of various kinds of volcanic rock with minor amounts of non-volcanic rocks such as granite, limestone, sandstone, and shale torn from the vent walls.

*Older Volcanic Rocks.* The oldest volcanic rocks exposed in the San Francisco Bay area are the basalts, diabases, tuffs, and breccias of the Upper Jurassic Franciscan formation. For the most part, these rocks are so badly altered that they are easily mistaken for silicified shale or sandstone. Most of them are dark colored and fine grained, except for some coarse-grained porphyritic varieties of basalt.

One of the most interesting of these older volcanic rocks is the pillow basalt, a name applied to a lava which solidified, probably under water, into piles of pillow-like or bulbous bodies. The pillows range in size from a few inches to several feet in diameter, and many are indented. Pillow basalts are closely associated with the red cherts of the Franciscan formation. Good examples are exposed at Hunters Point in sea cliffs at Point Bonita; along Highway 101 about half a mile north of the Golden Gate Bridge; and in the canyon of Lagunitas Creek, about 5 miles east of Point Reyes.

Vesicular and amygdaloidal basalts are also interstratified with sedimentary rocks of the Franciscan formation. Many of these are greatly decomposed and form inconspicuous masses. Basalt in the form of a sheet is well exposed on the flanks of Cahil, Sawyer, and Sweeney Ridges, San Mateo County. Several other good exposures can be found in Marin County, especially north of Mount Tamalpais. Basalt and diabase also occur as intrusive plugs and dikes, which cut the sedimentary rocks of the Franciscan formation. Several of these intrusive bodies occur in Marin, San Francisco, and San Mateo Counties.

*Younger Volcanic Rocks.* Although some evidence of Eocene volcanism is presented by glass (tuff) shards in diatomite of the Markley formation, the earliest indication of widespread volcanic activity in the Tertiary period in the San Francisco Bay area is shown by the presence of Miocene lavas in the vicinity of the New Almaden

mine; along the crest of the Santa Cruz Mountains between Pilarcitos Creek on the north and the Santa Clara County boundary on the south; and in the hills west of the Stanford University campus. The New Almaden district lavas are flows of rhyolite or dacite; the Santa Cruz Mountains examples consist of diabase dikes, thin basalt flows, and a few beds of tuff; and the volcanics west of the Stanford campus are largely flow basalt. Miocene basalts are commonly amygdaloidal; the vesicle fillings may be calcite, chalcedony, quartz, analcite, serpentine, or even petroleum.

The Pinole tuff is probably the oldest Pliocene volcanic rock exposed in the bay area. In most places it consists of stratified tuff composed of white to yellowish-white pumice ranging from dust-sized particles to fragments as much as 2 inches in diameter; the tuff is commonly interstratified with beds of poorly consolidated sand and gravel. The presence of andesite fragments and a general lack of quartz indicate that it is andesitic in composition. The rock is well exposed along the shore of San Pablo Bay between Rodeo and Oleum and in road cuts along Highway 40 west of Pinole.

A tuff similar to the Pinole and of approximately the same age is exposed in Lawlor Ravine in the southwestern corner of Antioch quad-



FIG. 5. Napa Creek Bridge, northeast of Zinfandel, Napa County. Constructed in 1913 of perlite rock, dacite, and rhyolite.





FIG. 6. Bennett Mountain, five miles southeast of Santa Rosa, Sonoma County. West limb of a syncline made up of east-dipping flows of andesite, basalt, rhyolite, perlite, and beds of breccia, agglomerate, and tuff.



FIG. 7. Holt wine cellar on Holt Ranch, east of St. Helena, Napa County. Constructed in 1896 of perlite rock from quarry near site of cellar. *Photo by G. D. Hanna.*



FIG. 8. Baker Street, San Francisco. Looking south from Vallejo Street. Pavement made of basaltic paving cobbles. *Photo courtesy Bureau of Engineering, City and County of San Francisco.*



FIG. 9. Old St. Helena Winery, St. Helena, Napa County. Built in 1880 of rhyolite, andesite, and dacite.

range. Because it is found on the Great Valley side of the Coast Ranges it is considered a separate formation, and has been named the Lawlor tuff.

Leona rhyolite occurs in a belt along the west flank of the Berkeley Hills from the vicinity of Claremont Canyon through Leona Heights to Decoto. When fresh, the rock is light bluish green in color, contains scattered phenocrysts, and in places contains pyrite. Where abundant enough to form ore bodies, the pyrite was mined for conversion to sulfuric acid. Leona rhyolite is probably Pliocene in age.

A number of small, isolated patches of rhyolite are scattered along the front of the Berkeley Hills from North Berkeley to Richmond. They are remnants of a flow which, for the most part, has been removed by erosion. Rhyolite from these remnants differs from the Leona rhyolite in that the rock is less uniform, is commonly flow banded, and in places is glassy; pyrite is rare. The rhyolite in this group of occurrences has been named the Northbrae rhyolite; it is late Pliocene in age.

Andesite and basalt, together with associated tuffs, are exposed in road cuts along Grizzly Peak Boulevard and along trails through the Berkeley Hills behind the University of California, as at Bald Peak. There are two series of these volcanic rocks, one lying stratigraphically above the other but separated from it by lake-bed sediments.

The lower series, here designated the Grizzly Peak volcanics, lies above conglomerate, gravel, and clay of the Orinda formation of lower Pliocene age. The most interesting member of this series is a dense, dark-colored, amygdaloidal andesite containing large chalcedony amygdules or cavity fillings. The centers of some of these chalcedony amygdules may be hollow, the hollow being lined with quartz crystals to which may be attached crystals of calcite, natrolite, and analcite. Opal may be present either in amygdules or as fracture fillings. Above the amygdaloidal andesite is a group of flows of andesite and basalt interstratified with rhyolite and basalt tuffs and some gravel. Topping the heterogeneous assemblage just described is massive flow andesite which is in part predominantly crystalline and in part porphyritic with a glassy groundmass. Some coarse breccia is interbedded with the massive andesites.

The upper lava series, here called Bald Peak volcanics, lies on light-colored lake-bed shale, sandstone, clay, limestone, and chert of the Siesta formation of Pliocene age; these sediments in turn lie on the lower volcanic series previously described. The upper series consists largely of basalt flows. Basalt specimens are porphyritic, the phenocrysts being predominantly plagioclase, feldspar, and olivine.

Sonoma volcanics occupy extensive areas in Napa, Solano, and Sonoma Counties, and smaller areas in Marin County. They consist of lava, tuff, agglomerate, and breccia, which are predominantly

andesitic in composition but which include flows of perlite, rhyolite, dacite, and basalt; also present are various pyroclastic equivalents of these lava types. The Sonoma volcanics accumulated in a basin approximately 30 miles wide, which extended northwestward from Suisun Bay to the vicinity of Healdsburg, a distance of 50 miles.

The best sections of Sonoma volcanic rocks occur in the vicinity of Penngrove and Burdell Mountain; in the Sonoma Mountains; on the west slope of the Mayacmas Mountains; in Napa Valley; and in the Howell Mountains. They reach their maximum thickness of about 2000 feet near the crest of the Mayacmas Mountains. The lavas are commonly flat lying or nearly so but may be inclined as much as 30 degrees.

A prominent upper member of the Sonoma volcanics is called the St. Helena rhyolite. It forms conspicuous outcrops on Mount St. Helena as well as in most areas where Sonoma volcanics occur. Once considered to be trachyte, the member is now known to be largely rhyolite. The rock is coarse grained, bluish gray to white, and porphyritic; phenocrysts are sanidine, albite, oligoclase, and quartz; the groundmass is largely feldspar and quartz. In some places the rock is glassy and may grade into vitrophyre, perlite, or obsidian; flow banding is common, and multicolored, well-banded varieties have been extensively quarried for flagstone.

A very unusual variety of rhyolite occurs in the Sonoma volcanics east of Petaluma and east of Glen Ellen. It contains the bluish-black soda-amphibole, riebeckite, which has an intense blue color in thin section, and is a very beautiful mineral. East of Glen Ellen, extensive flows of riebeckite rhyolite extend along the west side of the Mayacmas Mountains, from the Valley of the Moon quarry to Santa Rosa Canyon. The rock varies considerably in character between these two places. At the Valley of the Moon quarry, where the riebeckite rhyolite is being quarried for building stone and flagstone, the rock is bluish-gray, banded, vesicular, and granular. Specimens are porphyritic, and contain phenocrysts of sanidine, albite, and quartz set in a microcrystalline aggregate of quartz and feldspar. Scattered through the rock are numerous small, black, needle-like crystals of riebeckite and stumpy prismatic crystals of aegirite, a soda-bearing pyroxene.

Farther north the riebeckite rhyolite grades into a denser rock. In Sonoma Canyon, about a quarter of a mile below the Golden Bear Lodge, it occurs in a flow which dips steeply toward the west. At the top of the flow the rock is dense and bluish-gray; but it grades downward to dark greenish-gray at the bottom. Throughout the flow it is porphyritic and contains phenocrysts of quartz, sanidine, and riebeckite enclosed in a dense groundmass of quartz and feldspar. No attempt has been made to quarry the rock in this locality; however, andesite which lies below the rhyolite was extensively quarried in a small hill on the southwest side of Sugarloaf Ridge.



FIG. 10. Riebeckite rhyolite in the Valley of the Moon flagstone quarry, northeast of Glen Ellen, Sonoma County. Flow banding and jointing are parallel. *Photo by H. Ries.*



FIG. 11. Holt perlite rock quarry, Holt Ranch east of St. Helena, Napa County. Note columnar jointing. *Photo by G. D. Hanna.*



FIG. 12. J. M. Nelson quarry, near Cordelia, Solano County. General view of crushing and screening plant and stock pile of crushed basalt.



FIG. 13. J. M. Nelson quarry. Rock is olivine basalt in flat lying flows associated with tuffs and breccia. The basalt is now being quarried for crushed rock. Formerly used in making paving blocks.

Perlite is another of the Sonoma volcanics which deserves special mention because of its present economic importance to the building industry. It occurs in flows and irregular lens-like bodies, associated with tuffs and other varieties of volcanic rocks; perlite flows may contain obsidian. There are numerous perlite flows southeast of St. Helena and on Taylor and Bennett Mountains southeast of Santa Rosa.

The Putnam Peak basalt occurs 6 miles northwest of Vacaville, on Putnam Peak in Solano County. The rock, which is in isolated patches, is dark and dense, and is vesicular near the upper surface of the flow; it contains phenocrysts of labradorite, augite, and olivine set in a microcrystalline groundmass of augite and feldspar. The dark color results mainly from small grains of magnetite which are scattered through the groundmass.

The Putnam Peak basalt represents fissure outpourings of lava more or less contemporaneous in age with parts of the Sonoma volcanics.

*Source of Volcanic Rocks.* Very little is known about the sources of volcanic rocks found in the San Francisco Bay area. A casual glance at a few of the more prominent peaks, such as Mount Diablo, Mount Tamalpais, Mount St. Helena, and Hood Mountain, might suggest that they are extinct volcanic cones and craters which at one time expelled tremendous volumes of volcanic ash and pumice and extensive lava flows. This, however, is not the case. Mount Diablo is made up of Franciscan, Cretaceous, and Tertiary sedimentary rocks and attained its elevation through mountain-building processes which involved faulting and folding, and not volcanism. Mount Tamalpais for the most part is made up of Franciscan sandstone, shale, and chert. Mount St. Helena is made up of volcanic and sedimentary rocks. True, it resembles an extinct volcano, but it too owes its elevation to mountain-building processes rather than volcanic activity around some central vent. Those who have made the pleasant drive along Highway 29 between Sonoma and Santa Rosa have undoubtedly observed a conspicuous peak rising abruptly on the east side of the valley a few miles north of Kenwood. This peak, known as Mount Hood, could very easily be mistaken for an extinct volcano. Detailed geologic mapping of this mountain and the surrounding country indicates that it is made up of a series of lavas, breccias, and agglomerates that dip steeply westward. These volcanic rocks rest unconformably upon Franciscan serpentine, and were probably expelled from fissure-like vents near by. It has been suggested that Taylor Mountain might have been a source for some of the volcanic material in that part of the area, but not enough detailed geologic mapping has been done to substantiate this view.

In all probability, most of the volcanic rocks in the San Francisco Bay area came from fissure-like vents which are now covered by vol-

canic debris. Some of these vents might well be located in the northern Mayemas Mountains southeast of Mount St. Helena, where considerable amounts of andesitic agglomerate and breccia are exposed. Similar agglomerates and breccias are exposed along Sugarloaf Ridge east of Kenwood, and there is a possibility that these fragmental volcanic rocks occupy the position of former fissure-like vents. The tuffs in the Merced (upper Pliocene) formation at Lake Merced in southwestern San Francisco, and other tuffaceous deposits in the Berkeley Hills, probably derived their materials from vents north of San Francisco Bay.

*Utilization of Volcanic Rocks.* Prior to the advent of the automobile, the bulk of the volcanic rocks quarried in the San Francisco Bay area—especially andesite and basalt—went into paving blocks for the streets of San Francisco and other thriving communities. From 1887 to 1913 at least 136 million paving blocks, valued at \$5,712,000, were produced from numerous quarries in Marin, Napa, Solano, and Sonoma Counties. However, as the use of the automobile increased, a need for smoother streets arose, and there was a sudden decline in the paving-block industry and an increase in the production of crushed rock for macadamized roads.

Many of the streets in San Francisco are still made of paving blocks, especially those on steep hillsides such as Broadway, between Leavenworth and Taylor, and Sanchez, between 18th and 19th.

Volcanic rocks were also used for curb and foundation stones. Considerable quantities of basalt and andesite were crushed in the early days for concrete aggregate and road metal. The Petaluma Rock quarry supplied crushed rock (andesite) for the State Highway near Ukiah in 1913.

Some of the volcanic tuffs, particularly the compacted varieties, were quarried for building purposes, especially for public buildings and bridges in the counties north of San Francisco Bay. The materials used consisted of andesite, dacite, rhyolite, and perlite.

A few deposits of rhyolite were quarried for flagstone and building stone. Minor amounts of loosely consolidated rhyolitic tuff were ground for abrasive purposes. Pumicite, a volcanic ash, was mined near Calistoga and sold under the name "C'allustro" for polishing. The largest amount of pumicite used for abrasive purposes came from deposits in the Merced formation near Lake Merced, San Francisco.

By 1913 approximately 74 quarries were in operation in the San Francisco Bay area. Of these, 43 percent produced paving blocks; 30 percent, building blocks; 25 percent, crushed stone used for concrete and road metal; and 2 percent, abrasives including ground pumicite.

The present uses of volcanic rocks in the San Francisco Bay area are rapidly changing to meet the demands for new products in construction and industry. Many of the old quarries that once produced

paving blocks are now overgrown with trees and creeping vines. Some of these quarries, however, that are favorably located with regard to transportation, are currently producing crushed stone for concrete aggregate and road metal. Quarries in volcanic tuffs that formerly produced building blocks are now furnishing tremendous quantities of pumice for lightweight aggregate. Flagstones, building stones, and decorative stones are finding widespread use in the building industry. Quarries in rhyolite of Sonoma Valley are probably as active today as they were in any preceding period.

A new volcanic rock industry has been developing since 1947 in the San Francisco Bay area—the expanding of perlite for lightweight aggregate. This industry is only in its infancy, but several perlite-expanding plants are already in operation. Plaster aggregate has been manufactured from perlite rock quarried on the Holt Ranch in Napa

County, and from the C. M. K. Quinlan Ranch in Sonoma County. Other deposits of this material will undoubtedly be utilized in the future. The search for perlite has shown that the rhyolitic rocks in the San Francisco Bay area contain numerous large deposits of expansible perlite. Many of these deposits are favorably situated in regard to transportation to this rapidly growing consuming area.

Expanded perlite is used principally for insulating and acoustical plaster, for soundproofing and insulating pre-cast wallboard, for an insulating medium without use of a binder, as in frozen food lockers, and for abrasives used in scouring soaps and cleansers. It is also used as a filler in paints and rubber, as a filter aid, as an absorbent material, as a soil conditioner, as an insecticide carrier, as poultry litter, as a catalytic carrier in chemical processes, and as raw material for the manufacture of rock wool.

## CLAY AND THE CERAMIC INDUSTRY OF THE SAN FRANCISCO BAY COUNTIES

By MORT D. TURNER \*

The earliest use of clay in the bay region was in fired-clay Indian artifacts. These have been found from time to time, both by chance and by planned archeological investigations of dwelling mounds in the southern Sacramento Valley. The most common and conspicuous objects of this nature are cooking balls made to heat food, pipes, and fish-net sinkers of various shapes.

Though the Indians knew how to fire clay, those in central California produced no pottery vessels, probably because their art of basket weaving was so highly developed.

With the coming of the Spanish in the late 18th century, unfired adobe brick, and fired roofing tile and brick were introduced. The missions all used roofing tile made and fired locally by mission workers; but the only known use of burned brick in the bay counties during the Spanish period was at Mission Dolores and the Presidio of San Francisco. All the ceramic work done in connection with mission construction ceased prior to 1832. Little or no roofing tile was made from that date until after the Gold Rush. Local needs were satisfied by salvaging tiles from abandoned missions.

The vast increase in population during the fifties created a demand for a local source for the fired clay objects familiar in the everyday life of the eastern United States, such as common brick, drain and sewer pipe, kitchen stoneware, and refractory brick. The first brick house in California was built at Suttersville, south of Sacramento, in 1847, and the first commercial brickyard was established in Sacramento by Ryan in 1854. In 1864 N. Clark and Sons established a pottery in Sacramento for manufacture of clay ware. This plant has been in almost continuous operation since that date, but was moved from Sacramento to its present site in Alameda in 1887. Issac Dobree and Brothers of Antioch produced fire brick, crucibles, and stoneware around 1868, using clay from the Black Diamond coal mine at Nortonville. For several years around 1913, Contra Costa County had the largest production of porcelain ware in California. California's flourishing commercial art-pottery industry, now the largest in the United States, began its present development about 1915. In that year one of the earliest bay area art potteries, The Tile Shop, was established in Berkeley. This pottery is now operated by California Faience Company and produces fountains, garden ware, and art-tile objects.

In the early days of the California ceramic industry, potteries and brickyards sprang up wherever there was a local market, for

deposits of red-burning clay suitable for brick and sewer pipe were available near almost all centers of population.

Most of the brick and sewer-pipe clay used was of alluvial origin and was found in the valley fill and flood plains of rivers and streams. This material was not only abundant and readily accessible to most communities, but most of it contained enough sand to prevent excessive shrinkage during firing. It also contained sufficient iron oxide to bring about vitrification at low temperatures and to give the desired red color to the brick and pipe. The bricks were hand molded and fired in field kilns in which local wood was used for fuel.

Stoneware and refractory brick needed a clay of better quality which would not fuse until higher temperatures were reached. When a clay was to be used in stoneware, it was also desirable that it burn to a pleasing tan color. Such clays were found in the newly developed coal mines in Contra Costa, Sacramento, and Amador Counties, and later in the coal mines of Alameda and Placer Counties.

In 1875 production of fire clay started in open pits at Lincoln, Placer County, and a large plant was built there to help supply the market for ceramic products in the bay counties. Fire clays from the coal mines of the Tesla region, near the boundary between Alameda and San Joaquin Counties, were brought onto the market in 1896.

By 1900 most of the production of clay from the Mount Diablo coal field had ceased, and in 1912 the clay pits at Tesla closed down. From the beginning of World War I to the present time, the main local sources of high-grade ceramic clay have been limited to pits in the Ione formation in the Sierra Nevada foothills. These pits are located principally around Lincoln, Carbondale, Ione, Valley Springs, Knights Ferry, and Michigan Bar.

Some types of clay not found in or adjacent to the bay counties in sufficient amount to supply the local demand are shipped in from considerable distances. Significant quantities of bentonitic clay are now coming into the bay region from the Mojave Desert, Wyoming, and South Dakota. Kaolin and china clay are brought in from the Carolinas, Georgia, and England. Ball clay comes from Kentucky, Tennessee, and England. Most of the clay imported into the bay area comes by rail, but some of the foreign and eastern clays come directly by sea; a small quantity, from nearby sources, is transported by truck.

Plants which produce ceramic products from clay in the bay region are concentrated around the larger cities; only a few are scattered in other parts of the bay counties. Such centers of ceramic production are in the Sacramento-Stockton region, in the San Francisco area, and around southern San Francisco Bay. In the Sacramento-Stockton

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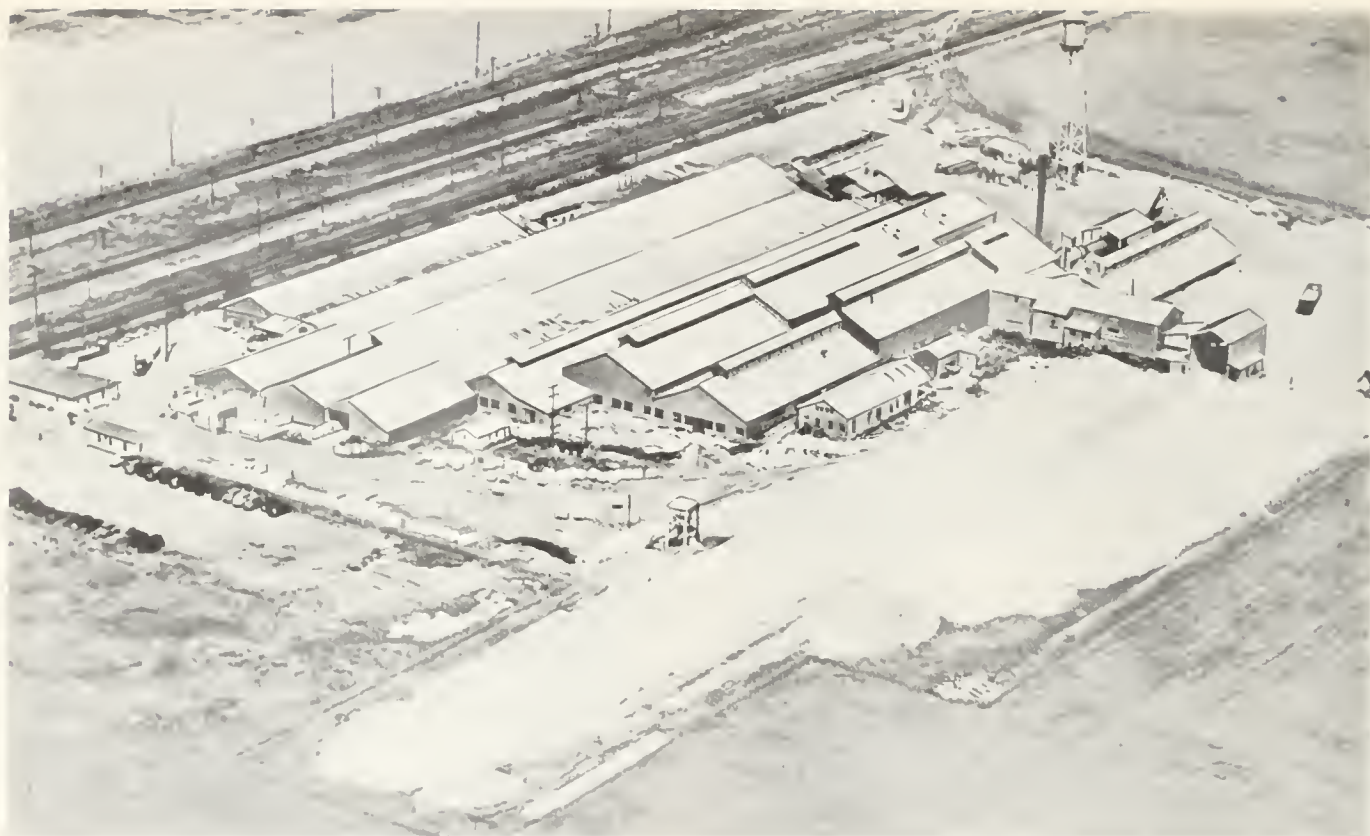


FIG. 1. Refractory brick plant of Gladding McBean and Company at Pittsburg, Contra Costa County. Plant utilizes high-grade clay and silica sand from Lone, Amador County, and clay from Lincoln, Placer County. *Photo courtesy Gladding McBean and Company.*

region there are eight clay-working plants; four are in Sacramento and four are in Stockton. Red earthenware, common brick, and various other heavy clay products such as sewer pipe, drain tile, and hollow building tile are made in both cities.

In Sacramento, Cannon and Company make pressed and fancy brick, drain tile and hollow building tile from local and Michigan Bar clays; Muddox Pottery utilizes local and Lone clays in drain tile, sewer pipe, and flue lining; Panama Pottery Company manufactures red earthenware from local clay; and Sacramento Brick Company makes common brick from local clay.

At Stockton, Laurel Potteries makes pottery dinnerware and bisque doll bodies. The plant utilizes white-burning clays from

Knights Ferry, Stanislaus County, and from the Ohio-Kentucky region. Stockton Brick and Tile Company makes hollow building tile, using Lincoln clay. Pacific Clay Products Company operates a large plant which produces sewer pipe, using Valley Springs clay. San Joaquin Brick Company makes common brick from local clay.

Two ceramic plants are operating in the north bay region, one at Pittsburg and one at Port Costa on Carquinez Strait. The Pittsburg plant of Gladding, McBean and Company is one of the largest refractory brick producers in the west. It utilizes clay and silica sand mined in the Lone district and shipped in by rail. Port Costa Brick Works makes common brick from blends of local clay shale from the Upper Cretaceous Chico formation and Lincoln clay.



FIG. 2. Ceramic ware plant of Krafftile Company two miles northwest of Niles, Alameda County. Glazed structural units, patio tile, and various kinds of special brick are the principal products. Plant consumes local alluvial clay and light burning clays brought from Lincoln, Placer County. Photo by Fred Mac, courtesy Krafftile Company.





FIG. 3. Brick kilns at Port Costa Brick Works. View north toward Carquinez Straits and Benicia.

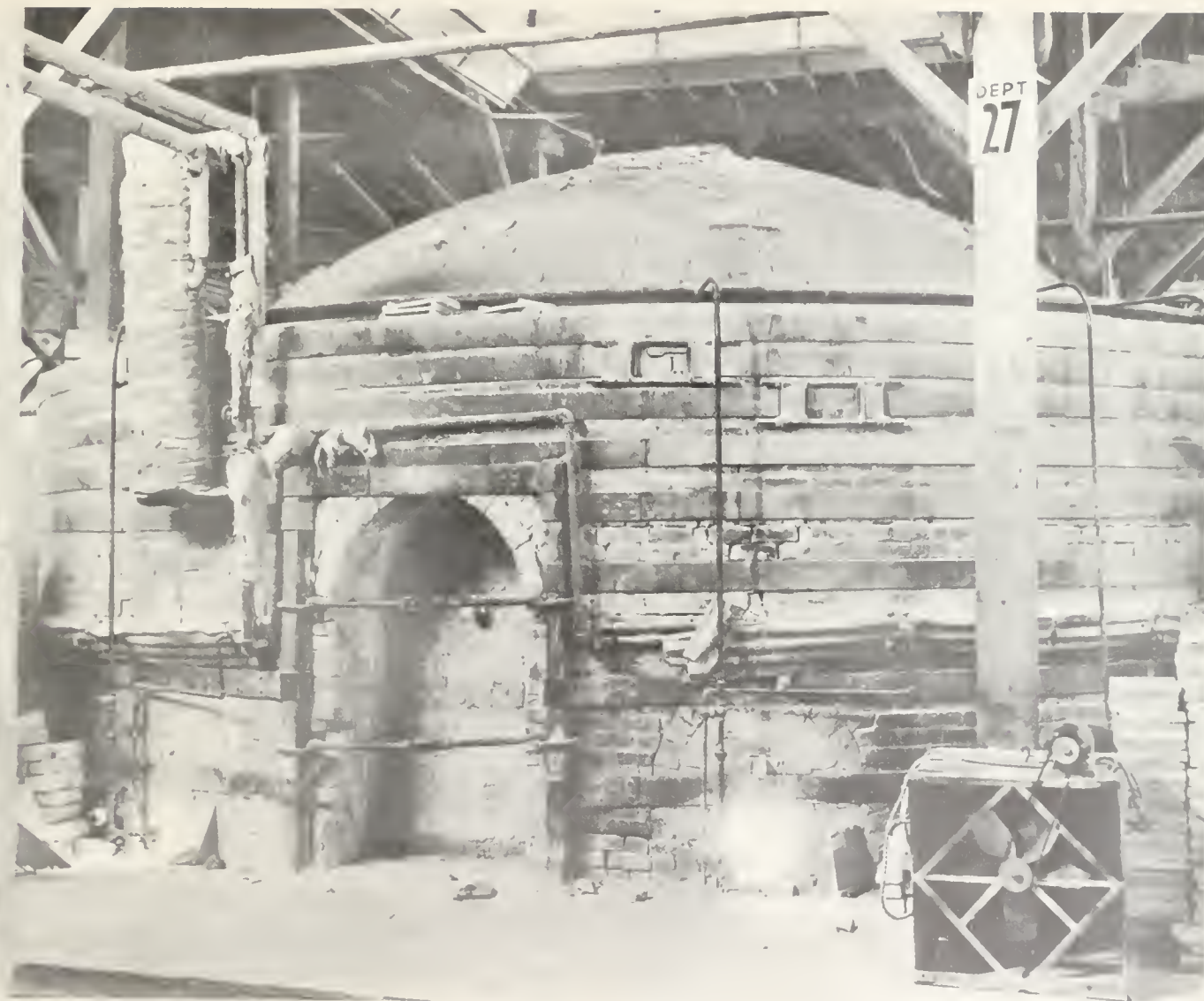


FIG. 4. Beehive kiln at California Art Tile plant, Richmond.

Clay products of the potteries of the San Francisco, east bay, and San Jose areas include terra cotta, white ware, refractories, tile, heavy clay products, and art ware. Three ceramic plants are located at Richmond. United Materials and Richmond Brick Company, Ltd., makes pressed and vitrified brick from shale quarried locally from the Franciscan formation; California Art Tile Company makes floor and wall faience, using Knights Ferry and Lincoln fire clay and Tennessee ball clay; American Radiator and Standard Sanitary Manufacturing Company produces sanitary ware from raw products from out of the state. Vitrified whiteware is manufactured at El Cerrito by Technical Porcelain and Chinaware Company, from Kentucky ball clay and Georgia china clay. Of the many plants which have been active in the Berkeley and Oakland areas in the past, only one, operated by the California Faience Company, is still running. It produces art pottery, garden ware, and art tile made from Ione fire clay and Humboldt County red-burning clay. In nearby Alameda a large sewer pipe and terra cotta plant is operated by N. Clark and Sons Division, Pacific Clay Products Company; red-burning clay from Livermore Valley and fire clay from Ione and Valley Springs are used there.

Four ceramic plants are operated in the Niles vicinity. Interlocking Roof Tile Company makes roof tile of special design, using local red-burning clay. M and S Tile Company produces machine-made and antique-style hand-made roofing tile from local clays. Kraftile Company makes structural clay products from local clays mixed with buff-burning clay from the Sierra Nevada foothills. California Pottery Company produces sewer pipe from blended local and Valley Springs clay. A fifth plant, near Niles at Warm Springs, is run by Laclede-Christy Clay Products Company and makes special glass tank refractory brick from Missouri bond clays.

At San Jose three operators make a wide variety of ceramic products. Gladding Brothers Manufacturing Company makes drain and roofing tile, chimney and flue lining, and sewer pipe from local and Sierra Nevada foothill clays. Garden City Pottery Company produces stoneware and red earthenware, using local clay for the earthenware and Lincoln and Ione clays for the stoneware. Remillard-Dandini

Company makes common brick from local clay. In the adjoining town of Santa Clara, Myers Ceramic Pottery manufacturers glazed wall and floor tile from raw materials purchased from local supply houses.

Numerous small private and commercial art potteries are scattered throughout the bay counties, especially in the vicinity of San Francisco. These activities cater largely to students and amateur ceramists, but a significant amount of art ware finds its way to the open market from such sources.

Deposits of raw materials of potential use to the ceramic industry exist in the San Francisco Bay region, which, for various economic reasons, are not now being exploited. New uses for idle materials are constantly being conceived. One of these new developments is an unusual material produced by the McNear Brick Company near San Rafael and marketed under the trade name "Haydite." Haydite is a lightweight aggregate used for lessening the weight of concrete structures; this material is made by burning selected shale from the Franciscan formation until it softens, expands, and becomes porous. The shale near San Rafael is better suited for this purpose than many others because it softens and expands at lower temperatures.

Mixtures of sand and clay from Corral Hollow, Alameda County, and similar deposits northeast of Mount Diablo might be mechanically separated to produce glass sand, china clay and various grades of fire clay. Research along these lines is currently being conducted by the Tesla Sand and Clay Company.

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## CERAMIC EDUCATION AND INDUSTRY IN THE SAN FRANCISCO BAY AREA

By JOSEPH A. PASK \*

Ceramic products are here considered to include all products made from nonmetallic inorganic materials, the processing of which at some stage requires the application of heat. The word *ceramics* had its origin in the Greek word *keramos*, defined as "burnt stuff" or burnt clay. *Keramos* in turn was derived from a much older Sanskrit word related to products made through the application of fire.

Ceramics, taken as a whole, constitutes a multibillion-dollar industry, most of the products of which have become essential in the conduct of the daily cultural life and industrial activities of civilization. Although the ceramic industry is large, it is carried on mostly by small and medium-sized plants. It is united mainly on a technological basis through mutual participation in the activities of the American Ceramic Society and Institute of Ceramic Engineers, and through educational and research activities on the part of universities offering such curricula.

*Education in Ceramics.* No formal training in ceramic engineering was available in this country until Professor Edward Orton Jr. started a course at Ohio State University in 1894. This was shortly followed by courses at Alfred, New York, University of Illinois, and University of Iowa. At present there are 15 major universities and colleges outside of the State of California which offer studies in ceramic engineering or technology.

The first courses in ceramic engineering in California were conducted by Professor Waldemar Dietrich at Stanford University from 1928-30. Some of his investigations resulted in the writing of *The Clay Resources and Ceramic Industry of California*, published by the State Division of Mines and Mining in 1928. Between 1928 and 1948 neither curricula nor courses in ceramics were available in California universities. Training in ceramic engineering was again started in the fall of 1948 with the establishment of courses under the Division of Mineral Technology in the College of Engineering at the University of California at Berkeley. In the fall of 1949 courses also were inaugurated in the College of Engineering at the University of California at Los Angeles.

In order to coordinate the activities on the two campuses and to avoid duplication of efforts, emphasis of the research program at Berkeley is on technology, but at Los Angeles is on engineering. On the Berkeley campus studies are made of raw materials, effects of impurities on them, phase rule, solid state reaction, and composition, together with effects of these factors upon production problems. In this work,

close cooperation is maintained with the State Division of Mines. Engineering studies at the University of California at Los Angeles will include forming, drying, firing, and measurement of the properties of ceramic products, as well as thermodynamic studies involving production problems. Stanford University does not offer courses in ceramic subjects. However, the Stanford Research Institute, located at Stanford, is undertaking research in ceramic problems.

Other ceramic educational activities in the San Francisco Bay area are represented by ceramic art courses at Mills College and California School of Arts and Sciences in Oakland, and at San Jose State College in San Jose. Some other colleges and high schools also maintain instruction in ceramic art or pottery.

*Magnitude of the Ceramic Industry.* At the time of the 1939 census, there were 231 ceramic plants in California; it is estimated that 77 of these, or 33 percent, were operating in the San Francisco Bay area. The census did not give statistics for individual counties. The number of plants was determined from manufacturers listings recently prepared from 1939 census lists by different Chambers of Commerce, and from partial returns of the 1947 census. As there is no other central source of such information, and as most of the source data are now more than 10 years old, there are probably some omissions in the above figures.

Preliminary figures for the 1947 census show 215 pottery plants in California and 491 in the nation, in contrast to 22 in California and 151 in the nation in 1939. In other words, in 1939 only 15 percent of the nation's pottery plants were located in California; whereas in 1947, 44 percent were located here.

The ceramic industry may be divided into six broad branches, and a seventh miscellaneous grouping, based upon the nature of the ceramic materials produced.

*Whitewares* are products fired to a white or nearly white color. Pottery is part of this group, as are earthenware, porcelain, and china dinnerwares, electrical porcelain (a general term for insulators of all kinds, including spark-plug bodies), and such structural products as floor and wall tiles, bathroom fixtures, and sanitary ware. Porcelain false teeth are also included in this classification.

*Structural clay products* consist mainly of bulky items used in construction. Most of them are reddish or brown in color, as common clays and shales from which such products are made contain sufficient iron to cause that range of coloration. In this group are common brick, face brick, structural tile, drain tile, roofing tile, and sewer pipe. Terra cotta, a facing material used chiefly in large buildings, is also

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a part of this group; clays for terra cotta, however, are carefully selected to produce lighter shades of color and to meet other requirements.

*Refractory* articles are capable of withstanding or resisting melting or fusion when exposed to high temperatures; many are also capable of withstanding abuse and deterioration of other sorts. These products are perhaps the least known to the average person, as they are used primarily by industrial plants. The light-colored brick which lines most fireplaces is a type of refractory or fire brick. Refractories are used in the construction of furnaces, kilns, stoves, fireplaces, open hearths, blast furnaces, incinerators, steel ladles, steam-generating plants, and the like. Variation in refractory products is more the result of composition than of shape and size, as various combinations of fire clays, silica, magnesite, zircon, silicon carbide, chrome, and alumina are used in their manufacture. The war has given impetus to extensive research on special refractories needed in construction of jet-propulsion engines, rockets, and atomic energy plants. Refractory materials such as silicon carbide and alumina, together with diamonds, constitute the basic abrasives; consequently, the abrasives industry is sometimes considered as a separate branch of the ceramic industry.

The term *glass* is broadly applied to products of a vitreous or noncrystalline nature, such as window panes, bottles, jars, lenses, or glass cloth. Glass is differentiated from other amorphous materials in that it is formed by fusion at relatively high temperature, largely of nonmetallic inorganic mixtures and compounds, such as sand, soda ash, limestone, lead oxide, and borax. Although most glasses appear similar to the casual observer, their compositions are varied in order to develop specific properties for specific uses.

*Porcelain enamels* are thin layers of glass of special composition fused onto metal, usually iron or steel; they differ from the organic finishes referred to as "enamels" without the qualifying term "porcelain." Porcelain enamels are vital to the manufacturing industries that utilize enamel-coated panels and shapes, particularly in the making of refrigerators, signs, kitchenware, stoves, and structural panels for store and theatre fronts. Considerable research has been and is being done to develop suitable glass coatings to protect metals against oxidation at high temperatures.

*Cement, lime and plaster* are powdered cementitious materials that have the property of setting or hardening when mixed with water. This property is developed by heating certain materials or groups of materials, such as a mixture of limestone, clay, and silica for portland cement; limestone for lime; and gypsum for plaster. These products are supplied to the construction operator who processes them on the job to obtain the serviceability desired.

Nonmetallic minerals include the raw materials upon which the ceramic industry depends. As most mineral materials require winning and beneficiation which does not involve application of high temperature, a consideration of them more properly falls within the domain of the mining industry. However, since the ceramic industry is concerned about the properties of its raw materials because of the effect they have upon the properties of the finished product, ceramic engineers and technologists do considerable work in this field. This is especially true in California and other western states where the problem of a suitable and adequate supply of raw materials is critical.

The chief attributes of the several types of ceramic products are durability when exposed to high temperature, to acids and caustics, to slag and metal melts, or to weathering.

Most people are familiar with the individual products appearing in the preceding outline, but few realize that the technology of plants producing them is similar or closely related, and that the various plants together form one great multibillion-dollar industry. This in many instances is also the case within the industry itself; that is, a number of glass plants or a series of brick operators may consider themselves allied under one type of enterprise; but they are not in the habit of affiliating themselves with the ceramic industry as a whole. One factor responsible for the development of this attitude is the highly competitive level on which ceramic products are sold. Another factor is that the ceramic industry perhaps has not advanced as far scientifically as some other industries, and there are still some ideas prevalent that existed during the period when the industry was an art of secret formulas and techniques handed down from father to son. However, this situation is slowly being changed.

*Raw Materials Utilized in the Ceramic Industry.* For many California ceramic plants the problem of obtaining an adequate supply of suitable raw materials is acute. Clays of high fusion point, and clays which fire white are particularly in demand. Consequently special clays, such as ball clay from Kentucky and Tennessee and china clay from the Carolinas, Georgia, and Florida, are shipped the long distances to California. On the other hand, red-firing clays used for structural clay products are sufficiently well distributed in California so that usable deposits can be located within a short distance of potential markets.

Silica, chiefly in the form of quartz, is another raw material used in almost every branch of the ceramic industry. The largest users are the glass industry; for glass, sand has proven the most satisfactory source of silica in California. This sand must have a very low iron oxide content, as iron has a strong discoloring effect. Large quantities of quartz are also used in refractory brick and shapes.

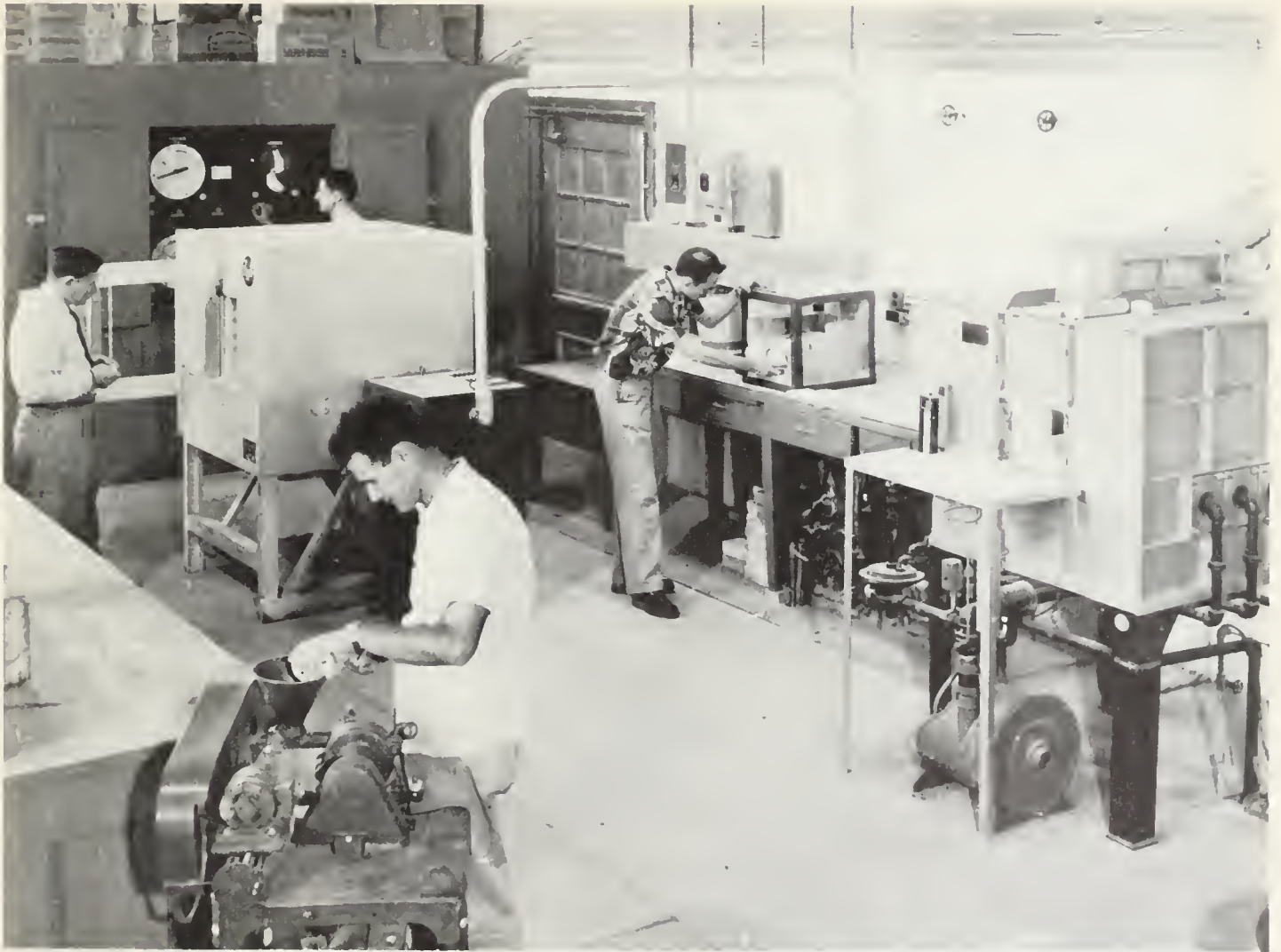


FIG. 1. Research workers in the ceramic laboratories of the University of California. *Photo by University of California.*



FIG. 2. Applying glaze to wall tile at California Art Tile Plant, Richmond. *Photo by Mort D. Turner.*

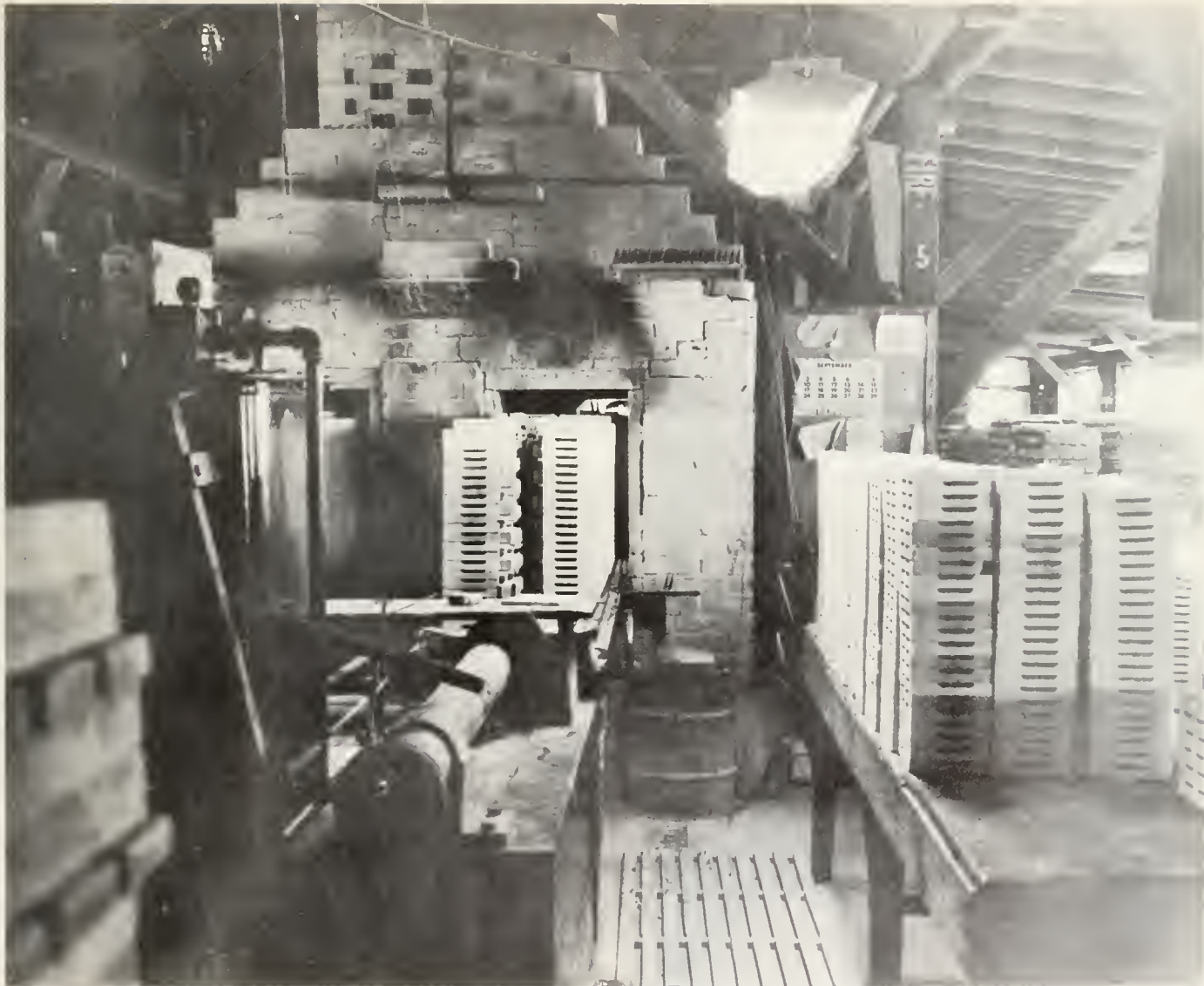


FIG. 3. Entrance to tunnel kiln at California Art Tile Plant, Richmond. *Photo by Mart D. Turner.*



Another scarce ceramic material is refractory clay. As the sale price of finished refractory products is low, shipment of refractory clays for long distances is not economically feasible. Therefore, not much top-quality fire-clay brick is manufactured in California; most of it is imported from eastern sources. Discovery and development of good refractory clays in California would be a boon to the refractories branch of the ceramic industry.

Other materials used extensively in whiteware bodies are feldspar and talc. Large deposits of feldspar as yet have not been found in California; but this state is one of the nation's leading producers of talc. Smaller amounts of limestone, magnesite, borax, soda ash, potash, and sodium nitrate are used in the ceramic industry.

*Processing of Ceramic Materials.* Processing of most ceramic materials involves weighing and mixing of various ingredients to form a ceramic "batch," after which the mix is formed into the desired shape, partially or wholly dried, and then fired at high temperature. The forming process may be dry-pressing, wherein only enough water is added to dampen the batch, and shaping is accomplished in a mold by application of pressure; extrusion, wherein sufficient water is added to form a plastic mass that can be extruded through a die; modeling, similar to extrusion, is shaping by hand; or casting, a process in which a rather large proportion of water is added so that a suspension or "slip" of required density and viscosity is formed. In casting the desired shape is obtained by pouring the slip into a plaster mould, deposition of a ceramic layer taking place on the mould because of the absorption of the water by the mould itself. After the layer is deposited, the excess slip is poured off.

Drying (a step necessary to remove water added for mixing and forming) and firing (which causes the reactions that produce hardness and other desirable properties in the body) are more or less universal procedures in all ceramic plants; the variations in procedure are mostly in design and operation of dryers, and furnaces or kilns.

In a glass plant, the forming process takes place after the principal firing period. The dry-mix batch is fed into a large rectangular furnace called a glass tank in which sufficiently high temperatures are maintained to melt the ingredients. The melt is cooled to a desired degree of fluidity under controlled conditions near the discharge end of the tank, and then is fed into forming machines which shape the glass article. During this step the temperature drops low enough to produce rigidity in the "formed" piece. After solidification the glass article is passed through a furnace known as a lehr at temperatures which do not melt or deform it, but only anneal it. Annealing or controlled cooling is necessary in order to prevent dangerous stresses which might be set up if the cooling were uncontrolled.

Processing of porcelain-enamelled articles is a modification of the procedure for glass. After fusion of the batch of special composition, the melt is poured into a water bath to form nodules, called frit. The frit is ground with other ingredients to form a slurry or enamel slip which is applied in a thin coating to a properly prepared metal surface either by spraying, dipping, or slushing. Afterward the article is passed through an enamelling furnace wherein the glass particles of the slurry coating are fused to form a continuous layer of enamel that adheres firmly to the metal surface.

Portland cement manufacture does not include a forming step in the sense of production of an article. The raw batch, wet or dry-mixed, is fed into a cement kiln, a long, tubular, slowly rotating furnace. The batch reacts to form crystalline compounds and emerges as nodules called clinker. The finely ground clinker becomes cement, and in this state reacts with water to form new crystals which may be employed to bind other materials together, as in concrete.

*Ceramic Plants in the Bay Area.* As might be expected from population concentrations, the majority of ceramic plants in the bay area are in Alameda, Contra Costa, San Francisco, and Santa Clara Counties. Napa, Solano, Sonoma, and Yolo Counties have none. All branches of the ceramic industry are represented somewhere in the bay area.



FIG. 4. Figure with flower container, designed by Adele Chase. Photo by Mort D. Turner.

## MANGANESE AND QUICKSILVER MINERALIZATION IN THE SAN FRANCISCO BAY REGION

By OLIVER E. BOWEN, JR. \*

Few residents of the metropolitan areas adjacent to San Francisco Bay think of their home counties as being or having been important as producers of metallic minerals. Nevertheless, manganese and quicksilver, two exceedingly critical materials in war time, are widely distributed through the hills adjacent to the bay, and more than \$63,000,000 has been realized from quicksilver and manganese mines within the 12 counties considered in this bulletin. The conditions under which these metallic ores were concentrated and preserved are sufficiently diverse to form an interesting geologic story.

*Manganese.* The initial event in manganese accumulation took place far back in geologic time, perhaps 100 million years, at a time when central California, as now outlined, lay beneath the waters of a shallow sea. A land mass of considerable relief existed at some distance to the west of the present coast line and stream systems on this land mass were depositing sand, clay, and some coarse detritus on the adjacent sea floor. At various times during this period submarine volcanic activity interrupted the orderly sedimentation on the sea floor. Tongues of molten rock penetrated the unconsolidated and partly consolidated sea-floor deposits, and at times flowed out upon the sea floor itself. Hot springs associated with the volcanic episodes evolved great volumes of silica-laden water which mingled with the sea water. Manganese and iron were likewise introduced by these thermal springs, but in smaller amounts. In response to falling temperature and probably to chemical interaction with dissolved materials in the sea water, these volcanic products settled to the bottom in the form of a silica gel. Over an indefinite period of time the gelatinous material became a solid mass of minute crystals mixed with glassy formless material. During this rock-forming process the siliceous solutions were transformed to porcelaneous chert; the manganese to manganese carbonate (rhodochrosite); and the iron to the red oxide, hematite. The almost invariable association of submarine volcanic rocks, chert, rhodochrosite or its alteration products, and hematite, together with normally stratified marine sediments containing fossils, leaves little doubt as to the environment in which the manganese accumulated. The chert commonly contains abundant microscopic marine fossils called radiolaria.

Following formation of the manganese deposits, continued deposition on a sinking sea floor resulted in burial of them to depths of many thousands of feet. Subsequently, in response to changing pressures within the earth's crust these marine beds containing manganese

were lifted above sea level, slowly folded into mountainous structures, and eroded until many of the manganese parts were exposed. This series of events probably required many millions of years.

By the action of various chemicals dissolved in percolating groundwater, the original minerals of the deposits, consisting of the gray to pink manganese carbonate rhodochrosite and the grayish-yellow silicate bementite, were converted to black oxides of manganese such as psilomelane, pyrolusite, and wad. In a few mines the original minerals rhodochrosite ( $MnCO_3$ ) and bementite ( $H_{10}Mn_3Si_7O_{27}$ ) have been preserved and can still be collected; in others only the earthy black oxide called wad, a mixture of several manganese oxides, and hard, massive material termed psilomelane can be found. The best places to observe and collect manganese minerals in the bay area are along the Corral Hollow road in the vicinity of the Ladd and Buckeye mines and along the Arroyo Mocho Road. Both these localities are southeast of Livermore in southwestern San Joaquin County and southeastern Alameda County.

*Quicksilver.* The conditions under which California Coast Ranges quicksilver deposits were formed were far different from those which accompanied the manganese mineralization. However, the two kinds of deposits have two things in common; both were probably dependent upon volcanic activity and both were most probably transported from deep volcanic sources to favorable places of deposition higher in the earth's crust as vapors or hot-water solutions. The volcanic episodes to which the quicksilver is related took place during a much later geologic epoch than did those connected with manganese accumulation. Quicksilver mineralization probably began less than 8,000,000 years ago; in a few places such as Sulphur Banks, Lake County, quicksilver deposition is still going on. This does not mean that deposition of quicksilver at any one locality lasted for 8,000,000 years, but rather that quicksilver emanations were given off from time to time over that period of years. Hence, the many deposits are not precisely contemporaneous in age. The exact amount of time consumed in formation of any given deposit is not known, but it is probable that some may have formed within a few tens of years while others required hundreds, thousands, or even millions of years. Few geologic processes are rapid when expressed in terms of human history.

If the quicksilver source is presumed to have been a volcanic one, the reader may wonder how the mineralizing vapors found their way from their source to positions remote from volcanic centers, and also what caused the vapors to deposit their metallic content.

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FIG. 1. Part of the mill at Mount Diablo quicksilver mine, located four miles southeast of Clayton, Contra Costa County. The large condenser tubes are a conspicuous part of most quicksilver refining mills.

Quicksilver deposits are always related to fissure systems, that is, a connected series of cracks which vapors and solutions can penetrate. Powerful stresses are being applied to various parts of the earth's crust and although rocks are elastic to varying degrees and may yield by bending or even by plastic flow, fracturing commonly occurs. Earthquakes are observable expressions of fracturing in the crust familiar to most Californians. As mountains are formed by severe crustal deformation it is, then, not surprising that the Coast Ranges embrace large fracture systems along which quicksilver in some places has penetrated.

Although faults and a myriad of lesser fractures act as avenues along which mineralizing vapor and solutions can migrate, these fractures seldom form cavities sufficiently large to accommodate the crystalline deposits as they are now found. How, then, do these deposits accrue?

Two factors make concentration possible. The first, and perhaps the most important, is that the chemical nature of the incoming material and of the rocks of the fracture walls is often such that there is chemical interaction between them. In this interaction quicksilver minerals are deposited as fast as the wall rock is dissolved by the

incoming solutions, the latter carrying away the products of decay of the wall rocks; this type of interchange is called replacement. The second is that differential movement may be repeated many times along a given crack during the period of mineralization, thus creating new openings at or close to previously initiated centers of deposition.

In addition to chemical interaction between incoming quicksilver-bearing mineral waters and susceptible wall rocks, deposition may take place in cavities and open fractures by any of several changes or combinations of changes. The most obvious and probably the most important of these are falling temperature and pressure as the hot materials rise toward the earth's surface. Interaction between incoming solutions from several different sources also may result in ore deposition near the point where the mixing occurred. Evaporation of water from mineralizing solutions may also raise the concentration of metal high enough to cause precipitation.

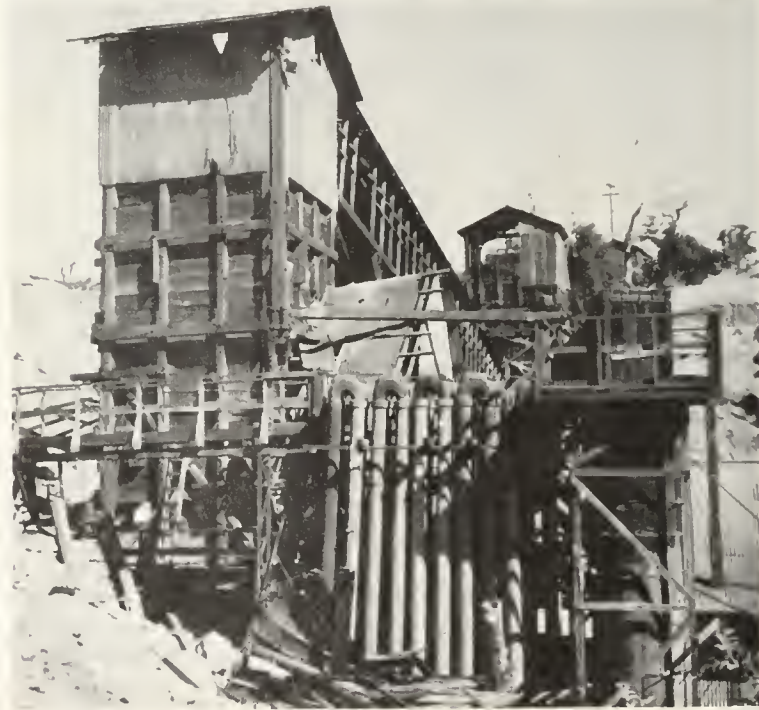


FIG. 2. Mount Diablo quicksilver mine and mill near Clayton. Formerly an underground mine, the operation was turned into a large-scale open cut working during the early 1940s. Although currently inactive, a large tonnage of low-grade ore remains in the deposit.



FIG. 3. Close-up of condenser tubes in a typical quicksilver-refining mill, New Idria, San Benito County. *Photo courtesy Pacific Gas and Electric Company.*

So far, the control of interconnecting fractures has been stressed; but the location of impervious rocks in relation to these fissure systems is also of prime importance. Although some sizable deposits have accrued by simple replacement of wall rocks adjacent to fissures, most of the large ore bodies have formed against impervious barriers which either halted the flow of mineralizing solutions in the fissure system or else slowed them to near-stagnation. Under stagnant conditions more time is available for changes in temperature, pressure, and con-

centration to make deposition effective. Fissures may be capped or otherwise obstructed locally by clay, igneous intrusions, or finely ground vein material. Abrupt change in direction of a fissure may also inhibit the movement of vein solutions sufficiently to produce deposition, particularly if the bend is such that a nearly vertical fissure becomes nearly horizontal. Low-angle faulting may truncate a vein system and throw an impervious body of rock across the fissure up which the mineral solutions are travelling. In the New Idria mines in San Benito County, the mineral traps were caused predominantly by overthrust faulting. At New Almaden, in Santa Clara County, the ore bodies occur predominantly in an overthrust anticlinal (arched) structure in which a body of serpentine and clay forms the impervious cap. Structural traps in the Oakville district, Napa County, are formed largely by abrupt changes in direction of the fissures.

The field conditions under which quicksilver occurs may be observed at many places in the bay counties. Some of them are readily accessible from paved roads; others can be reached only with difficulty. Although the general field setting of the deposits is easily seen, it is usually hard to find quicksilver minerals either in place in the mine or in broken rock on the mine dumps. Quicksilver is readily extracted from its ores simply by heating the rock in retorts and condensing the mercury vapor. Consequently, even low-grade ores have been thoroughly gleaned, and it is difficult to locate even ordinary specimen material. Many mine workings are either caved or flooded and should be entered with extreme caution.

Six quicksilver districts are worthy of mention, one of which is located within 30 miles of San Francisco. This is the Mount Diablo district, reached via Marsh Creek road and located 4 miles southeast of Clayton. Here the open workings are visible from the road. Quicksilver was recovered from a zone of porous opaline rock locally called "quicksilver rock." The Mount Diablo mine, largest in the district, was operated from 1936-46 but has since been idle.

The New Almaden district, located in Santa Clara County near the town of Almaden and accessible by paved road from both San Jose and Los Gatos, has been the most important producer of quicksilver in the United States. The value of quicksilver produced exceeds the value of output of any gold district of California of like size. Although the New Almaden district mines are now idle, they are by no means exhausted.

A third important quicksilver-producing area includes the Maacmas and Oat Hill districts, located in western Napa and eastern Sonoma Counties near the towns of Aetna Springs, Middletown, and The Geysers. Many of the old mines are accessible from the Calistoga-Middletown segment of Highway 29; others from the paved Calistoga-Pope Valley-Middletown road.

The Oakville quicksilver district adjoins the Mayaemas district on the southeast and includes a group of mines situated in the hills west of the towns of Oakville and Rutherford in Napa County. These may be reached by side roads which, 7 miles northwest of Calistoga, connect with Highway 28. Dumps of one of the mines, the Bella Oaks, can be seen to the west of Highway 28 northwest of Oakville, 1½ miles. Principal mines of the district are the La Joya, Bella Oaks, and Summit. Mineralization is similar to that of the Mayaemas district.

A small quicksilver-bearing area is situated north of Sulphur Springs Mountain 2 miles south of Highway 40 and 6 miles northeast of Vallejo. The locality is best reached via the Sulphur Springs road, but it is necessary to travel some distance on foot in order to reach the mines. The St. John and Hastings mines were the principal producers. A small quantity of quicksilver was shipped from the St. John mine during the recent war years. Ore occurs in silica-carbonate rock adjacent to an andesite intrusion.

Another small quicksilver-mining district is located near the town of Guerneville in north-central Sonoma County. It is accessible from Highway 12, which traverses the famous Russian River country; Guerneville is 18 miles west of Santa Rosa. A paved road from Guerne-

ville connects with the two principal mines, the Mount Jackson and the Great Eastern, via Fife Creek Canyon. The ore bodies are found in yellowish-brown silica-carbonate rock in which opal is a common mineral associate.

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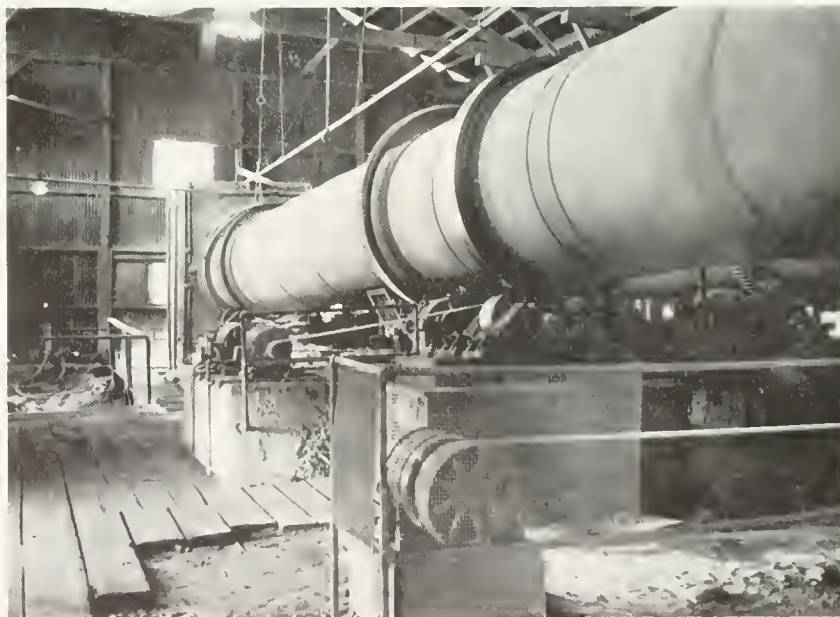


FIG. 4. Inclined kiln for roasting quicksilver ore at New Idria, San Benito County. The mines are wartime sources of vitally important quicksilver. Photo courtesy Pacific Gas and Electric Company.

## THE NEW ALMADEN QUICKSILVER MINES\*

By EDGAR H. BAILEY †

The New Almaden quicksilver mines are located a few miles south of San Jose, in Santa Clara County, California, in an area largely devoted to ranching and cattle grazing. Now, because the mines have been comparatively inactive in recent years, most of the inhabitants of the bay area, and even of the areas close to the mines, appear to have little idea of their former prominence, or the important role they played in the history of the bay region. This is surprising when one realizes that the largest of these mines—the New Almaden mine proper—is older than any of the gold mines of the state, has been in operation over a longer period of time, and has yielded metal of greater total value than any other metal mine in California. It alone produced over 1,000,000 flasks ‡ of quicksilver, or about a third of the entire production of the United States. Except for the Guadalupe mine, whose production ranks sixth in California, the other mines in the New Almaden district are small.

The history of the discovery and development of the New Almaden mine is fully as fascinating as that of the better known mines of the Mother Lode, but unfortunately it has never been popularized by a Bret Harte or Mark Twain. To be sure, the recently published book *Vermilion* by Idwal Jones has the New Almaden mine as its principal locale, although it is referred to by a different name; but, except for the general setting, this interesting book is strictly a novel and does not deal with the true history of the mine.

*History.* The original discovery of the bright-red, eye-catching mercury sulfide, the mineral known as cinnabar, probably was made long before white men reached California. According to an oft-repeated legend, Indians living on a low foothill of the Santa Cruz Mountains, known as Los Capitancillos Ridge, knew of a "red cave" to which their forefathers had retreated to paint their bodies with the vermilion found along its walls. The red paint made from this rock caused skin eruptions, and, believing the cave to be possessed of an evil spirit, the Indians thereafter shunned it. This legend is somewhat supported by tales of early visitors to the New Almaden mine, which mention an old 50- to 100-foot irregular opening or tunnel which when cleaned out, was found to contain a number of Indian skeletons together with rounded boulders that might have been used in making the crude excavation. Corroborative evidence is also contained in reports of early explorers who found that Indians in other areas obtained vermilion by trading with those of the New Almaden region.

In contrast to the legendary nature of the Indians' discovery of the ore on Mine Hill, the details of its rediscovery in 1824 by a Mexican named Luis Chaboya are well authenticated. Chaboya believed the heavy red cinnabar formed a rich ore of silver rather than of quicksilver, and together with two others began mining it at what he termed the Chaboya mine. After erecting a mill in the nearby canyon he sent to San Luis Obispo for a flask of quicksilver to use in amalgamating the silver, but, as the ore yielded no metal, the mine was abandoned. Eleven years later, in 1835, a second unsuccessful attempt was made to recover silver from the ore. Thereafter for 10 years the heavy red ore remained a well-known curiosity, but no one realized that it contained the mercury-bearing mineral cinnabar.

Late in 1845 a Mexican army officer, Don Andrés Castillero, dispatched from Mexico to attempt to purchase Sutter's Fort for that country, paused in his journey from Monterey to the fort at the Santa Clara Mission, about 15 miles from the mine. His curiosity was aroused by a piece of the ore shown to him, and after visiting the mine he returned to the mission where on November 22, 1845, he denounced § the mine, naming it the Santa Clara and claiming it contained "a vein of silver and a little gold". Possibly Castillero may have taken a piece of the ore along with him on the rest of his trip to Fort Sutter in order to ask those he met about it. In any event, on December 3, 1845, he returned to the mission and proved the ore contained mercury by sprinkling a little of it on hot coals and condensing droplets of the metal on an inverted tumbler placed over the ore. Following this demonstration, which confirmed the first discovery of quicksilver ore in the North American continent, Castillero claimed that quicksilver also occurred in the ore of the Santa Clara mine, and on December 30, 1845, he was awarded possession of the mine property by Antonio Maria Pico.

Castillero immediately formed a mining company, and, as production was required to hold his title, employed William Chard of New York to get the mine into production. This Chard quickly did by making a crude retort formed by a battery of six gun barrels which were charged with small pieces of cinnabar, and with remarkable persistence in face of the small recovery, he successfully employed this method for some 4 to 6 weeks. Soon, however, to increase the size of the charge of ore, he made use of whalers' trying pots by placing them upside down over a pile of ore and building a fire on top. Although

\* Published by permission of the Director, U. S. Geological Survey.

† Geologist, U. S. Geological Survey.

‡ A flask containing 76 pounds of quicksilver is the standard unit of sale for this metal throughout the world.

§ At that time mining discoveries were "denounced" or proclaimed, no real claim could be made as the ore-bearing land, like other land, was the property of the governing country until bestowed upon one as a gift by its king or governing official.

a large amount of quicksilver must have been lost as fumes, he recovered some 2,000 pounds of metal by this ingenious method.

Meanwhile Castillero returned to Mexico City to obtain financial aid for the development of his mine. After several disappointments he sought capital from Barron, Forbes & Co., an English banking firm doing business in Tepic, Mexico. This company took a 16-year lease on the mine, gave it, without even seeing it, the optimistic name of the New Almaden mine after the world's greatest quicksilver mine in Spain, and dispatched Alexander Forbes from Mexico with miners, money, and materials to initiate large-scale production.

Little is recorded about activity at the mine during the next few years, but the establishment apparently grew rapidly. Although new and better furnaces were added for the reduction of the ore, the mining methods used by the Mexican miners remained those which had been used for hundreds of years in the mines of Mexico and Peru. The miners carefully followed leads up and down in tortuous passageways, digging out "rooms" wherever they encountered pods of rich ore, and the resultant workings near the top of Mine Hill have been described as resembling "rabbit burrows". This early erratic development must have been yielding ore in quantity, although no production was recorded until 1850. In that year the large amount of 7,723 flasks was reported, and the following year's production increased to 27,779 flasks—an amount comparable to the average annual production of the entire United States over the last 20-year period.

While Barron, Forbes & Co. were bringing the mine up to a production of over \$1,000,000 worth of quicksilver a year, other events which profoundly affected the subsequent history of the mine were taking place. Gold was discovered in California, and the New Almaden mine became the principal source of the quicksilver vitally needed for its amalgamation; California was admitted as a state on September 9, 1850; and arguments between "squatters" and holders of real or fictitious land grants from Mexico became commonplace.

To settle the land disputes Congress passed in March 1851 an Act establishing a Board of Land Commissioners in California to which persons claiming title to property by virtue of a Spanish or Mexican land grant should present claims within 2 years under penalty of loss of the land to the public domain. One of the most valuable pieces of land held under such title was the New Almaden mine property which involved three different grants. The legal battles for its ownership were fought through state and federal courts and finally settled by international arbitration.

Two of the titles to parts of the New Almaden property resulted from agricultural grants, with the vaguely defined line of separation passing close to the center of the mine area; a third title to an overlapping circular area about the mine resulted from the original mining grant to Castillero. Barron, Forbes & Co. had obtained possession

of Castillero's grant and one of the agricultural grants, but the other agricultural grant came by a series of deals into the hands of the newly organized Quicksilver Mining Company, an eastern concern. Each company duly presented its claim to the Board of Land Commissioners, and, oddly enough, each title was declared valid, leaving the ownership of the mine as muddled as before.

To settle this dispute, early in 1858, Edwin M. Stanton was sent to California by the Attorney General of the United States with the result that, after an exceedingly colorful trial which lasted for weeks, Castillero's title was declared void and an injunction was levied on the mine. Barron, Forbes & Co. consequently stopped mining on October 31, 1858, after having recovered about a quarter of a million flasks of quicksilver that sold for more than \$10,000,000. In January 1861, however, when the court decision had been appealed to the U. S. Supreme Court, they again began operating the mine even though the injunction had not been lifted. When the Supreme Court also decided against them, they continued to operate in defiance of the U. S. Government, which led to one of the most interesting events in the history of the mine and one which might easily have changed the course of the progress of two western states.

On May 8, 1863, President Lincoln dispatched Leonard Swett to California bearing a writ ordering C. W. Rand, the U. S. Marshal for northern California, to enter onto the New Almaden property, to put off the operators by using force if necessary, and to turn over the property to Swett. Apparently Swett, a trusted friend of Lincoln, had been contacted by the still active, although mineless, Quicksilver Mining Company, for he arrived in San Francisco accompanied by its president, S. F. Butterworth. When these two, accompanied by Rand, reached the mine they were refused entry, and the refusal was backed by 170 tough miners armed with rifles and shotguns. The official party hastily withdrew, and the federal cavalry were ordered in readiness to march from Sacramento and seize the mine. Before this could be done, however, public opinion was inflamed by scorching editorials in the newspapers which suggested that the Government was planning to seize all mines, and, because of the importance of mining in California and Nevada, the citizens of these states were clamoring to withdraw from the Union and join the southern states in the Civil War. The Governors of California and Nevada, and other influential friends, sent frantic wires to Lincoln requesting he rescind his order; this he did in a telegram that explained that no wholesale seizure of mines was contemplated. Thus the carefully planned scheme of the Quicksilver Mining Company was thwarted by public opinion, but on September 1, 1863, this company obtained title to the property through arbitration by King William I of Prussia by payment of \$1,750,000 to Barron, Forbes & Co.

When the Quicksilver Mining Company took over the New Almaden mine it had been developed to a depth of about 600 feet beneath the original outcrops near the apex of Mine Hill, but the ore that had been followed downward in a compact group of large stopes seemed to be bottoming. In spite of a prevalent belief that the deposit had been largely exhausted, the new company began extensive lateral exploration and almost immediately was rewarded by finding some of the largest and richest masses of ore ever developed in the mine. During the next few years the mine prospered, the six furnaces with a combined capacity of 300 tons yielded a steady stream of liquid metal, and the nearly 2,000 Mexican employees and their families living on Mine Hill enjoyed a period of high wages. The mining camp became known throughout the state for its boisterousness and lawlessness; in fact, it is said to have been a dull pay-day evening which did not produce at least one fatal stabbing. After 7 prosperous years, however, the ore bodies were again apparently near exhaustion, and the grade of the ore had fallen to the unprecedented low level of only 5 percent of quicksilver.

In the summer of 1870 J. B. Randol, the New York secretary of the Quicksilver Mining Company, was sent to the mine as its new general manager. Although he had absolutely no mining training, his marked executive ability and good judgment proved his appointment had been a wise one. During his first year he was content to let his mining captains direct the underground operation while he merely observed, but he immediately set about to change the surface camp from a notoriously lawless and dirty one to an outstanding community. To accomplish this he adopted the autocratic method of posting edicts in both English and Spanish on a great many bulletin boards throughout the camp, and then he saw to it that they were carried out. The methods by which his orders were enforced are well illustrated by the story of one gambler who refused to leave the camp when ordered because he owned his house if not the ground on which it was standing. When the gambler still remained after his allotted time, the camp constable and a crew of carpenters seized his house, sawed it into pieces, loaded it into wagons, and transported it several miles to a point beyond the company property where it was unloaded and reassembled. Needless to say, by such methods Randol quickly reformed the notorious but highly colorful Spanish camp.

Also on Mine Hill a smaller and far more orderly English camp gradually had grown up. This camp was populated chiefly by Cornish miners trained in the Almaden mine in Spain, and was located around the site of the present mine office buildings. Now, only a very few of its original structures are still standing. A third community, populated by a small group of "white-collar" workers, developed along the canyon floor downstream from the old furnace buildings, at the place where the town of Almaden now is located. Some of its old

wood and adobe houses are still in use, and the palatial "Casa Grande," formerly occupied by Randol, has now been converted to the clubhouse for "Club Almaden" near the mouth of the canyon.

It soon became obvious to even an inexperienced mining man like Randol that unless new mining practices were employed, full production could not be maintained because of dwindling reserves and rising mining costs. Ore was now being mined below the main access tunnel on the 800-foot level, up to which it had to be carried on the backs of the miners. In order to explore down the inclination of the known ore shoots at greater depth Randol decided to begin the first of the more than a dozen shafts that eventually were put down on the property. This shaft, known from the first as the Randol shaft, was begun in June 1871, and because of Randol's lack of mining experience it was very small and contained only a single hoisting compartment. As it was destined to serve as the principal outlet for most of the ore mined in the next 20 years, this error in judgment profoundly affected the rate of production, and consequently the profits of the mine. Because of the primitive methods employed, the sinking of the shaft did not reach the 1100 level until 1874, but, when a crosscut was run in search of the downward continuation of the ore on this level, it penetrated a body of good ore and followed it for a distance of 250 feet. This wide ore body was the cause of considerable rejoicing as drifting on higher levels had found only small pods of ore which were quickly exhausted, and production during 1874 had been the smallest since 1850, the first year of recorded production.

Attempts to supply the insatiable furnaces resulted in new and costly development. Two large deep shafts were put down north and west of the Randol shaft, but although these were equipped with very massive steam hoisting engines they were so situated that they failed materially to alleviate the hoisting burden of the Randol shaft. Other attempts were directed toward exploiting, by means of other shafts, little-developed prospects on the periphery of the main mine. Workings driven from several of these actually encountered ore bodies, but they proved to be relatively small and to die out above the 900-foot level. More ambitious was the attempt to drive a mile-long adit from the canyon above the Hacienda to a point under the center of Mine Hill to serve as both a drainage and haulage outlet. However, after an 8- by 8-foot adit had been driven more than half way, the project was abandoned.

In 1889 J. B. Randol, who had become a wealthy man, elected to leave the New Almaden mine. When he had arrived the known ore bodies were believed to be nearly exhausted, and mining was becoming increasingly costly. By farsighted but expensive development work he had nearly doubled the production, paid off an outstanding debt, and returned as dividends about half a million dollars to the stockholders. However, by the time of his departure the outlook for the mine





FIG. 1. An old photo of the southeast slope of Mine Hill, New Almaden, Santa Clara County, showing the lower section of the Mexican camp. The level area in the right foreground is a planilla or ore-cleaning ground. *Photo courtesy Jimmie Schneider, San Jose.*



FIG. 2. Spanish town and the China mine dumps at New Almaden, about 1875. *Photo courtesy Jimmie Schneider, San Jose.*



FIG. 3. Mine buildings and houses in the vicinity of the St. George shaft, Kenpville, New Almaden, 1889. *Photo from Bulmore Winn collection, courtesy Jimmie Schneider, San Jose.*



FIG. 4. New Almaden in the early 1860s. Opening of the main tunnel is in the left middle distance. The shed and large level area to the right of it were used to stack and sort ore coming from the tunnel. These level cleaning grounds were called planillas by the Mexicans. Compare this photo with Figure 1, taken in the same direction at a much later date. *Photo of an old drawing, courtesy Jimmy Schneider, San Jose.*



FIG. 5. Mule-driven windlass for hoisting and lowering the skip (shaft car) in the prospect Shaft No. 1 at New Almaden, 1880. *Photo courtesy Jimmie Schneider, San Jose.*



FIG. 6. A working face in the New Almaden Mines showing detail of the massive timbering used to support the ceiling and walls. Note the large rectangular hand-wrought spikes in one of the timbers on the right. *Photo from the Bulmore-Winn collection, courtesy Jimmie Schneider, San Jose.*



FIG. 7. The Hacienda and Hacienda Store at New Almaden in the 1890s. *Photo from Bulmore-Winn collection, courtesy Jimmie Schneider, San Jose.*



FIG. 8. Hanging "Judas" in effigy during a celebration of Holy Week in the Mexican camp at New Almaden, about 1880. *Photo from the Bulmore-Winn collection, courtesy Jimmie Schneider, San Jose.*

was quite comparable to what it had been on his arrival. A great deal of money had been spent on useless shafts, the known ore bodies were nearing exhaustion, and production had fallen to 13,000 flasks a year, recovered from ore containing 1.73 percent of quicksilver. No dividends had been paid for the last 8 years, and little capital was available for the search for new ore bodies. Mine Hill was considered to have been thoroughly explored, and during the last few years workmen who had spent their entire lives on the New Almaden property had been dismissed.

Direction of the declining mine for the next 20 years became successively the responsibility of three individuals who had all worked under Randol and were thoroughly familiar with the extensive underground workings, which by now totalled more than 30 miles in length. These men felt real affection for the old mine and put forth every effort to maintain production with the limited capital at their disposal. The first, Captain James Harry, put down another shaft close to the mine camp and found an entirely new ore body in the supposedly exhausted mine. This body, which became known as the Harry ore body, proved to be extensive and supplied most of the ore furnished for a period of 5 years. Other workings were put down in the old mine to the 2450-foot level, about 600 feet below sea level and far deeper than workings in any other quicksilver mine in the world, but they failed to encounter any ore. Old stopes were reopened and stripped of ore formerly rejected in the days of plenty, old dumps were sorted over, and even the old brick furnaces were torn down for their residual mercury. Also, in the frantic search for ore, new attempts were made to work some of the outlying mines on the new Almaden property. These attempts, however, were all handicapped by lack of adequate capital and generally were abandoned before much ore was recovered. As a result of the ever-dwindling supply of ore the miners were gradually dismissed, and by 1909 the once thriving communities on Mine Hill became little more than ghost towns. In 1912, the Quicksilver Mining Company was declared bankrupt.

In 1915 George H. Sexton, who ultimately gained complete control of the property, obtained a 25-year lease and appointed W. H. Landers, a specialist in quicksilver mining, as general manager. Landers reopened the Senator mine, one of the outside mines on the west end of the New Almaden property, adjacent to the Guadalupe mine, and installed there the first Herreshoff furnace and electrolytic dust precipitator ever used at a quicksilver mine. From the first these functioned satisfactorily in treating the fairly low-grade ore developed at the Senator mine. Encouraged by high wartime prices for quicksilver, Landers also attempted to make use of the then popular mechanical concentrating devices to treat some of the very low-grade ore that remained in the New Almaden mine. When Landers left to

join the armed services in 1917 his successor junked the concentrating equipment, but under several operators, the Senator mine remained in production until 1926.

During 1927, for the first time since 1849, no production from the property was recorded, and until 1935 only small amounts of quicksilver were recovered by lessees who retorted ore from old dumps and recovered quicksilver from beneath the old furnaces. In the latter part of this period, a C.C.C. camp, established at the site of the old English Town on Mine Hill, benefited the property through the erection of new buildings and repair of water lines and roads.

With the approach of World War II the value of quicksilver increased at a rapid rate. On May 1, 1940, the New Almaden Corporation, with C. N. Schuette as general manager, obtained a working lease on the property. Its operations, which extended through the war years, consisted largely of open-cut mining of low-grade ores and dump material. However, an attempt was made to recover fill from old stopes by reopening the 800-foot level Day Tunnel and the Santa Rita shaft. This operation ended in 1945, after yielding nearly 7,000 flasks of quicksilver, and in 1946 the modern rotary furnace which had been installed near the open cuts on Mine Hill was removed from the property.

When this article was prepared in 1949 only one man was retorting ore at the once great New Almaden mine, and owing to the caving of shafts and access adits, most of the mine had again become inaccessible. Its future is dependent on so many unpredictable factors that it would be hazardous even to guess as to whether or not the mine will ever again be important. It is supposed by many to have been thoroughly exploited, but several other times it has appeared worked out, only to yield large quantities of ore as a result of additional development. The exhaustive study made in recent years by the U. S. Geological Survey suggests that there still are in Mine Hill unexplored geologic structures that may reasonably be expected to contain untapped ore bodies, and, further, such ore bodies, if equal in grade to those that have been mined, could be profitably worked even at the prevailing low price of quicksilver and high mining costs.

*Geology.* Most of the rocks that comprise the mineralized belt along which lie the New Almaden mines are members of the heterogeneous Franciscan group, of Jurassic (?) age. These rocks have been intruded by sill-like bodies of serpentine that are only slightly younger in age. Parts of the intrusives, notably their margins, have been further altered at a much later time by hot waters to form siliceo-carbonate rock, which is the host rock for all of the sizeable ore bodies. Locally old gravels are above the general valley level along spurs that lead down from the ore-bearing Los Capitancillos Ridge, and in at least one place these gravels contain detrital cinnabar, though in

insufficient quantity to form ore. An accumulation of younger gravel fills Alamitos Canyon, and where this canyon is joined by Deep Gulch, which drains part of Mine Hill, it contains enough large nuggets of cinnabar to have been profitably mined since World War II.

The rocks of the Franciscan group are poorly exposed, as is common in the central Coast Ranges, but fragments of these rocks in the heavy residual soil are abundant enough so that the principal different varieties can be determined and mapped separately. The group includes large amounts of graywacke, some arkose and shale, and a little conglomerate, limestone, and chert; it also includes a variety of surficial mafic igneous rocks which, because of their altered character, are generally classed as greenstones. Along the mineral belt these greenstones are partly lavas, including some pillow lavas, but tuffs and breccias predominate. One distinctive variety of tuff, now altered but originally made up chiefly of basic volcanic glass, forms a unit several hundred feet thick and traceable for several miles through the mining district. It is of interest largely because it is an uncommon variety in the Franciscan group and, with the limestone, provided a stratigraphic sequence that materially aided in unravelling the regional structures.

Also included with the very slightly metamorphosed rocks of the Franciscan group are other metamorphic rocks that are largely re-crystallized and in many places coarsely crystalline. Most of these more strongly metamorphosed rocks contain a considerable quantity of at least one of several metamorphic minerals, such as glaucophane, crocidolite, or hornblende, which are generally absent in the normal rocks of the group. In mapping the mining district the varieties of these metamorphic rocks were separated. The hornblende-bearing rocks were invariably found to have formed either adjacent to or close to serpentine bodies where these intruded certain tuffaceous greenstones. The glaucophane- and crocidolite-bearing rocks, however, had a more irregular distribution as isolated blocks, and seemingly were more closely related to zones of shearing than to serpentine intrusives.

The geologic structure of the ore-bearing Los Capitancillos Ridge, although complex, can be deciphered with considerable confidence where the rocks are penetrated by the workings of the Guadalupe and New Almaden mines, but in the area between these mines it can be interpreted only from the pattern of rock distribution obtained by detailed surface mapping. In the eastern part of the ridge explored by the New Almaden mine the major structure is a northwest-trending anticline, or up-arched fold, whose southwest limb is puckered and sheared along a bordering major shear zone. The crest of the anticline is close to the apex of the ridge, and the trend, although somewhat irregular, is roughly the same as that of the ridge. Two major sills of serpentine, which converge near the crest of the anticline, were

intruded up the north limb, across the crest, and down the southern flank for a short distance. Where these sills join near the crest they also appear to have broken through to levels higher than even the present land surface, and to have put out other thin tongues downward along the sides of the fold. The larger and deeper ore bodies of the New Almaden mine were formed along the margins of the two major sills, but the ore bodies nearer the surface were formed along the narrower tongues of serpentine.

The anticline trends northwestward several miles to the vicinity of the Enriquita mine, where it is cut off obliquely by a fault which trends more to the north than the anticlinal axis. The effect of this fault is to offset northward the part of the anticline that lies to the west of the fault, with the result that the Senator and Guadalupe mines although along the northwestward projection of the axis, actually are in the southwest limb of the fold. The northeast limb in this area has been dropped downward by a major west-trending fault and is entirely covered by younger rocks.

*Ore Bodies.* Most of the ore bodies that have been mined were both large and exceptionally rich. The largest was about 200 feet wide, 15 feet thick, and extended down the dip for about 1,500 feet. The ore furnaceed during the first 15 years of recorded production at the New Almaden mine contained more than 20 percent quicksilver, but the ores were cobbled and hand-sorted to obtain this amazing grade. Through the years the grade steadily declined to less than 1 percent because of the utilization of lower-grade ores and less careful mining and sorting. The remarkable richness of the average ore of this mine, however, is well shown by the fact that the average grade of all of the ore furnaceed throughout its 100-year productive history is only a little less than 4 percent quicksilver, or about a flask of quicksilver to the ton. The ores of the Guadalupe mine were only a little less rich, whereas those of the Senator mine contained only about 10 pounds of quicksilver to the ton.

The mineralogy of the quicksilver ore bodies is simple. The only ore mineral of real economic importance was cinnabar, although locally native mercury impregnated and enriched the ores. Accompanying sulfides, present in only small quantities, included pyrite, stibnite, chalcopyrite, sphalerite, galena, and bornite. Gangue minerals that were introduced with the cinnabar were dominantly quartz and dolomite with some hydrocarbons.

The cinnabar that forms the ore bodies occurs chiefly as a replacement of the silica-carbonate rock along steep northeast-trending fractures. This replacement extended only a few inches out from the fractures, but within this limit was so complete that commonly over 50 percent of the replaced rock was cinnabar. In many of the large ore bodies the steep fractures occurred as swarms so closely spaced

that much of the intervening silica-carbonate rock was rich ore. Another occurrence of the cinnabar, believed to be of lesser importance, was as a filling with gangue minerals in the steep fractures. The resulting veins commonly cut the ore bodies and were followed as a guide to ore, although they generally did not themselves contain enough cinnabar to be minable. Locally, as in the Senator mine, these veins were rich enough to form ore even where the bordering wall rock was not replaced by cinnabar.

The distribution of the ore bodies in the district is not a random one, but is restricted to certain rocks and certain structural environments. Nearly all the ore bodies were formed in silica-carbonate rock, although this rock occupies only a small part of the district. Further, only that part of the silica-carbonate rock close to the contacts with rocks of the Franciscan group was particularly favorable for ore deposition, and most of the ore bodies were richest within a few feet of these contacts. Two other structural factors apparently controlled the distribution of the ore bodies along the contacts, although their importance varied with the steepness of the contacts. Where the contacts were steep, the swarms of the northeast-trending fractures were a dominant factor in localizing ore bodies; in places where the contacts were inclined at less than 45 degrees, the shape of the contact assumed equal or greater importance. Along the more gently inclined contacts the ore bodies tended to form at the crests of domes or plunging anticlines.

*Origin of the Ore Bodies.* Any discussion of the origin of the ore bodies should properly start with a discussion of the formation of the silica-carbonate host rock with which the ore bodies are so closely related, not only in this district but in many other districts throughout the Coast Ranges. The field relationships and the relief textures of the rock leave no room for doubting that the silica-carbonate rock formed from serpentine through a process of replacement. Analyses of the parent serpentine and the derived silica-carbonate rock of the New Almaden area indicate that the principal change in the rock has been a simple substitution of carbon dioxide for water, resulting in a rock composed of a fairly definite proportion of quartz and magnesite. This type of silica-carbonate rock probably is widespread in the Coast Ranges, but another less widespread type that consists largely of opal or quartz is recognized to have had a different origin. The time of the hydrothermal alteration of the serpentine to silica-carbonate rock is

indicated to be at least as late as middle Miocene, and therefore the altering solutions can hardly be related to either the serpentine or its parent magma. The writer believes these solutions were closely related both in time and origin to those that deposited the quicksilver ores.

The quicksilver ore bodies are believed to have been deposited during the Pliocene epoch by hydrothermal solutions rising from a deep-seated source. This source probably is the same magma chamber that gave rise, in upper Miocene time, to intrusives and flows of rhyolite and dacite in the New Almaden area. The exact chemical character of these solutions can not be determined, but they are commonly supposed to have been alkaline. The rising solutions followed fractures that were best developed in the silica-carbonate rock near the contact with rocks of the Franciscan group. They deposited cinnabar in an interval extending from near the present surface to a depth of about 2,600 feet, and in a temperature range believed to have been between 50° and 125° C. Rich ore bodies were formed where a spreading-out and stagnation of the solutions was caused by structural traps formed by a capping of relatively impervious sheared rocks of the Franciscan group; but along steep contacts replacement from solutions flowing through fractures was extensive enough to form ore bodies even where structural traps were absent.

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## SERPENTINE AND CHROMITE DEPOSITS OF THE SAN FRANCISCO BAY COUNTIES \*

BY FRANCIS G. WELLS †

The term serpentine is loosely applied to any of several members of a group of closely related, magnesium-rich minerals. It is also commonly used as a name for rocks composed predominantly of minerals of the serpentine group. Most serpentine rocks are alteration products of peridotites that originally were composed predominantly of silicate minerals rich in magnesium and iron, such as olivine and some pyroxenes. Under subsurface conditions not fully understood these hard silicate minerals combined with water to form softer serpentine minerals of much different character. As peridotite rock bodies are almost always partly serpentinized and as serpentine masses commonly include some unaltered peridotite, the terms serpentine and peridotite are sometimes used interchangeably.

Most land surfaces underlain by serpentine are distinctive. The rock tends to be full of cracks and commonly has little or no soil cover. Rain falling on these bare rock surfaces tends to sink quickly deep into the rock, leaving the surface dry. Serpentine terrains commonly are strewn either with blocks or scattered piles of blocks projecting through rust-colored or maroon-colored soil, or with accumulations of shot-sized pellets of iron oxide. Tufts of grass and low bushes grow among the scattered blocks and a few trees are found at wide intervals. Because serpentine rocks are extensively fractured, landslides are common on the flanks of serpentine hills. Depressions in which water accumulates commonly develop behind these landslides. In arid regions bare hills of rusty red serpentine stand out prominently on the landscape, and early settlers named many Red Mountains or Red Hills in various parts of the Coast Ranges and Sierran foothills.

Peridotites, from which most California serpentines are derived, are medium- to coarse-grained rocks consisting of various proportions of olivine and iron-magnesium-rich pyroxenes. The rocks are given varietal names according to the kind and abundance of minerals in them. A variety composed almost entirely of olivine is called dunite; one with more than 95 percent pyroxene is called pyroxenite. The most common variety in the bay counties contains large amounts of both olivine and the pyroxene enstatite, and is called saxonite. Although saxonite masses are most common, dunite and pyroxenite may occur anywhere within saxonite as irregular bodies; some of these are rudely layered. Dikelets of dunite and pyroxenite may cut the saxonite and each other as well.

Dunite rock surfaces tend to be smooth and even-grained, like a medium-grained sandstone, showing an occasional black grain of chromite or magnetite. Saxonite surfaces are similar except that they

may be sparsely studded with one-eighth inch to one-fourth inch crystals of enstatite. Enstatite is recognized by its rectangular shape and by its conspicuous cleavages at right angles to each other. It flashes in the sun, and rock containing a large proportion of it sparkles like a cluster of rhinestones. In peridotites containing a large percentage of enstatite the crystals may be so large and numerous that the rock has an exceedingly rough surface.

Most freshly broken unaltered peridotite has a water-green or yellowish-green glassy appearance. If altered to serpentine, however, the freshly broken rock tends to be greenish-black in color and feltlike or sugary in texture. Even though altered, the enstatite crystals commonly retain their original form, and their softer alteration product, called bastite, looks much like the original pyroxene.

In some serpentine masses narrow veins of amphibole asbestos are found. This type of asbestos is used for acid-filtering and insulating purposes, so there is a market for material of good quality. Chrysotile asbestos, a variety of serpentine which is the most widely used commercial variety, is not common in serpentines of the bay area, but is found in a few places in veinlets an eighth of an inch or less wide.

The type of serpentine that is probably most familiar to residents of the bay counties and especially of the San Francisco and Marin peninsulas is one aptly called "slickentite" because of the numerous polished, slick or slippery surfaces in the rock. A good example of slickentite may be seen if one travels west from Belmont on the Halfmoon Bay road. Inasmuch as most serpentine minerals are physically weak they tend to deform easily, commonly by shearing, and the smooth surfaces are the results of small movements of one fragment against another. Because of the shiny surfaces, slickentite is much more conspicuous than serpentine that has been less deformed. Slickentite is common in major fault zones that cut across or follow the edges of the larger peridotite bodies. At the north abutment of the Golden Gate Bridge a sheetlike mass of serpentine has been completely crushed by fault movements. Outcrops of the most intensely deformed serpentine are greenish gray, the color of weathered bronze. The material is cut by innumerable curved slip surfaces that are braided together to form plaits; and these in turn are braided together on a larger scale. The slip surfaces curve around scattered blocks of unsheared, feltlike serpentine that is commonly dark green or black. Some extensively sheared severely altered material is almost white, but scattered through it are unsheared blocks of serpentine that weather to a rusty red. Sheared material also may be honey colored or otherwise light colored, and tends to have a waxy luster and to be translucent.

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Some of the material found in sliectentite is an impure, talcose, soapstone that may easily be scratched with the fingernail. Most soapstone is light colored—apple-green, white, or light gray being the most common colors; impurer material is darker. Like serpentine, soapstone contains water, magnesium, and silica, but its content of water and silica is greater than that for serpentine. It is a product of a further step in the alteration of peridotite during which some magnesium is removed from the original minerals.

Continued alteration of serpentine or talc by carbonate-laden water produces silica-carbonate rock that is made up of a mass of chaledony, opal, quartz and carbonates—chiefly magnesium carbonates. Silica-carbonate rock weathers to prominent, distinctive outcrops of rust-brown to light-tan, porous rock. Where the rock is rich in silica minerals, cliffs, knobs, and reefs tend to stand out in bold relief against the more subdued serpentine topography. The rock is known to miners throughout the Coast Ranges as quicksilver rock because quicksilver minerals are commonly found in it. Silica-carbonate rock is well exposed at New Almaden in Santa Clara County.

In the alteration processes described briefly in preceding paragraphs, magnesium has been removed from the original peridotite or serpentine minerals and in some cases redeposited nearby in silica-carbonate rock. In some places, however, the magnesium has been carried away in carbonate-water solutions and deposited as relatively pure magnesium carbonate, the mineral name of which is magnesite. Where large enough, such deposits have commercial value. One of the largest of these deposits is on Red Mountain, which is southeast of Livermore in Santa Clara and Stanislaus Counties. There, magnesite occurs in veinlike deposits within a large body of serpentinized peridotite. The magnesite probably was deposited from hot water solutions associated with Pliocene or possibly more recent igneous activity. Delicate white needles of magnesite are also found in crevices in sliectentite, apparently deposited from ground water percolating through the rock. Some surface waters also carry magnesite in solution, as conglomerates of serpentine pebbles cemented by magnesite are found in the stream beds of some gulches that drain serpentine areas. In such places, too, the magnesium apparently was leached from serpentine.

Peridotite bodies in the bay counties are of all sizes. Some are less than an acre; one, located northeast of Madrone, Santa Clara County, is about 15 square miles in extent. In general, peridotite masses are long and relatively narrow. The tendency toward a lenticular shape is well exemplified by the large mass in northern Napa County. These outcrop patterns indicate that the masses are tabular and are either sills, intruded essentially parallel to the enveloping rocks, or dikes that cut across the older formations. It has been shown

that throughout the Coast Ranges sills are the predominant type and that they were folded with the enveloping rock while still plastic. Peridotite intrusions also tend to lodge in unconformities. In many places faulting takes place along masses of serpentinized peridotite because of the ease with which it fractures or shears, and faulting commonly accentuates the lenticular shape of the serpentine masses. Folding tends to give a hooked shape to the outcrops. Masses which are circular in plan are uncommon.

Peridotites are intrusive igneous bodies; they are rocks that were once molten, which made their way up into the crust of the earth in molten or partly molten condition, and then solidified. As pebbles of peridotite are found in the Lower Cretaceous Horsetown formation and as peridotite penetrates the Upper Jurassic Knoxville formation, it follows that the peridotite bodies were intruded in Knoxville time. Consequently, peridotite is found in Knoxville and older rocks, especially the Upper Jurassic (?) Franciscan group. In the central Coast Ranges east of Parkfield, Fresno County, peridotite is enclosed in rocks younger than the Knoxville. In such cases it seems clear that serpentine was squeezed into the overlying formations in the same way that salt may be pushed up to form salt domes like those found in some Texas oil fields.

Some striking and mineralogically interesting rocks known collectively as glaucophane schists are abundant in Franciscan rocks close to serpentine masses. They also occur in Franciscan rocks where there is no sign of adjacent serpentine bodies. Glaucophane schists vary broadly in mineral composition and texture, and many are not sufficiently laminated to be considered schistose. Some are composed predominantly of the amphibole glaucophane, in which case they are indigo blue to blue black. However, the common occurrence of glaucophane with other minerals such as green actinolite, pyroxene, and chlorite; red garnet; and light-colored quartz, feldspar, lawsonite, and mica, in various combinations, produces rocks of widely variable color, texture, and general appearance. These rocks were probably formed from preexisting wall rocks by action of rising solutions and gases associated in some way with the emplacement of serpentine.

One of the most valuable products obtained from peridotite is chromite. Nearly every hand specimen of peridotite, or its alteration product serpentine, contains a few grains of chromite, and in places the chromite is concentrated in solid lumps containing tens or rarely hundreds of tons. Chromite is a chemical combination of chromium, iron, magnesium, aluminum, and oxygen. It has a dense black or bluish-black color, pitchy luster, and specific gravity of 4.5. This mineral may be distinguished in the field from black manganese ores by its higher specific gravity, and from black iron minerals by the chocolate-brown powder produced when the mineral is scratched.



FIG. 1. Typical surface expression of massive serpentine bodies in California Coast Ranges (Clear Creek, San Benito County). Scattered indiscriminately among dense stands of manzanita and other thorny brush are small irregular areas more or less devoid of vegetation. The monotony of the landscape is broken in places by craggy outcrops of reddish-brown silica-carbonate rock, an alteration product of serpentine along faults. *Photo by C. W. Chesterman.*



Chromite is the only chromium mineral of economic importance and from it is obtained all of the metallic chromium used in stainless and specialty steels and in chromium plating. Commercial quantities of chromite are found only in rocks of the peridotite group, and in the bay counties exclusively in dunite. Accumulations of chromite large enough to be mined may be more or less mixed with the host rock or they may form dense aggregates of crystals. The first type is called disseminated ore. It may consist of chromite grains scattered through dunite but more frequently it consists of narrow streaks, called schlieren, in which the chromite grains may constitute from 20 to 90 percent of the mass. These schlieren may be arranged in definite patterns, banding being the one most commonly seen. Disseminated ore can be seen on the Meeker Ranch, Sonoma County, 17 miles west of Santa Rosa in secs. 15, 16, and 17, T. 7 N., R. 10 W., M. D.

Dense aggregates of crystals, called massive ore, vary so widely in shape that they are herein designated by the noncommittal term pod. The contents of such deposits range from a few pounds to hundreds of tons, and it is from such pods that all the production of chromite in the bay counties has come. Pods commonly, though not always, occur either singly or in bunches in shear zones. At the Meeker mine, for example, most of the pods have been small and contain from 5 to 10 tons. The largest one mined had yielded 150 tons and still showed a face of 4 feet of ore in the bottom of the stope when it was visited in 1918. A few feet beyond this pod, one of 75

tons had been mined. Chromite is practically insoluble in the rain and ground water that dissolve and wear away the enveloping serpentine. As it is heavy, it remains on the surface as grains, lumps, and even large blocks, showing that the serpentine now wasted away contained chromite and that more may be present in the underlying rocks.

Production of chromite from the bay counties has been small, probably less than 5000 tons. From the history of mining and what is known of the deposits it is likely that future production will not equal this amount.

It has been pointed out that serpentines contain magnesia. Most of the serpentine in the region probably contains as much as 35 percent of the oxide and therefore can be considered a potential resource of magnesium. A process for extracting magnesium from serpentine has been developed but at present it cannot be produced at a sufficiently low cost to be economic.

A few years ago the Permanente Metals Corporation quarried serpentine near Almaden for making magnesium phosphate fertilizer. It was blended with phosphate rock from Montana and the mixture was fused, chilled rapidly, and crushed. This fertilizer is said to yield a greater amount of available phosphate than most fertilizers having a lime base. Other economic considerations have caused the fertilizer product to be discontinued.

## MAGNESITE MINERALIZATION IN THE RED MOUNTAIN DISTRICT \*

By A. J. BODENLOS †

Magnesite, the carbonate of magnesium, is commercially important as a source of magnesia for refractories, magnesium oxychloride cement, and minor industrial and chemical products, and also is an ore for magnesium metal. California has a number of magnesite deposits, none of which is being operated at present. A group of large deposits at Red Mountain, one of the higher peaks in the southern part of the Diablo Range, located 31 miles by winding road south of Livermore, furnished one of the major tonnages of mined magnesite during the period of active operation, which lasted from 1905-45.

Magnesite occurs in deposits of commercial size in three forms: as crystalline massive material resembling marble; as dense vein material resembling unglazed porcelain; and as dense sedimentary material resembling fine-grained limestone. The California deposits predominantly are of the porcelain type and occur in veins; such deposits at one time provided enough ore to make California the leading producer of magnesite in the United States. The deposits at Red Mountain belong to this type, and the mine workings afford the best display of the characteristic mineralization that can be found anywhere in the country today. Deposits of limestone-like sedimentary material occur in the Mojave Desert but have been mined only in small amounts.

The Red Mountain district is on the border of Santa Clara and Stanislaus Counties, principally in sec. 18, T. 6 S., R. 5 E., M. D. It can be reached via the county road leading south from Livermore and following the Arroyo Mocho into the valley of Sweetwater Creek and San Antonio Valley. The district also is accessible from Patterson, in the San Joaquin Valley, via a 28-mile county road following Puerto Creek westward, and from Mount Hamilton via the road leading down the east side of the peak beyond Lick Observatory. The three roads meet in San Antonio Valley, just southeast of the magnesite deposits. Access roads to the principal deposits branch from the Livermore and Patterson roads.

The area traversed by these roads is deeply dissected by actively downcutting streams and the topography is similar to that of much of the Coast Ranges of the San Francisco area. Vegetation is sparse, consisting chiefly of chaparral and grass.

*General Geologic Features.* The Livermore and Mount Hamilton roads cross terrane of the Franciscan formation of Jurassic (?) age, whereas most of the Patterson road crosses terrane of rocks of Cretaceous age. Rocks of both ages are largely sedimentary and consist chiefly of sandstone, shale, arkose, and chert; all types weather

to drab brown soil. The strata generally dip steeply and are slightly metamorphosed, or recrystallized, reflecting the strong folding sustained during an ancient mountain-building period. The sedimentary rocks also have been intruded by numerous quartz veins and by several bodies of igneous rock. The geology along much of the Livermore road is described in the report on the Tesla quadrangle by Huey published by the State Division of Mines in 1949.

Most igneous bodies occur in rocks of the Franciscan formation and appear to be sills, or tabular bodies paralleling the sedimentary strata. They were intruded prior to the mountain-building period and were folded with the sedimentary rocks. For the most part the igneous rocks are ultramafic in composition; that is, they consist of minerals containing a high percentage of magnesia.

A large sill of ultramafic rock underlies Red Mountain and contains the magnesite deposits. It extends from about a mile east of the Patterson road to about 8 miles west of the road and is just north of the Livermore road and San Antonio Valley. The soil derived by weathering of the ultramafic rocks is bright red or in places olive-brown, very distinct from the soil overlying weathered sedimentary rocks. Along the Livermore road, this distinctive red soil is first seen about 29 miles south of Livermore and north of Sweetwater Creek; the Patterson road crosses from the sedimentary rocks of Cretaceous age into the intrusive rocks about 22 miles west of Patterson, in the headwater area of Puerto Creek. Numerous outcrops along the Patterson road are among the most accessible for study of the ultramafic rock. Along the Livermore road the south edge of the intrusive body is north of Sweetwater Creek and hence not easy to reach from the road.

*The Ultramafic Sill.* The most common primary minerals in the ultramafic sill are olivine ( $(\text{MgFe})_2\text{SiO}_4$ ) and minerals of the pyroxene group, chiefly the orthorhombic variety enstatite ( $(\text{MgFe})\text{SiO}_3$ ) and to a lesser extent the monoclinic pyroxenes (calcium-magnesium-iron-aluminum silicates). Plagioclase feldspars (triclinic calcium-sodium-aluminum silicates) occur sparingly in most of the intrusive body but locally are abundant. Very small amounts of chromite ( $\text{FeCr}_2\text{O}_4$ ) occur with olivine and the pyroxene minerals. Much olivine and some pyroxene have been altered to serpentine (magnesium silicate plus water), a common hydrous mineral in ultramafic rocks, and magnetite ( $\text{Fe}_3\text{O}_4$ ). Depending on the mineral composition, the rocks are classified into several ultramafic rock types: peridotite, consisting chiefly of olivine but containing some enstatite; dunite, consisting almost wholly of olivine or its alteration product serpentine; pyroxenite,

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† Geologist, U. S. Geological Survey.

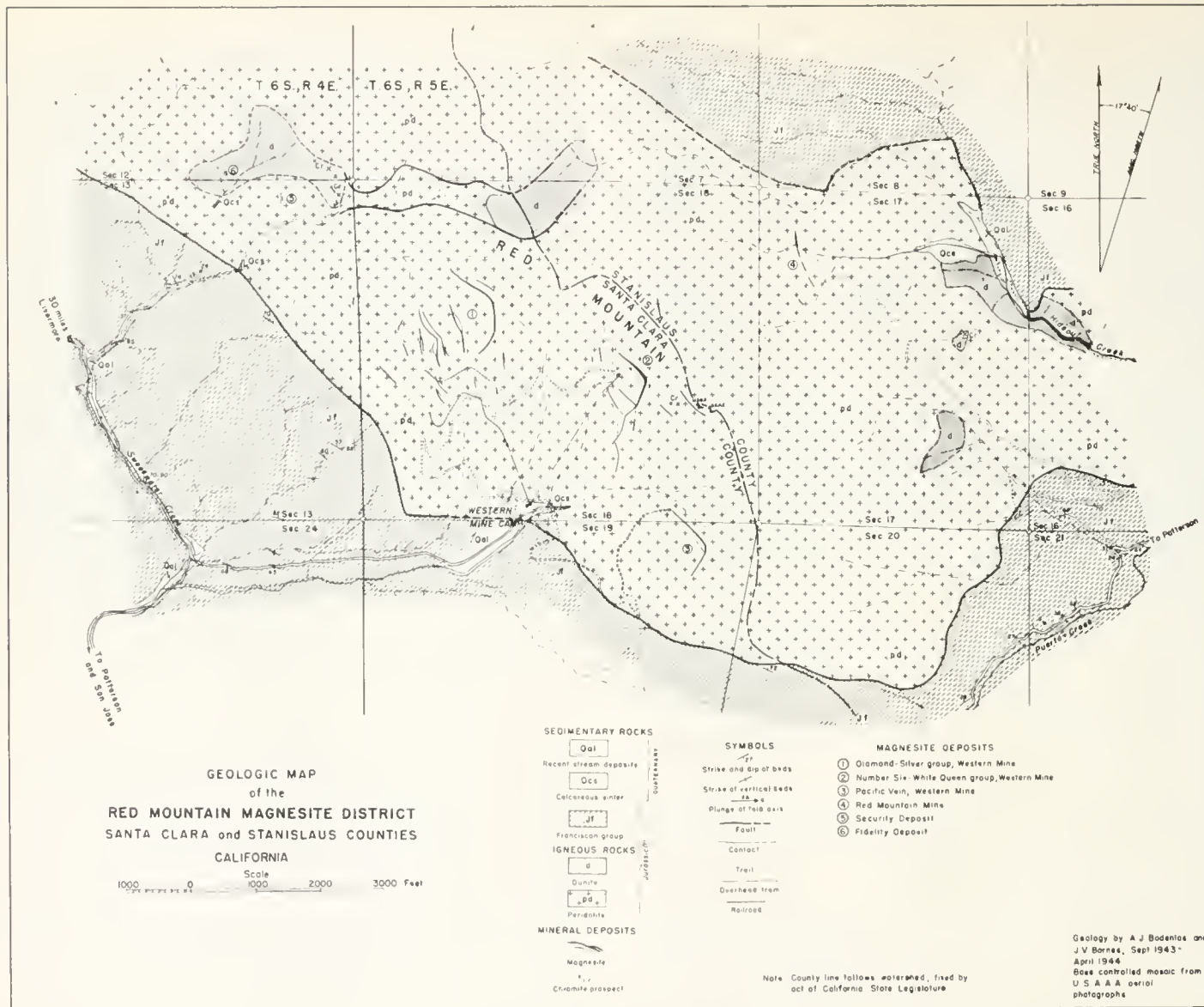


FIG. 1. Geologic map of the Red Mountain magnesite district, Santa Clara and Stanislaus Counties, California, *Reproduced from California Jour. Mines and Geology, vol. 16, no. 2, pt. 38.*

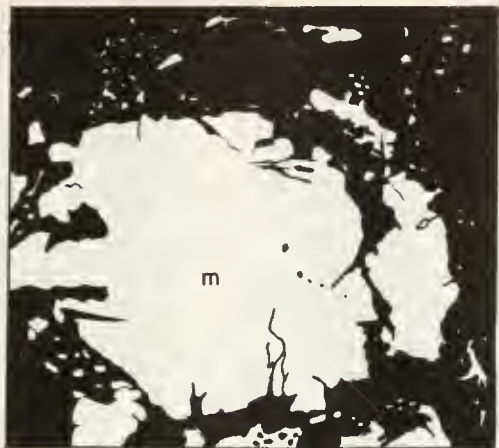


FIG. 2. Large magnesite nodules in serpentine. Reproduced from *California Jour. Mines and Geology*, vol. 46, no. 2, p. 242.

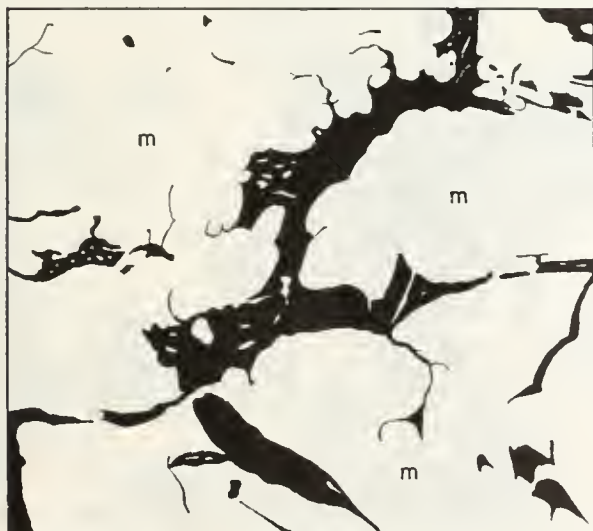


FIG. 3. Nodular magnesite replacing serpentine. Reproduced from *California Jour. Mines and Geology*, vol. 46, no. 2, p. 242.

consisting chiefly of pyroxene minerals; and gabbro, consisting chiefly of pyroxene minerals and plagioclase feldspars. The olivine, pyroxene minerals, and serpentine all are green and impart some shade of this color to all fresh rock of the intrusive body. The red soil derives its color from ferric iron set free when the rock decomposes during the process of weathering.

*Magnesite Deposits.* Most of the magnesite deposits are near the crest of Red Mountain, west of Del Puerto Canyon area, which contains several chromite deposits. The Western mine, which is operated on the largest magnesite veins, is accessible via a short spur road leaving the Livermore road at the entrance to San Antonio Valley. At the Red Mountain mine, on the northeast flank of Red Mountain, ore was extracted from two veins; the area is accessible by foot from the end of the road leading up Hideout Creek, west of and beyond the chromite mines. The upper levels of the mine can be reached via a spur road leaving the Patterson road three-quarters of a mile south of the Puerto Creek-Hideout Creek fork. The Security and Fidelity deposits, consisting of either small veins or breccia zones, are in valleys tributary to Sweetwater Creek, north of the veins worked by the Western mine. These deposits are accessible by trails leading from the Livermore road. The strikingly white mine dumps at the Western mine are the only marks of the deposits or operations visible from the roads; they are noticeable from a number of places in San Antonio Valley and also may be seen from the east side of Mount Hamilton.

The Western mine was one of the most successful of the California magnesite operations. The white outcrops of magnesite were noticed in the nineties and development work started in 1899. By 1905 ore was being shipped, and mining continued until 1945. The veins of the Red Mountain mine were discovered in 1915, following which the deposit was operated intermittently until 1941; the other two deposits were explored and operated only during World War I. The total recovery in the district was close to 1,000,000 tons, the bulk of which was extracted from the veins of the Western mine.

Fractions and shear zones, formed as the result of ancient movement in the rocks, contain the magnesite veins and ore bodies of the Red Mountain district. The veins occupy parts of two distinct fracture and shear systems. One of the systems strikes northwest, dips northeast, and consists of long straight fractures, joints, and narrow shear zones. The other system, formed at a later period, strikes generally north and consists of shorter, irregular wide shear zones and associated fractures characterized by variable dips. The north-striking system contains the major veins and ore bodies; the northwest-striking system is mineralized only in those fractures or shear zones that are close to the mineralized parts of the north-striking system. The ultramafic rock in all fractures and shears or shear zones has been

serpentinized, indicating that the primary olivine and enstatite minerals were altered to hydrous minerals. Geologic evidence confirms that this hydration was accomplished by waters emanating from deep-seated sources well below the present level of the mineral deposits.

Fracturing and serpentinization of the ultramafic rock were processes preliminary to deposition of the magnesite; the fractured rocks provided the necessary channels for movement of mineralizing solutions and sites of mineral deposition. Subsequently, solutions rising from a deep source deposited the mineral assemblage of the magnesite deposits. Rock movements alternated with mineral deposition throughout a long period, and although such movements were of small magnitude, they fractured, shattered, ground, or sheared previously deposited minerals. Open fissures resulting from the movements were filled by later minerals. This alternation of deposition and rupture produced very complex mineral distribution in many parts of the veins. All told, at least eight periods of movement and associated rupture occurred during mineralization.

The minerals in the veins at Red Mountain, in order of deposition, are magnesite, dolomite, manganese oxide, silica and magnesium silicate minerals, and calcite. Of these, magnesite and the silica and magnesium silicate minerals form the bulk of the deposits.

The characteristic dull porcelain-like appearance of the magnesite results from its extremely fine grain—the individual grains cannot be distinguished from one another. Most of the magnesite is dead white, although some is tinted light green or pink by small percentages of included impurities. The mineral is moderately soft, is generally compact, and is slightly soluble in dilute hydrochloric acid.

Dolomite, which is always intimately mixed with magnesite, cannot be seen by the naked eye; its presence is known only by means of microscopic or chemical analysis. Manganese oxide forms dendrites, or thin, fernlike leaves on the surfaces of magnesite nodules or in fractures cutting magnesite.

Chalcedony and opal are the silica minerals; both are amorphous, or noncrystalline, and range in color from milky white through cream, buff, orange buff, to red brown. Deweylite and sepiolite are the hydrated magnesium silicate minerals; they are amorphous, and although their colors generally are in the same range as those of the silica minerals, they are much softer minerals. Calcite is crystalline and white to light gray.

Magnesite bodies have irregular shape and distribution in the fracture and shear zones. This, for the most part, may be attributed to the two modes of deposition of the mineral: as replacement of serpentine, and as filling of open fractures. The replacement mechanism consisted of simultaneous deposition of magnesite and solution of serpentine, forming pellets or nodules where replacement was on a

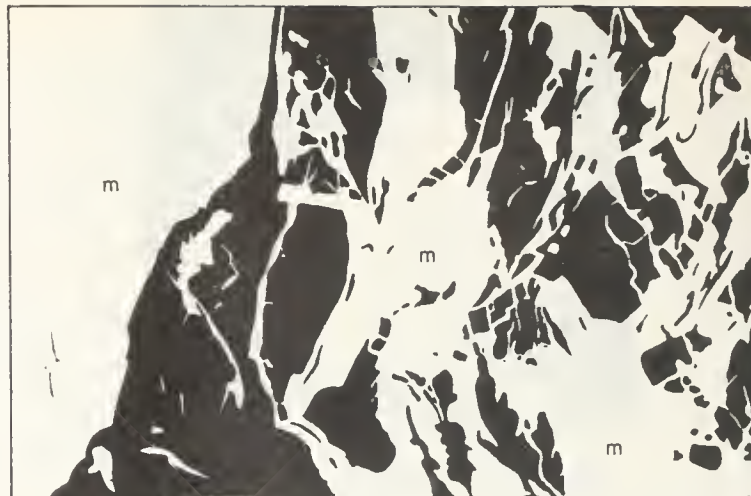


Fig. 4. Replacement and fissure-filling magnesite. *Reproduced from California Jour. Mines and Geology, vol. 46, no. 2, p. 244.*

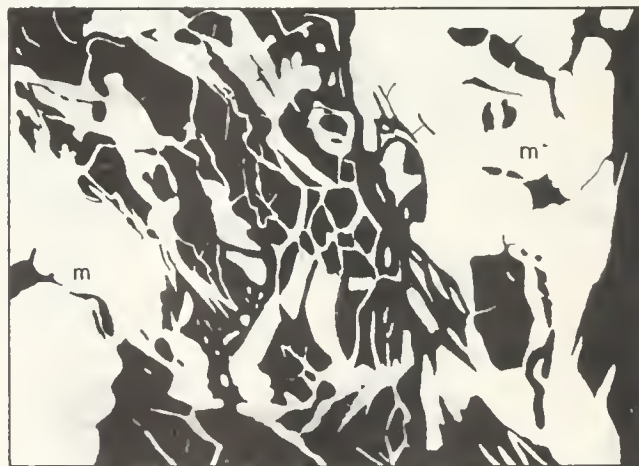


Fig. 5. Replacement and fissure-filling magnesite. *Reproduced from California Jour. Mines and Geology, vol. 46, no. 2, p. 244.*

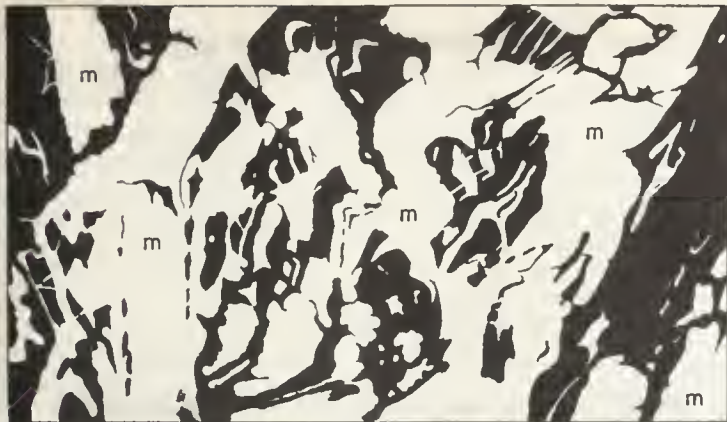


FIG. 6. Magnesite replacing serpentine. *Reproduced from California Jour. Mines and Geology, vol. 46, no. 2, p. 246.*

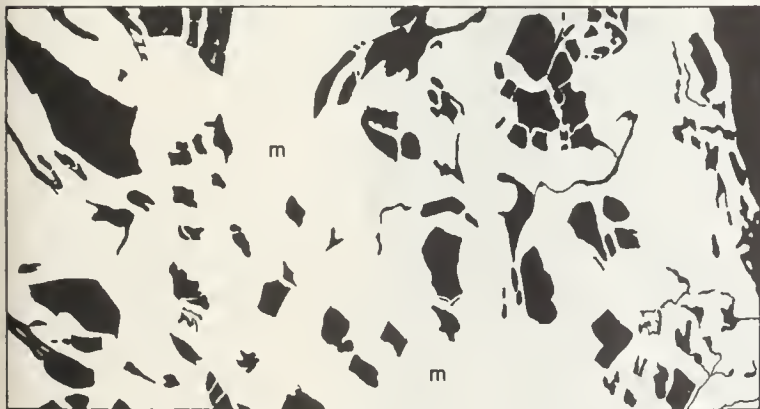


FIG. 7. Replacement magnesite in a breccia zone. *Reproduced from California Jour. Mines and Geology, vol. 46, no. 2, p. 246.*

small scale and cauliflower-shaped masses where on a large scale. Such bodies range in size from several millimeters to solid masses 6 feet in diameter. Commonly the nodules coalesced where replacement was intense and formed even larger irregular masses and lenses. Magnesite deposited in open fractures formed small veins whose size and shape depended on the configurations of the original fissures. The replacement process was dominant and formed the larger and purer bodies.

All minerals of the silica and magnesium silicate group were deposited in fractures or shatter zones open at the time of deposition, and veins of each are cut by veins of the later members of the sequence. The silica and magnesium silicate minerals are found in nearly all magnesite-bearing veins, but calcite occurs only in several veins of the deposits operated by the Western mine.

Study of the relative positions of magnesite with respect to configurations of the irregular fracture and shear zones shows that the locations of greatest deposition coincide with changes in attitude or branches of these structures. The correlation suggests that the attitude of the structures governed the sites of principal deposition; this geological concept is termed "structural control" of mineralization, a feature of vein deposits of many minerals. It is useful to mine operators in predicting the more probable locations of minable ore bodies in advance of ore exploration.

Magnesite and the silica-magnesium silicate minerals can be derived from serpentine by reaction with carbon dioxide and water. Geologic analysis of the Red Mountain deposits indicates that mineralization was accomplished by warm waters carrying considerable carbon dioxide which reacted with serpentine at depth and then rose and deposited the minerals so derived where structures in the shear zones provided a favorable chemical and physical environment.

In the two vein groups at the Western mine some 30 veins have been mineralized. The Red Mountain mine is on two veins, and the other two deposits are on single veins or shatter zones. The mineralized parts of the veins range from short segments less than 100 feet long to large composite bodies 900 feet long; most mined ore bodies in the Western mine were 300 to 400 feet long. The magnesite bodies range from very thin fissure-filling veinlets to solid masses 35 feet wide. Zones of shattered ultramafic rock adjacent to the veins in places are filled with magnesite veinlets. These zones of veinlets may be as much as 120 feet wide, but such magnesite "stockworks" contain too high a percentage of impurities in the form of the host rock to qualify as ore. The maximum known vertical extent of magnesite veins in this district is 660 feet, or 860 feet down the dip of the vein.

*The Magnesite Industry of California.* Since the discovery of magnesite in California in 1886, more than 50 magnesite districts have been found. From these, more than \$11,000,000 worth of ore

was mined. California led all other states in magnesite production up to 1916, when the production from the massive deposits in Washington exceeded that of the California vein deposits. In recent years depletion of reserves and competition from larger deposits have resulted in gradual decline of California production. At the end of World War II the last of the active mines stopped operations.

Fortunately for California, a magnesia chemical industry developed on the basis of production from the deposits. The research staffs of the various companies kept abreast of new developments and experimented with extraction of magnesia from sea water. Marine Magnesium Products Corporation, of South San Francisco, was the pioneer in this field. Permanente Metals Corporation built a sea-water plant at Moss Landing and operated a magnesium-metal plant. The California Chemical Company built a plant at Newark to recover magnesia from brines evaporated by the Leslie Salt Company. Thus, although the mines are now closed, California has a legacy of chemical plants and still is an important producer of magnesia and the

associated salts derived from the extensive supply offered by the ocean waters.

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FIG. 8. Mill at Western mine on Red Mountain, Santa Clara County, in 1940. The mine was last operated during the early 1940s, but has been idle since; it is one of the largest magnesite mines in California, having produced 800,000 tons of ore. *Photo by Olaf P. Jenkins.*

## DIATOM DEPOSITS

BY G. DALLAS HANNA \*

The major topographic and geologic features of the San Francisco Bay area have been adequately described in other chapters of this guidebook. To give a little additional insight into that which constitutes geology, an attempt is made in this paper to give some information about the microscopic plant remains found in one particular type of sedimentary rock which is well represented in the area.

Rain, wind, and the waves on the beaches gradually wear down land surfaces; and the particles which are loosened and swept away have to go somewhere. Eventually most of them are washed into the sea or into lakes, and after they have accumulated on the bottom they are called sediments. In the passage of time great thicknesses of sediments, that is, many tens of thousands of feet, may be laid down one upon the other, and they become consolidated into rocks of greater or lesser hardness. These are sedimentary rocks.

While sedimentation is going on, certain biological processes are concurrent. Animals and plants are growing, multiplying, and dying in great profusion. Their remains or the residue from them likewise settle to the bottom, along with the purely detrital fragments washed in from the land surfaces. Everyone is familiar with muddy water. The mud may be derived from either one or both of these sources; but given time, the water will clear.

The soft parts of most animals and plants decompose more or less completely either through digestion by others or by simple decay. Hard parts, however, such as bones and shells, are more resistant to decay. Many of them are buried in the sediment, and if conditions are favorable they may persist as visible objects for eons of time. These are called fossils, and the study of them is called paleontology if they were animals, paleobotany if they were plants.

The movements of the crustal layers of the earth, called warping or folding and faulting, have brought many sections of what was once ocean bottom above sea level; and thus many deposits of sedimentary rocks of diverse ages are available for study close at hand.

Almost nothing is permanent; and organic materials in general are unstable. Even such relatively insoluble things as shells may gradually be dissolved away, and leave no trace in the sediments. There are in existence great areas of sedimentary rocks, which must have contained remains of organisms at the time of deposition, that are now utterly barren.

During several periods of geologic history there have been violent outbursts of volcanic activity in the western part of the United States. Many of these have been accompanied by explosions which

yielded very finely divided rock fragments called ash. Part of the material settled in the lakes and adjacent seas and part was washed into them by streams. This ash formed characteristic and easily recognizable strata, which were subsequently elevated. Many of the layers are very thick, and contain scarcely any recognizable material other than ash. A deposit of this type of rock is well exposed on the bay shore, on the road going north from Rodeo toward the Union Oil Company refinery at Olenum after the turn at Rodeo. This is Pinole tuff of Pliocene age. Other extensive deposits occur north of the bay.

Diatoms, which were once thought to be tiny microscopic animals, are now known to be plants. They contain a brown coloring matter allied to chlorophyll which enables them to convert inorganic matter to organic matter in a manner somewhat similar to that in higher plants. Diatoms are abundant in almost all waters, both fresh and salt; they have been referred to as the forage of the sea—that is, they form one of the most important groups of basic organisms upon which all other aquatic life depends to some degree.

The diatom has a hard skeleton called a frustule in which most of the soft parts are contained. This casing is composed of silica combined with a little water, the proportion being the same or nearly the same as in opal. At certain times, when conditions are favorable, diatoms live and multiply in unbelievable abundance. They sometimes color the water brown like beef broth.

Diatoms have to have silica for their frustules, and ordinarily silica is not readily soluble in water. It seems to be somewhat more soluble, however, in the form in which it is found in volcanic ash. Most fossil diatoms have been obtained from beds of those periods during which much ash was being deposited. In some places the rocks are composed of 90 percent or more fossils. This is especially true in the Coast Ranges from San Francisco south. At Lompoc in Santa Barbara County there is a great deposit over a thousand feet thick which is being mined commercially on a large scale by Johns Manville Corporation. This rock is usually called diatomite or diatomaceous earth.

It is known from direct observation that diatoms exist at the present time in vast numbers where ash is practically nonexistent, and also that they must have existed during long periods of geological history when non-diatom-bearing sediments were being accumulated. Apparently they are absent because the ground waters in the darker non-ash sediments are sufficiently basic (that is alkaline) to dissolve the silica of the frustules. Organic silica is notoriously unstable toward such solutions.

\* Curator, Department of Paleontology, California Academy of Sciences.



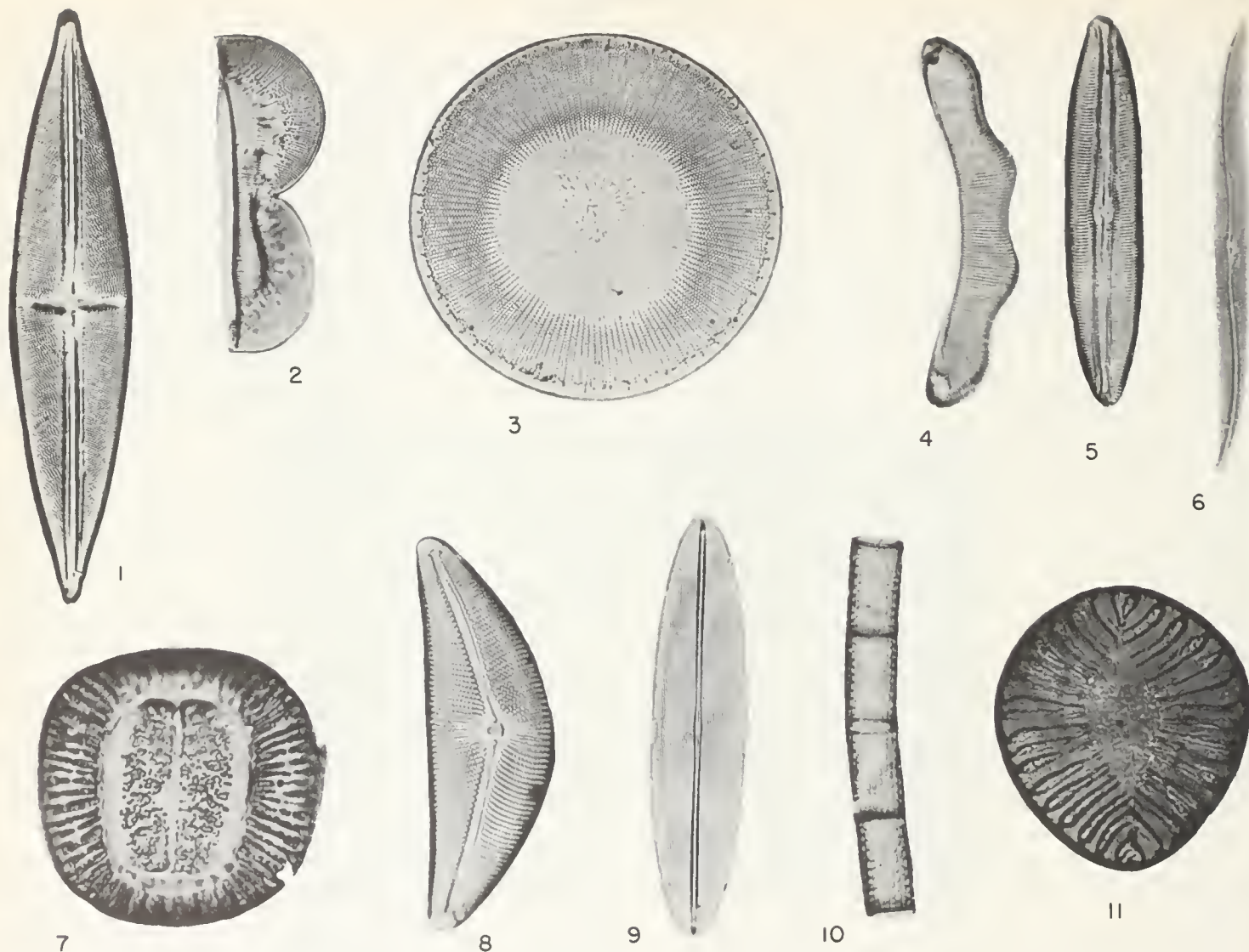


FIG. 1. Living and Pleistocene fresh- and brackish-water diatom species. Nos. 3 and 10 are fossil fresh-water forms; nos. 6, 7, and 9 are ordinarily found in brackish or saline water. (1) *Stauroneis phoenocenteron* Nitzsch. McLeod Basin, Florida, peat deposit. (2) *Amphiprora alata* Ehrenberg. Pyramid Lake, Nevada. (3) *Stephanodiscus niagrac* Ehrenberg. Laguna Seca, Fresno County, California. Tular, Pliocene. Spec. no. 3362. This is one of the few circular and flat species of diatoms which inhabit fresh waters. (4) *Eunotia diodon* Ehrenberg. McLeod Basin, Florida, peat deposit. (5) *Navicula (Caloneis) liber* W. Smith. Pyramid Lake, Nevada. (6) *Pleurasigma strigilis* W. Smith. Pyramid Lake, Nevada. (7) *Campylodiscus clypeus* Ehrenberg. Pyramid Lake, Nevada. (8) *Cymbella mexicana* Ehrenberg. Pyramid Lake, Nevada. (9) *Frickia lewisiana* Greville. Bolinas Bay, California. (10) *Melosira granulata* Ehrenberg. Laguna Seca, Fresno County, California. Spec. no. 3363. This species formed extensive deposits in the western states during the Miocene; it is a fresh-water form. (11) *Surirella utahensis* Grunow. Pyramid Lake, Nevada.

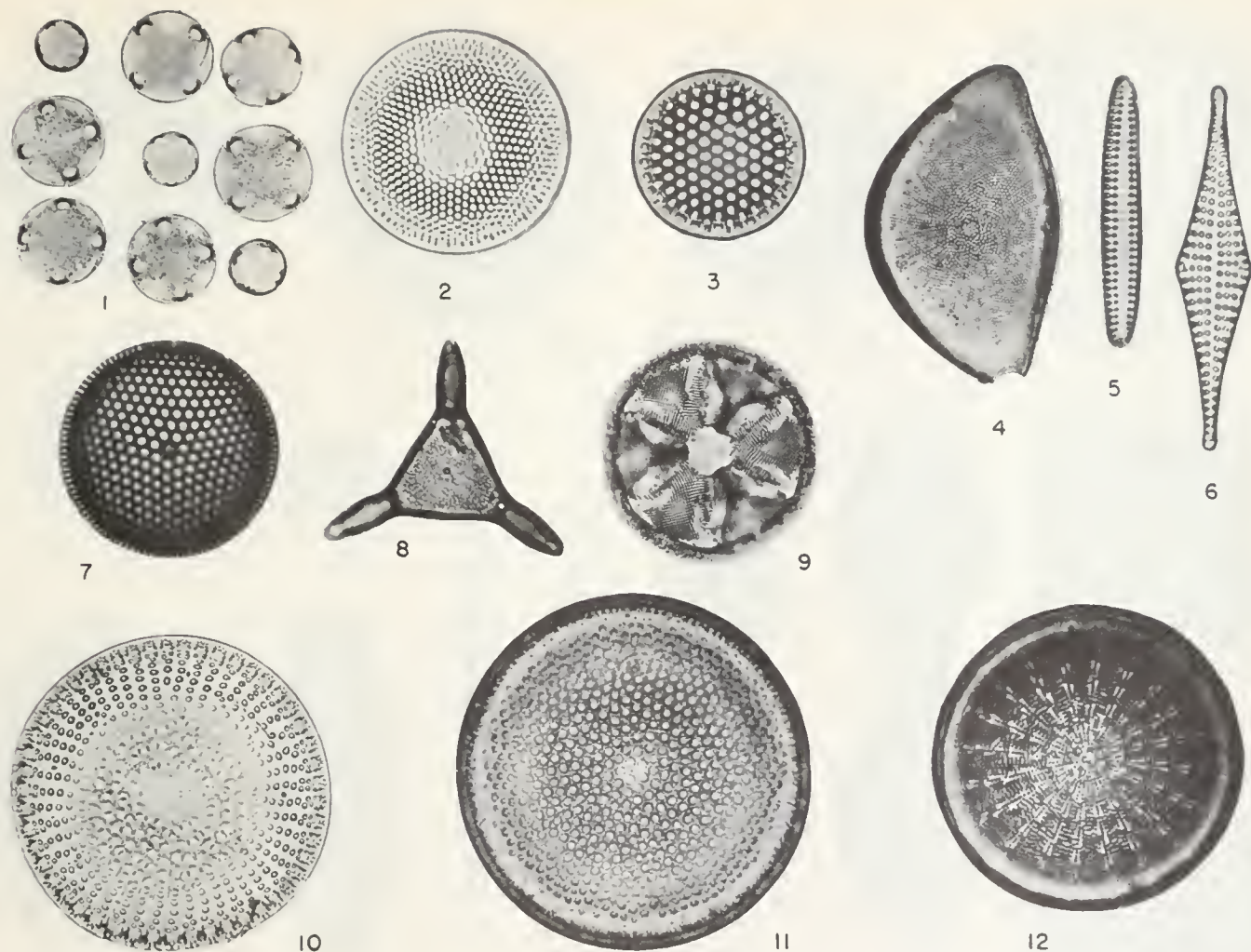


FIG. 2. Living and Pliocene marine diatom species. (1) *Aulacodiscus kittoni* Arnott. This is a living diatom species, abundant along the California, Oregon, and Washington coasts. These diatoms sometimes wash ashore in such quantity that windrows of them are formed on the beaches. The specimens pictured came from the beach at Halfmoon Bay, San Mateo, California. (2) *Coscinodiscus* sp. A remarkably symmetrical form from a Pliocene marine deposit on St. Paul Island, Bering Sea, Alaska. (3) *Coscinodiscus* sp., also from the Pliocene of St. Paul Island, Bering Sea, Alaska. (4) *Hymnodiscus simplicissimus* Hanna and Grant. Pliocene, Harris Grade, Santa Barbara County, California. (5) *Thalassionema* sp. Pliocene, Harris Grade, Santa Barbara County, California. (6) *Rhophonis rhombus* Ehrenberg. Pliocene, Harris Grade, Santa Barbara County, California. (7) *Coscinodiscus concentricus* Ehrenberg. Pliocene, Harris Grade, Santa Barbara County, California. (8) *Lithodesmium cornigerum* Brun. Pliocene, Harris Grade, Santa Barbara County, California. (9) *Actinoptychus clevei* Schmidt. Pliocene, Harris Grade, Santa Barbara County, California. (10) *Stictodiscus californicus* Greville. Pliocene, Harris Grade, Santa Barbara County, California. This specimen was found near the top of the exposed section and may have been redeposited from the upper Miocene, in which the form is common. (11) *Coscinodiscus herculus* Brun. Pliocene, Harris Grade, Santa Barbara County, California. (12) *Actinocyclus ehrenbergii* Ralfs. Pliocene, Harris Grade, Santa Barbara County, California.

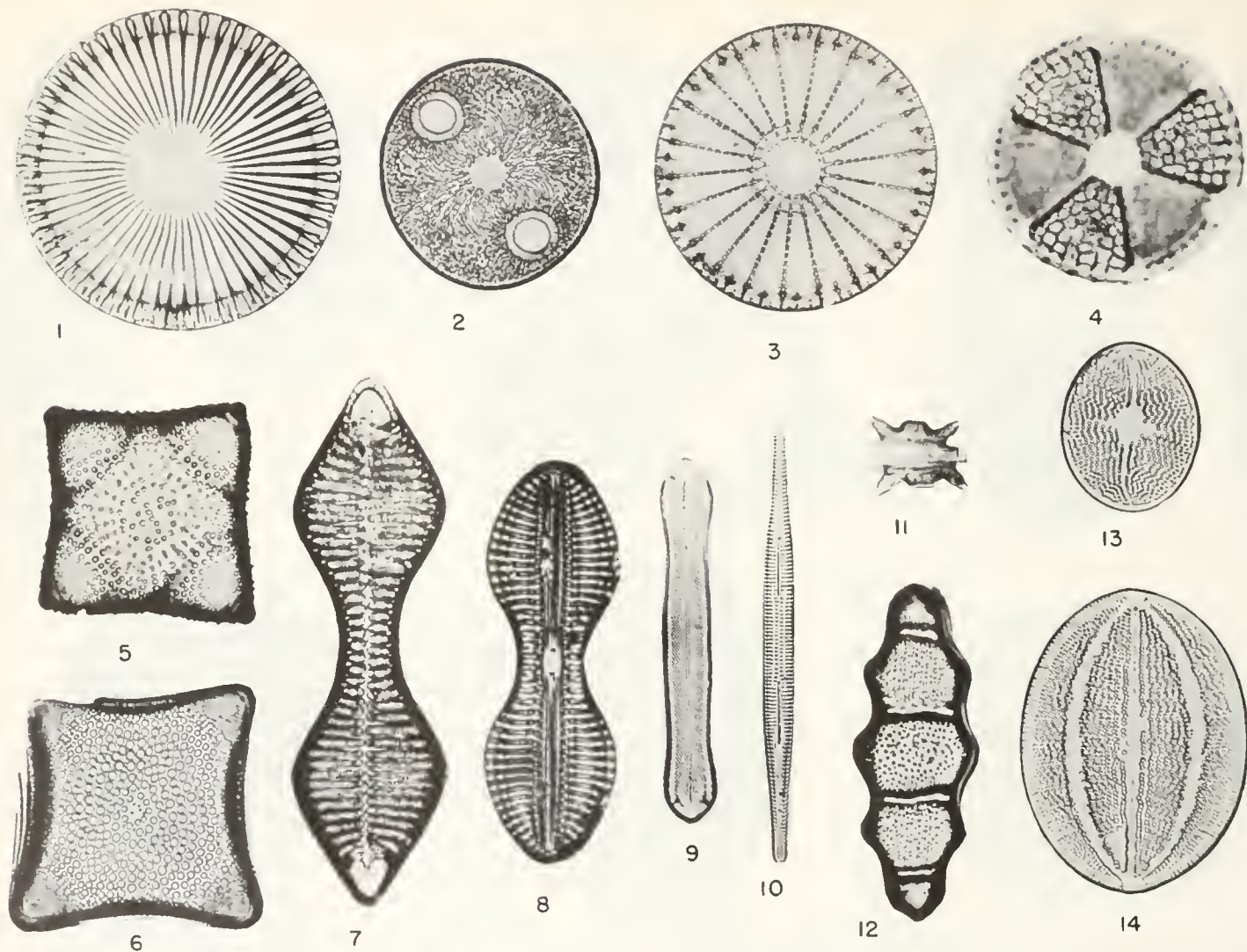


FIG. 3. Diatom species from Monterey formation, upper Miocene. All of the forms illustrated in this figure came from loc. 1277 (California Acad. Sci.), four miles east of Del Monte, Monterey County, California. (1) *Melosira clavigera* Grunow. (2) *Auliscus albidus* Brun. (3) *Arochnoidiscus chrenbergii* Bailey. (4) *Actinoptochus astur* Brun. (5) *Triceratium cf. junctum* Schmidt. (6) *Triceratium californicum* Grunow. (7) *Rhabdonema biquadratum* Brun. (8) *Diploneis crabra* Ehrenberg. (9) *Grammatophora* sp. (10) *Rousia californica* M. Peragallo. (11) *Biddulphia aurita* Brebisson. (12) *Biddulphia tuomeyi* Bailey. (13) *Cocconeis oculus cuti* Brun. (14) *Cocconeis cf. antiqua* Brun.

At any rate, California has the most extensive deposits of diatoms known to geologists. The only comparable ones are those now being formed in the arctic and antarctic regions where the source of silica seems to be the finely ground rock flour produced by glacial action on the land surfaces. The most ancient deposit regarding which detailed geologic information is available is on the west side of the San Joaquin Valley in Fresno County. This is in the Moreno shale of Upper Cretaceous age. Some deposits of similar age (as judged by the similarity of the diatoms) are found in the interior of Russia, but little or nothing has been published about them and even the localities are very vaguely indicated. Samples were obtained many years ago by microscopists who studied the organisms solely because of their beauty.

There are some published reports of early Paleozoic diatoms having been found, but in no case has the occurrence been verified. Diatoms must have originated prior to the Upper Cretaceous, however, because at that time they were abundant, highly organized, and of many diverse forms; apparently a place favorable for their preservation simply has not been found.

In upper Eocene time the Kreyenhagen shale accumulated; it is a vast deposit, the detrital material of which is largely light-colored ash. It, or its equivalent under other names, is found from the Tehachapi Range north into Washington. In the rocks of this age there are some excellent deposits of diatomite.

The Miocene was an age of much volcanism, the effects of which were world wide. In sediments of this age are the greatest known accumulations of diatoms. Millions of years were required to form these deposits. One in Kern County, not all diatomite, by any means, but all of somewhat similar composition, is over 7,000 feet thick and thinly laminated throughout. No one has counted the laminations and it is not known for sure that each one represents a year, but that is a probability. Literally hundreds of species of diatoms are found in the Miocene deposits, many of them of exquisite beauty. Members of some of these ancient species are living today. By comparing diatoms in the California Miocene deposits with forms in certain deposits elsewhere (on the east coast of the United States, in Spain, Africa, New Zealand, or Japan), it has been possible to establish that the time of deposition was the same. Since a great many forms, when living, are pelagic, or free-floating in the sea, the same species may spread over very wide areas at the same time.

Large quantities of ash washed into the sea during the Miocene, and equal or greater quantities gathered in the lakes. There are many widely distributed freshwater deposits of this age in the western states. It appears that diatoms may have first entered fresh waters early in the Miocene, for there are vast deposits made up solely of one species, *Melosira granulata*. An earlier formation in the Great Basin area, the

Green River shales of Eocene age, seems admirably adapted to the preservation of such fossils, yet not a single one has been reported from it to date.

During the Pliocene ash was deposited, but on a much smaller scale. The Pleistocene diatoms are scarcely distinguishable from those of today.

How to distinguish diatom deposits of marine origin from those of freshwater origin at first puzzled many California geologists; but it so happens that among the 25,000 or more known species, living and fossil, there is not one which has been found in both situations. Diatoms of a brackish-water environment are distinctive; and diatoms that make alkaline lakes their habitat are different from those that live in waters less saline; species which attach to rocks and sticks in running streams are not ordinarily found elsewhere.

The age of the various diatom-bearing marine deposits in California was also once difficult to determine. All are usually yellowish or brownish in color, many weather white, all are siliceous to a certain degree, and rarely do any of them contain other fossils by means of which their age can be determined. Thus the Cretaceous and the Eocene were once thought to be Miocene in spite of their position. Freshwater deposits of Nevada were thought to be marine because they were soft and white like the Lompoc deposits. Careful study of the diatoms from many localities, however, made it possible to place the various deposits in their proper sequence; and this sequence has since been verified by extensive research on foraminifera. Many of the oil fields in California are closely associated with large deposits of shale in which diatoms are either abundant or obviously once were present. This association has led to a theory that at least some of the oil originated from diatoms. This may or may not be true, but certainly each living diatom contains a very conspicuous globule of oil—not petroleum, however.

The physical structure of the diatom frustule or body covering is such that many uses have been found for diatomite. Diatomite is very porous, and as a consequence some of the purer grades weigh only a few pounds per cubic foot. This makes a good, fireproof insulator. If added to many liquids, diatomite adheres to any minute suspended particles, so that when filtered out it clarifies the solution. Very large quantities are used in sugar refineries to take the coloring matter out of the liquid prior to crystallizing out the sugar. Furnace bricks in large quantity are made from a grade of diatomite that has just enough clay to act as a binder when fired. Only a very large deposit such as that at Lompoc, where products can be standardized as to quality, can ordinarily be operated on an extensive scale. Many other deposits in the west were opened at one time or another, but none was active for long. Some material was mined on the north end of Catalina

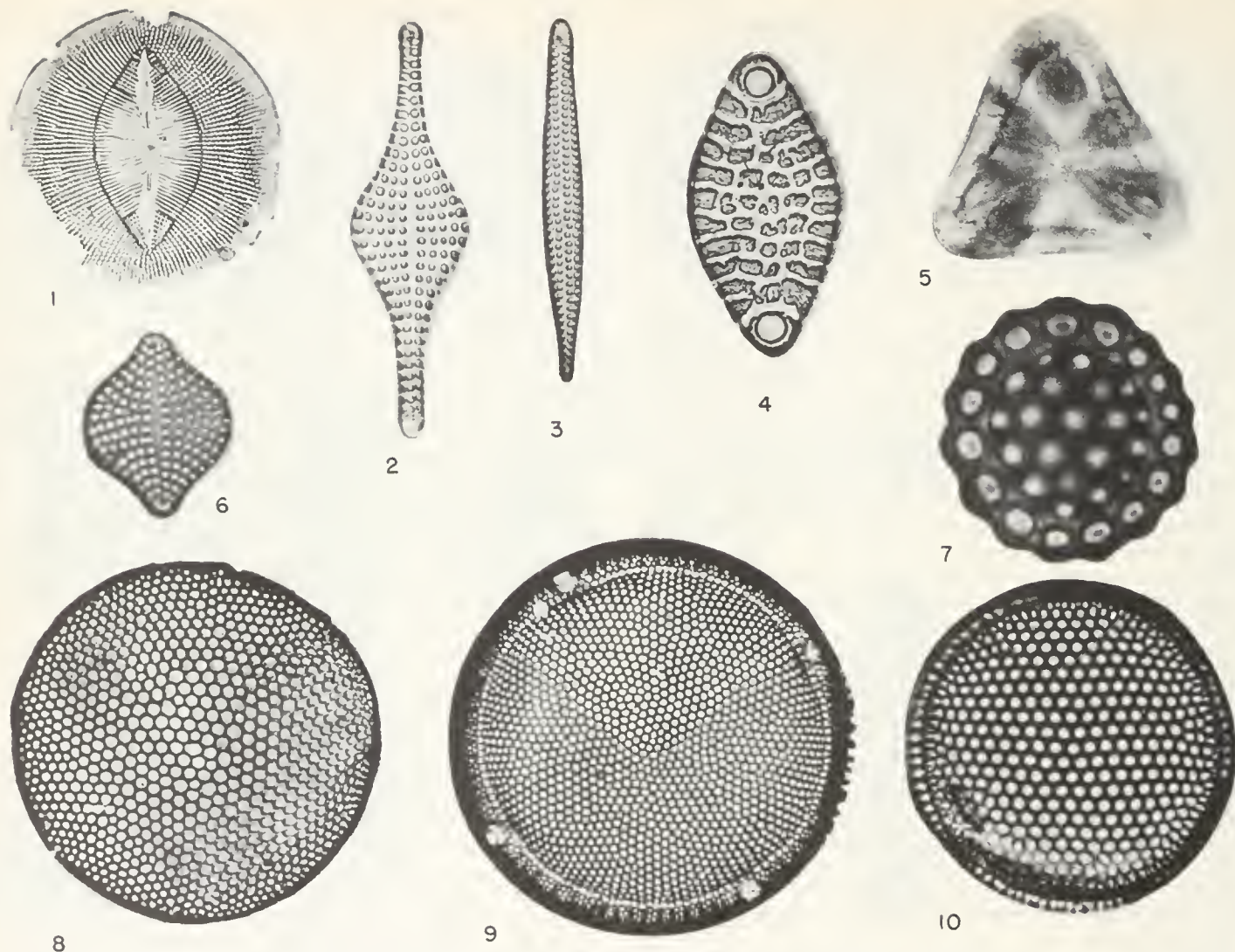


FIG. 4. Diatom species from Temblor formation, middle Miocene. All of the specimens illustrated in this figure, except No. 4, are from the shales exposed on Sharktooth Hill, Kern County, California. (1) *Raphidodiscus marylandicus* Christian. (2) *Rhaphoneis elegans* Pautocek and Grunow. (3) *Sceptroneis caduceus* Ehrenberg. (4) *Axstotheca hustedti* Hanna, Smuggler's Cove, Santa Cruz Island, California. E. C. Johnson, collector. (5) *Cymatogonia amblyoceras* (Ehrenberg). (6) *Rhaphoneis obesula* Hanna. (7) *Macrora stella* (Azpeitia). (8) *Rattrayella inconspicua* (Rattray). (9) *Eupodiscus antiquus* Cox. (10) *Coscinodiscus lineatus* Ehrenberg.

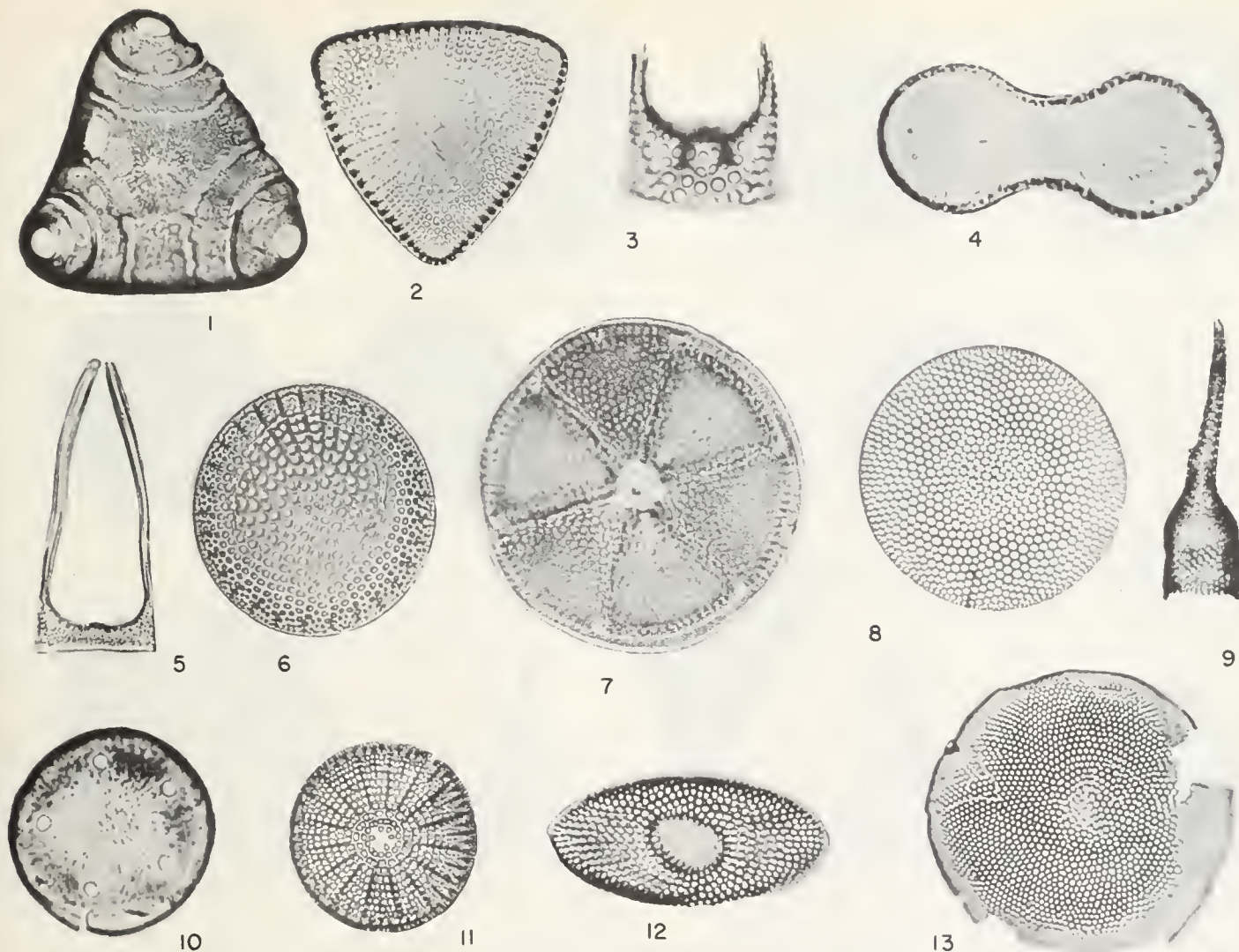


FIG. 5. Diatom species from Kreyenhagen formation, upper Miocene. Loc. 894 (California Acad. Sci.); Phoenix Canyon, a small branch of Oil Canyon, about seven miles north of Coalinga, Fresno County, California, sec. 20, T. 19 S., R. 15 E., M. D. Loc. 1832 (California Acad. Sci.); 2½ miles south of Antioch, Contra Costa County, California, sec. 2, T. 1 N., R. 1 E., M. D. Loc. 2256 (California Acad. Sci.); one-half mile southwest of Crow Hill, Stanislaus County, California, sec. 1, T. 7 S., R. 7 E., M. D. (1) *Triceratium lineatum* Greville; loc. 1832. (2) *Stictodiscus coalingensis* Hanna; loc. 894. (3) *Hemialus polymorphus* Grunow; loc. 894. (4) *Xanthiopyxis spectularis* Hanna; loc. 894. (5) *Hemialus claviger* Schmidt; loc. 894. (6) *Stictodiscus hardmanianus* Greville; loc. 894. (7) *Actinoptychus camarucensis* Grunow; loc. 894. (8) *Coscinodiscus radiatus* Ehrenberg; loc. 894. (9) *Pyrrilla intermedia* Tempere and Forti; loc. 1832. (10) *Rattrayella californica* Hanna; loc. 2256. (11) *Arachnoidiscus indicus* Ehrenberg; loc. 1832. (12) *Crispedodiscus oblongus* (Greville); loc. 1832. (13) *Roperia marginata* Hanna; loc. 1832.

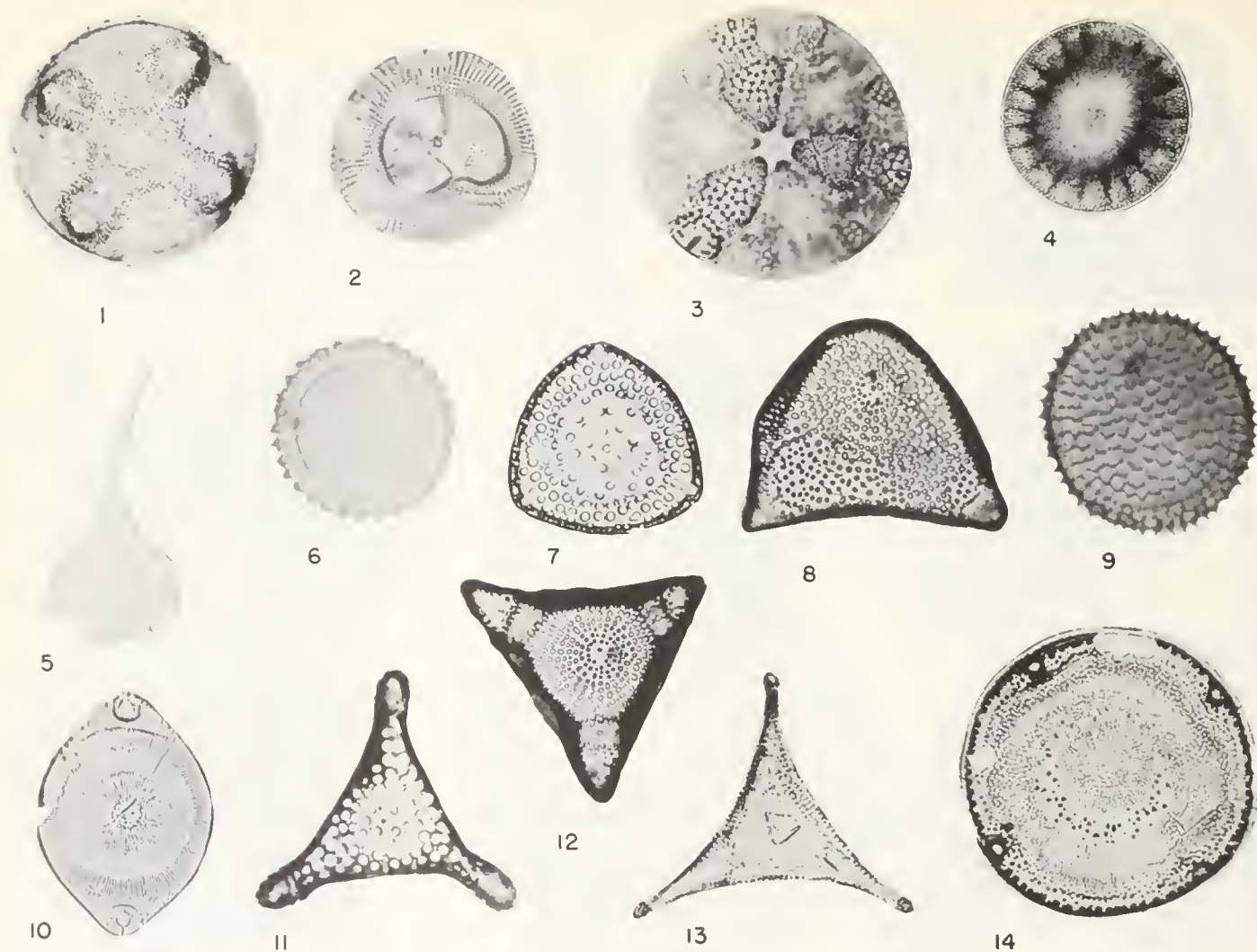


FIG. 6. Diatom species from Moreno formation, Upper Cretaceous, Loc. 943 (California Acad. Sci.); Moreno Gulch, Panoche Hills, Fresno County, California, Loc. 1144 (California Acad. Sci.); Panoche Hills, Fresno County, California, sec. 6, T. 15 S., R. 12 E., M. D. (1) *Aulacodiscus archangelskianus* Witt; loc. 1144. (2) *Benctorus fantasmus* Hanna; loc. 943. Long, Fuge, and Smith have a similar diatom listed as *Craspedodiscus morenoensis* (Long, Fuge, and Smith, pl. 17, fig. 1). (3) *Gloriptychus callidus* Hanna; loc. 943. (4) *Coscinodiscus steinyi* Hanna; loc. 943. (5) *Kentrodiscus aculeatus* Hanna; loc. 943. (6) *Melosira fausta* Schmidt; loc. 943. (7) *Triceratium hertleini* Hanna; loc. 943. (8) *Triceratium bicornigerum* Hanna; loc. 943. (9) *Stephanopyxis discrepans* Hanna; loc. 943. (10) *Metrasulus gracilis* Hanna; loc. 943. (11) *Trinacria uries* Witt; loc. 943. (12) *Trinacria tristicta* Hanna; loc. 943. (13) *Trinacria excavata* Heiberg; loc. 943. (14) *Hyalodiscus strigillata* Witt; loc. 1144.

Island many years ago, and there are deposits on San Clemente, Santa Cruz, and Santa Rosa Islands.

The study of diatoms dates far back in history, but those who first saw the organisms by means of their simple microscopes could not make out the distinguishing features very well. The individual plant skeleton is very small. It has been estimated that from the beginning all students of diatoms put together have not looked at more than a few cubic inches of diatom material, a single cubic inch of which has been computed to contain 75,000,000 individuals. And California can measure its diatom material by the cubic mile!

For a great many years the study was concerned mostly with admiration of the beauty and geometrical symmetry of the frustules. Enthusiasts pressed their microscopes to the utmost and demanded better and better ones of the manufacturers. Today the markings on certain kinds of diatoms are used to determine the perfection of microscope lenses, and it is still likely that there is much that has not been seen, even by the most expert manipulators with the best of equipment; photographs taken with an electron microscope have shown that markings lately considered to be the most minute have still smaller markings imposed on them.

The first fossils from California that were described in technical literature were diatoms. The localities were given merely as Monterey and San Francisco, but the latter is the deposit at Pinole on the east side of San Francisco Bay. The material is exposed on both sides of the highway at the south edge of town. The original sample was obtained by a Captain Chilton and eventually reached G. C. Ehrenberg in Berlin. He mentioned the fossils in 1853, and published figures of them in 1854.

Along Grizzly Peak Boulevard, in Berkeley and Oakland, large masses of yellowish-brown rock can be seen in the road cuts. This is Monterey shale, of Miocene age. Diatoms are not preserved in it so far as is known. It has been modified into a hard, cherty, porcelaneous shale, as if the silica had turned to a sort of gel and then solidified.

Over on the east side of Mount Diablo there are fine exposures of Eocene rocks, among which is the Kreyenhagen shale. This is well exposed in Markley Canyon, and contains beautifully preserved diatoms. There is much Cretaceous rock around Mount Diablo but thus far no diatoms have been found in it.

There are a few slightly elevated, rather recent deposits of impure diatomite around San Francisco Bay. One is on the south side of San Pablo Point, elevated a few feet above the bay level; it contains large numbers of a saddle-shaped brackish-water form called *Campylodiscus*.

North of the bay, ash beds are common in several counties, but there are no known deposits of marine diatoms. In a few places fresh-

water beds have been found. One of the better known is at Mark West Spring 8 miles southwest of Healdsburg, Sonoma County. In Lake County there are many deposits, especially in the vicinity of Kelseyville; here the diatoms and tuff are interbedded with such rocks as obsidian, rhyolite, and other lavas.

In the plates herewith an attempt has been made to show enough representative diatoms to enable the reader to get an understanding of what they look like. It is obviously impossible to do more, when there is such a very large number from which to choose. The literature on the subject is very extensive (over 5000 titles), widely scattered, and difficult to collect. A few representative titles have been listed below for ready reference.

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PART VI  
WATER

**Editorial Note:**

PART SIX is devoted to the controlling factor of California's civilization—WATER. To supplement local surface and underground supplies, water is brought into the bay region from the Sierra Nevada, from mountain streams which first contribute hydroelectric power for the cities, then clear, pure, fine-tasting water for homes and for industry and irrigation. The story of providing and distributing adequate supply of satisfactory water to the San Francisco Bay area ties in very closely with the story of minerals and their use.

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## SURFACE WATER SUPPLIES IN THE SAN FRANCISCO BAY AREA

By ROBERT L. WING \*

One hundred years ago the San Francisco Bay region was for the most part undeveloped. Cattle ranged the hills surrounding the bay and grazed the plains of the great valleys. The white population of only a few thousand centered in the villages of Yerba Buena, now San Francisco, San Jose, and Sutter's Fort; near the old missions of St. Francis, Santa Clara, San Jose, San Rafael, and Sonoma; and around the haciendas of the Spanish rancheros. With the possible exception of small irrigation developments around the old missions, water-supply systems were non-existent. A meager water supply for domestic purposes was secured from nearby streams, small springs, or shallow wells.

Today over 3,000,000 people live in the San Francisco Bay region. The straggling villages have grown into great cities. Factories line the bay shore and the cattle have been driven from the valleys by an intensive irrigated agriculture which often raises two or even three crops a year. Great water-supply systems have also been developed; reservoirs store the winter runoff from the streams around the bay; deep wells and pumps draw water from the gravels underlying the valleys; and great aqueducts bring water many miles from the snow-covered peaks of the Sierra Nevada.

For the most part these systems did not spring into being full grown. They are the product of a gradual evolution responding to changing needs and an ever-growing demand, controlled in part by the separation of the region into distinct geographical units by the bays, straits, and rivers; in part by available sources of supply; and in part by political boundaries. Although most of the systems were started as private enterprises, nearly all of them are now publicly owned. As the larger systems grew, many of the smaller and competing systems were absorbed. Others, while retaining their corporate independence, have become dependent upon the larger systems for either standby service in dry periods or for a large portion of their annual supply. Others, still independent, probably will turn to the larger systems for additional water as their present sources of supply become inadequate.

*City of San Francisco System.* One hundred years ago the City of San Francisco derived its water supply from springs, shallow wells, and from water carts distributing water brought on barges from the streams of Marin County north of the Golden Gate. Today, the City of San Francisco administers the largest water-supply system in the bay region, serving not only the city itself but also the many suburban communities which occupy the bay shore of the San Francisco penin-

sula as far south as Palo Alto. At first under private ownership, but since 1930 under municipal ownership, this system has gradually extended its supply lines farther and farther until now it is bringing water from the upper Tuolumne River in the Sierra Nevada over 170 miles from the city.

The first large supply to replace the water carts of 1849 was brought in by the San Francisco Water Works from Lobos Creek on the southwest border of the Presidio in 1858. However, as the urban area spread into the drainage basin of Lobos Creek the waters became increasingly unsuitable for use, and this source was finally abandoned in 1900. The first water from sources still in use was imported from Pilarcitos Creek in 1862 by the Spring Valley Water Works. This company, which soon absorbed the San Francisco Water Works, proceeded to develop the peninsula supply in a rapid and efficient manner. The Pilarcitos dam, storing 1 billion gallons was completed in 1866; the San Andreas dam, storing 6 billion gallons, was built in 1870; and the Upper Crystal Springs dam, storing 5 billion gallons, was completed in 1877. At this time Lake Merced, a natural lake fed by springs in the southwest corner of the city, was connected to the system by pumps. Finally in 1888 the development of peninsula sources was completed by the construction of the Lower Crystal Springs dam with a storage capacity of 17.5 billion gallons. The Lower Crystal Springs dam flooded the downstream face of the upper dam and these two reservoir now operate as one, serving not only to conserve the local runoff but also as a terminal reservoir for the aqueducts bringing water from both the Alameda Creek system and the upper Tuolumne River 155 miles away.

Early in the development of the peninsula system the Spring Valley Water Works, with commendable regard for the purity of its supply, started the acquisition of its watershed lands. As a result of this foresightedness practically the entire 32 square miles of watershed tributary to these reservoirs is city owned. It is now administered as a state fish and game refuge and, except for resident keepers and patrolmen, is uninhabited.

Development of Alameda Creek as a source of supply for the City of San Francisco began in 1875 when the Spring Valley Water Works purchased the Niles dam. The first pipe line across the bay was completed in 1888. In 1898 the development of the Pleasanton wells was started and in 1900 the Sunol diversion dam, filter galleries, and aqueduct were completed. The Calaveras dam, storing 31.5 billion gallons, completed in 1925, was the last major development under private ownership. In 1932 the City of San Francisco, having acquired the

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FIG. 1. San Pablo reservoir in San Pablo Canyon east of Berkeley and north of Orinda. Largest of the four water-storage basins for the East Bay Municipal Utility District, the reservoir has a capacity of 14 billion gallons. Water for the reservoir comes from the Mokelumne River in the Sierra Nevada. Hills on either side of the reservoir are principally land-laid sediments and interbedded lava flows of Pliocene age. *Photo by Commercial Photo and View Company, courtesy East Bay Municipal Utility District.*

properties, built the Upper Alameda Creek diversion dam which added 35 square miles to the watershed tributary to the Calaveras reservoir. As in the case of the peninsula development, the Spring Valley Water Works pursued the policy of protecting the quality of its waters by ownership of the lands, and most of the habitable areas in the Calaveras Creek and upper Alameda Creek watersheds are now city owned and administered.

In 1900 the City of San Francisco adopted a charter in which the policy of acquiring the public utilities was declared. Soon thereafter city officials filed on the waters of the upper Tuolumne River as a source of municipal supply. However, all was not clear sailing. Many other sources, both in the Sierra Nevada and in the north coastal ranges, were actively promoted by a myriad of supporters. Others maintained that sufficient water for many years to come could be secured from the properties of the Spring Valley Water Works. Active opposition to use of the Tuolumne waters arose from the farmers along the lower reaches of the stream. The flooding of the mountain meadows by man-made lakes was opposed by nature lovers. Since rights of way through national park and forest lands were required the proposal was carried into Congress and a bitter fight ensued. Eventually the proponents of the project were successful and in 1913 the Raker Act granting the necessary rights of way was passed by Congress. Bonds had already been voted and construction of the project was started immediately. Lake Eleanor, storing 9 billion gallons, was completed in 1918, and O'Shaughnessy dam, storing 67 billion gallons, in 1923. Increasing costs, however, necessitated the issuance of additional bonds and it was not until 1934 that the Hetch Hetchy aqueduct was completed and Tuolumne River water was delivered by it to the Crystal Springs reservoir.

The present safe yield of the City of San Francisco water-supply system is estimated to be 25.5 million gallons daily from the peninsula system, 41 million gallons per day from the Alameda Creek system and 400 million gallons per day from the Hetch Hetchy system, or a total of 466.5 million gallons per day. This is over 4.5 times the annual use of 101 million gallons per day in the 1947-48 fiscal year. However, the full development of the upper Tuolumne River supply will require the construction of additional reservoirs and pipe lines.

*East Bay Municipal Utility District System.* The water-supply system of the East Bay Municipal Utility District which serves the many residential and industrial communities lining the east shore of San Francisco and San Pablo Bays from San Lorenzo on the south to Vallejo on the north is the second largest water-supply system in the San Francisco Bay region. As was the case with the City of San Francisco the system was built up and operated for many

years under private ownership. The shift to municipal ownership came when the exhaustion of nearby supplies forced the importation of a large supply from a distant source.

The local system in its final form resulted from the amalgamation of a number of small companies. As each of the many small separate communities developed, independent companies were organized to supply the necessary water. For the most part these secured their supply either by surface diversion from small creeks in the hills or from nearby wells. As the communities grew these local sources became inadequate and the small companies were absorbed by the larger and better financed ones which were able to supply water through either surface storage or by importation from distant well fields. Finally the larger ones combined into a single system, the East Bay Water Company. During most of the operation under private ownership the major sources of supply were well fields extending from the Pinole Creek delta on the north to the Alameda Creek cone on the south, and surface supplies from San Lorenzo Creek. After the Municipal Utility District acquired the properties and brought in a supply from the Mokelumne River, these well fields were abandoned as a source of municipal supply. Private wells, however, are still operated by some east bay industries.

The first surface storage was provided by the construction of the Temescal dam, with a storage capacity of 150 million gallons in 1869. The urban area having spread throughout the drainage basin, this reservoir was abandoned as a source of supply when Mokelumne River water became available, and is now a part of the regional park system. The next surface development occurred with the construction in 1892 of the Lower San Leandro dam, storing about 5 billion gallons in Lake Chabot. After this, additional development was confined to well fields until the available underground waters were practically exhausted as a source of additional water supply. The San Pablo reservoir, storing 14 billion gallons, was built in 1920. The construction of the Upper San Leandro reservoir in 1926, with a capacity of 13.5 billion gallons, was the last development under private management.

In 1918 the surface reservoirs then constructed went dry and it was necessary to prohibit the irrigation of gardens and to restrict domestic use to the barest necessities. This condition continued in a greater or lesser degree until the completion of San Pablo reservoir in 1920. Spurred on by this catastrophe the people of the east bay communities organized the East Bay Municipal Utility District in 1923 for the purpose of developing an adequate water supply. Many different sources of supply, including the possibility of joining with the City of San Francisco in the Tuolumne River project, were investigated. However an independent supply from the Mokelumne



FIG. 2. Lafayette reservoir in the hills southwest of Lafayette, Contra Costa County. Completed in 1932, it is the smallest of the four storage basins that impound the water brought in by aqueduct from the Mokelumne River in the Sierran foothills. It has a capacity of  $1\frac{1}{2}$  billion gallons. Ridges in the middle distance are soft land-laid clays and poorly consolidated sands and gravels of Pliocene age. Photo by Commercial Photo and View Company, courtesy East Bay Municipal Utility District.

River was finally chosen. Construction of Pardee dam, storing 72 billion gallons, and of the aqueduct to the bay were started at once and, impelled by fear of a second drought, carried on at maximum speed. In 1928 the reservoirs and distributing system of the private company were acquired and in June 1929 water was delivered to San Pablo reservoir just in time to avert another water shortage, for less than a 2-month supply remained in the local reservoirs at that time.

The present safe yield of the East Bay Municipal Utility District system is estimated to be about 216 million gallons per day, of which 200 million gallons per day comes from the Mokelumne River. Present consumption is slightly over 100 million gallons per day or about half the present safe yield.

*Contra Costa Canal System.* Another large system serving the San Francisco Bay region is the Contra Costa canal, one of the units of the Central Valley Project, constructed by the United States Bureau of Reclamation. This system serves the agricultural and industrial areas along the south shore of Suisun Bay and the Carquinez Straits in Contra Costa County, from Martinez to Antioch. It was not the result of gradual growth but came into being full size.

The early municipal and industrial developments in this area procured their water supply for the most part by pumping from the Sacramento and San Joaquin Rivers near their entrance to Suisun Bay. However as upstream developments in the Sacramento and San Joaquin Valleys diverted more and more water from these rivers for irrigation and other uses, the quality of the water in their lower reaches progressively deteriorated. Eventually the summer flows became so low that salt water intruded from the bay up to and past the intakes of the pumping plants, and diversion was only possible during periods of high flows. Resort was had to wells but the well waters were found to be limited in amount and of poor quality. The solution of this problem was one of those undertaken by the state in 1921 when it started the investigations which led to the adoption of the Central Valley Project by the people of the state in 1933. Under this project flood waters stored in Shasta reservoir are to be released in sufficient amount to maintain water of good quality in the delta and also to provide additional fresh water for export from the delta to places of need. The project includes four pumping plants which lift the water from Rock Slough and a canal leading along the north shore of Contra Costa County from Rock Slough to a terminal reservoir near Martinez. The pumping plants and first sections of the canal were completed before World War II and served water during that period. The remainder of the canal has now been completed and is serving water as far as Martinez. As constructed the canal has an intake capacity of 350 second feet at the pumps, which is gradually reduced to a capacity of 22 second feet at the terminal reservoir.

Should a consolidation of the City of San Francisco, East Bay Municipal Utility District, and Contra Costa canal systems into one large metropolitan supply ever become desirable, it would be a relatively simple problem. Only about 10 miles separate the Hetch Hetchy aqueduct of the City of San Francisco and the southern end of the East Bay Municipal Utility District system. In fact a connection between the two systems was made in 1933 when, prior to the introduction of Tnolumne River water, the City of San Francisco system was suffering from drought conditions. At that time the East Bay Utility District delivered water to the City of San Francisco. The Mokelumne River aqueduct parallels the Contra Costa canal for several miles and could either deliver water to the canal or receive water pumped from it if desired.

*Santa Clara Valley Water Conservation District System.* At the present time the cities and smaller towns of the Santa Clara Valley obtain their water, for the most part, by pumping from the large basin which underlies the valley floor. There has however been considerable development of surface supplies in the streams entering the valley. Stanford University secures irrigation water from reservoirs on San Francisquito Creek and the San Jose Water Works, the largest private water company in the San Francisco Bay region, obtains a part of its supply from reservoirs on Los Gatos Creek. The major surface developments, however, have been made by the Santa Clara Valley Water Conservation District.

Under a combined pumping draft for both irrigation and municipal uses the water level in the underground basin had been falling rapidly prior to 1933. In an effort to alleviate this condition the Water Conservation District was formed and reservoirs were built on many of the streams entering the valley. For the most part these are small reservoirs designed to release stored waters as fast as they can be absorbed into the underground basin through the stream channels and other works. However, the Coyote and Anderson reservoirs on Coyote Creek, and the Lexington reservoir on Los Gatos Creek, now under construction, have been designed for over-year storage. The district operates to maintain the level of the underground waters and does not sell or distribute water for consumptive use. During the wet period from 1938 to 1943 water levels were raised to very nearly their former elevations. However, the increase in development since the war, with its concomitant increase in draft, combined with the dry period of the last few years, has resulted in again lowering the ground water to maximum depths and Santa Clara Valley interests are now seeking a source of additional supply.

*Marin Municipal Water District System.* The Marin Municipal Water District derives its supply from a system of three reservoirs, Lagunitas, Alpine, and Bon Tempe on Lagunitas Creek which drains the north slope of Mount Tamalpais, and Phoenix Lake on the east-



ern slope of the mountain. The system was started by the construction of Lagunitas dam, which created a reservoir storing 108 million gallons, in 1872. In 1908 the available storage was increased 200 million gallons by the construction of Phoenix dam. Alpine dam, now storing 3.0 billion gallons, was built in 1917 and raised to its present height in 1942. Bon Tempe reservoir, with a storage capacity of 1.4 billion gallons, was completed in 1949. The average yield of the watershed above Alpine dam is estimated by the Marin Municipal Water District to be about 13 million gallons per day. The present consumption is about 8.2 million gallons per day.

*City of Napa System.* The City of Napa secures its supply from two reservoirs. Milliken dam, storing 650 million gallons of water, was built on Milliken Creek in 1924, and Conn Valley dam, storing 9.8 billion gallons, was completed in 1946. The safe yield of this system is far in excess of present needs and will provide an adequate supply for many years to come.

*City of Vallejo System.* The earliest development of water for the City of Vallejo was by the Vallejo Water Company which built Chabot dam, storing 380 million gallons, on Sulphur Springs Creek just north of the city, in 1870. Relations between the city and the water company, however, were not satisfactory and the city soon decided to acquire its own water supply. In this case the city did not buy out the private company but built an independent supply and distribution system. Competition between the two systems was keen. Under these conditions the private system shrank as the municipal system grew. Eventually service by the private company was restricted to a few industries and agricultural areas outside of the city limits. Finally, a few years ago, the city purchased the properties of the Vallejo Water Company and all service from that source was discontinued. It is planned to develop Lake Chabot, now idle, as a municipal park.

The present system of the City of Vallejo consists of three reservoirs, Lakes Madigan and Frey, storing 550 million gallons and 350 million gallons respectively on Wild Horse Valley Creek, and Lake Curry with a storage capacity of 3.5 billion gallons on Gordon Valley

Creek. Lake Frey was built in 1894, Lake Madigan in 1908, and Lake Curry in 1926. This system provides a net safe yield of about 3 million gallons per day, which was adequate until the rapid expansion of the city and vicinity occurred during the late war. At that time the City of Vallejo connected its system with that of the East Bay Municipal Utility District and is now receiving most of its supply from the latter agency.

Since Vallejo is not a part of the East Bay Municipal Utility District it may not be possible to procure water from that source after the present contract expires. The city is therefore now in search of an additional supply. Possible sources are the proposed Monticello reservoir on Putah Creek, the City of Napa's system, and diversion from the Sacramento River.

*City of Sacramento System.* Water supplies for those portions of the San Francisco Bay region which lie in the central valley area have for the most part been secured by pumping either from adjacent streams or from underground basins. The only large municipal system using surface waters as its source of supply is that of the City of Sacramento, which pumps its water supply from the Sacramento River. This system, which has always been municipally owned and operated, was in 1949 in its 97th year of operation. During its early years, and until 1924, water was pumped directly from the river into the distribution mains, the only treatment provided being chlorination at the pumps.

However, a modern treatment plant was built in 1924 and this has been enlarged and improved as conditions demanded. At the present time the water, which is unusually soft in comparison with other California municipal water supplies, is coagulated, settled, filtered, and chlorinated, before being pumped into the distribution system. The water produced is of a high standard as to taste, odor, clarity, and purity. The pumping and treatment plants are located just north of the city limits on Jibboom Street. The demand on the plant in 1948 averaged about 31 million gallons per day, or about 237 gallons per day per capita, one of the largest in the United States. The maximum use during summer months is almost twice the average. The plant is capable of supplying a considerable increase in demand.

PART VII  
PLACES TO GO AND ROUTES TO TRAVEL

**Editorial Note:**

PART SEVEN guides the reader and traveler in the field to show him first hand many of the significant geologic features of the bay area as exposed along roads and in other interesting locations. The information has been in part compiled from various published reports, but much of it has been secured and prepared especially for this volume. A better understanding of the preceding chapters will be gained after the reader has followed in the field the suggested places to go and the roads to travel. As the reader completes his perusal of this volume and has been guided along ways in the field by these descriptions, the Division of Mines would be pleased to receive his comments on this method of approach to the study of the geology and mineral resources of a given area.

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## GEOLOGY OF THE FARALLON ISLANDS

By G. DALLAS HANNA •

A part of the City and County of San Francisco known in detail to few people is a group of small scattered islands approximately 30 miles off shore. They are seven in number, comprising South Farallon, the largest, and a few nearby rocks; Middle Farallon, about  $2\frac{1}{2}$  miles northwest of South Farallon; and North Farallon, a group of five rocks about 5 miles farther northwest. Beyond North Farallon are Noonday rock, almost awash, and Cordell Bank, which is submerged under 20 fathoms of water. All of these form what is sometimes called the Farallon ridge, which extends parallel to the coast line from the vicinity of the Golden Gate to that of Point Reyes. The high points of the islands are visible from San Francisco in clear weather; and San Francisco, from them, shows up at night as a magnificent, multi-colored glow of light in the eastern sky.

Although the islands are now rarely considered in the economy of the city or state, they loom large historically. If land values be based upon the production of materials useful to man, as they sometimes are, it is doubtful if any part of the city of equal area can match these islands. During the early part of the last century fur seals and sea otters were taken on and about the Farallons in numbers which now seem incredible. Both species were hunted to virtual extinction. When tens of thousands of emigrants entered San Francisco Bay after news of the discovery of gold had spread over the world, there was very great need for food of many kinds, and it was necessary to resort to numerous unusual expedients. Some enterprising individuals (now unknown) hit upon the idea of furnishing fresh eggs to the thriving city of San Francisco by collecting those of sea birds on the Farallons. It is recorded that in 1853 one boat in 2 days gathered 120,000 eggs, which were sold for one dollar per dozen. Considerable rivalry developed between different groups and an amusing "egg" war was once fought. Prior to 1856, when the Farallon Egg Company was formed to unite the various interests engaged in the work, between three and four million eggs had been taken. For a long time the yearly crop was as much as 25,000 dozen, and as late as 1873 it was 15,000 dozen. Some San Francisco residents still remember the beautifully spotted and colored eggs in the markets. The industry continued until 1903, when further collecting was prohibited; and in 1909 the islands were made a bird reserve under the jurisdiction of the Light House Service, now the U. S. Coast Guard.

South Farallon has an additional value which cannot be estimated in dollars. On it is located a celebrated light which guides ships

and aircraft to San Francisco Bay. This light evidently was established between 1852 and 1855, because in the latter year Lieutenant W. P. Trowbridge published a report describing the island in considerable detail and an excellent map showing the topography, and also three views showing the light. A fog signal was established in 1858 by mounting a locomotive whistle over a hole at the upper end of one of the sea caves or covered surge channels. It was later destroyed by a storm, but the bricked-up aperture still remains. In late years, first radio beacon signals and then radar have been added to safeguard navigation.

At one time a weather station was built near the center of the island. Some of the wreckage of the building is still scattered over the rocks. The cement walks and steps and the brick foundations should persist for many more years.

Accounts vary as to who first saw the Farallons. Some say it was Cabrillo in 1542, but there is no definite evidence that this is the case.



FIG. 1. Vertical view of South Farallon Island, July 1945. The system of surge channels shows up well on this photograph. Photo courtesy U. S. Coast Guard.

• Curator, Department of Paleontology, California Academy of Sciences.



FIG. 2. Drawing of South Farallon Island as it was in 1855. From Trowbridge, U. S. Coast Survey, 1855 Rept.

It has even been stated that the name was given in honor of the pilot Bartolome Ferrello; but his name, according to Wagner, was correctly spelled Ferrer. The evidence indicates that the islands were not only seen but visited by Sir Francis Drake after he had reconditioned his ship at the bay which now bears his name. On July 23, 1578, the *Golden Hinde* sailed from Drake's Bay and within 24 hours stopped at what was named "Islands of Saint James having on them plentiful and great store of seals and birds"; and from one of them took "such provision as might competently serve our turne for awhile."

There are other ways by which the islands were supposed to have been named, but it seems obvious that the "farallon" which means in Spanish a sharply pointed rock in the sea, should have been applied to them. In 1603 Vizcaino mentioned Isle Hendida which is believed to refer to South Farallon.

By the time Vancouver explored the northwest coast the islands had become known as Farallones de los Frayles (Friars), presumably to distinguish them from other farallons elsewhere.

Much has been written upon the natural history of the islands, especially South Farallon. The birds are very well known, as might be expected since this is stated to be the most populous rookery on the coast of California. Only one land bird, the rock wren, is resident; but many others make brief landings, especially during migrations.

There are no native mammals. The European rabbit was introduced by some misguided individual and has become a curse. Much effort has been expended in attempts at extermination, but all without effect. The animals live in burrows and, being largely nocturnal,

they are difficult to hunt. By some queer but fortunate circumstance they have not become established on the mainland. Just when they were introduced on the islands has not been determined, but they were exceedingly abundant in 1892.

There are no snakes and no lizards, but a species of small spotted salamander is common.

The islands are essentially barren. There are few plant species, no shrubs, and no native trees; however, two cypresses were planted many years ago, and a large number of small trees of several species were set out during the spring of 1949. The native plant which is most in evidence is the succulent *Baeria maritima*, or "Farallon weed." It has a small yellow flower and is used extensively by gulls and cormorants in nest building. Many introduced plant species are found about the buildings—even thistles.

Although the natural history of the surface of the south island is fairly well known, the waters thereabout have scarcely been explored. And, strangely, the geology is even more obscure. So far as the records examined have disclosed, no geologist had ever visited the islands prior to 1949. Trowbridge's observation in 1855 that the south island is granite has been repeated over and over. J. W. Blankenship, a botanist, made a few additional remarks on the geology, but otherwise the story has not been told.

Through the courtesy of Commander H. F. Stolfi of the U. S. Coast Guard, Mr. Allyn G. Smith and the author had the rare privilege of spending a week, May 6-13, 1949, on South Farallon. This gave an opportunity for unhurried examination of most of the accessible parts of the island, which is definitely granitic throughout. The rock is deeply weathered and brown on the surface, but fresh material is light gray. Crystals of quartz, feldspar, mica, and hornblende are commonly as much as half an inch across, and on weathered surfaces quartz stands out in bold relief. The main rock mass contains very few accessory minerals. Some small masses of pyrite were seen in hand specimens. One "inclusion" of finer-grained material was found. There are no dikes or seams of pegmatite or other material so common in such rocks.

Secondary minerals are scarce, and those present were largely derived from guano. There are some seams in the granite which contain a material at first thought to be gouge; but a sample brought back to the mainland and analyzed was found to be a phosphate. In other parts of the world some phosphate minerals have been found associated with guano, and it is reasonable to expect a similar association on the Farallons.

Fractures and joint planes extend in all directions in the granite, but from the general northwest and southeast trends of the surge channels worn by the sea, it is obvious that zones of major weakness extend in these directions. A little west of the center of the island,



FIG. 3. South Farallon Island; Sea Lion or Saddle Rock on the left. This shows the nature of the largest of the marine terraces.



FIG. 4. Aperture of a sea cave which was converted to a fog signal in 1858.



FIG. 5. Looking northwest along a typical surge channel.



FIG. 6. An ancient surge channel, elevation a little over 50 feet.



FIG. 7. Aerial photograph of South Farallon Island; Marin County shore line in the distance; June 1949. Sea Lion or Saddle Rock is in the foreground.  
*Photo courtesy U. S. Coast Guard.*



FIG. 8. Aerial photograph of South Farallon Island; Middle Farallon in the distance; June 1949. *Photo courtesy U. S. Coast Guard.*





FIG. 9. Elevated sea caves, on road to north landing.



FIG. 10. Sea Lion or Saddle Rock.



FIG. 11. Arch Rock, a portion of an elevated sea cave.



FIG. 12. A typical weathered surface showing joint planes. Ancient sea cave at base of cliff.



FIG. 13. North landing ; Sugarloaf Rock on the right.



FIG. 14. Excessively weathered surface, West end.



FIG. 15. West end terrace, covered with guano.



FIG. 16. Looking east across Jordan River. Remains of old weather station in center of photograph.

surge channels, which meet at high tide from opposite sides, divide South Farallon into an eastern and a western end. The gorge is called "Jordan River"; it is spanned by a bridge, now in dangerous condition. On the west wall of the channel, a little below high tide line, there is a slight seepage of water. Below the point of exit and almost constantly wet with salt spray, there is an area of light cream-colored secondary deposit. There are similar occurrences elsewhere on the island below high tide line. A few small patches of sand are found at the heads of surge channels, but no sand beaches worthy of the name; the material is mostly ground-up shells of various kinds.

Sea terraces are very conspicuous; buildings of the Coast Guard are located on one, and another obvious one is at the west end of the island. These terraces are about 50 feet above sea level, and are marked where they join the higher portions by numerous old sea caves and surge channels. Some of the caves extend under the high point (elevation 340 feet) upon which the light house is located.

On the north shore of the west end of the island (Indian Head), and just across a low divide from "Shell Beach", there is a huge sea cave extending eastward under a steep cliff. To the south there is a smaller one extending nearly at right angles. The latter is not very large and has, just inside the entrance, a tide pool as brilliantly colored with marine life as one might expect in the tropics. Farther inside, the floor of the cave can be reached, but not without some danger if a heavy sea is running. The place was visited twice, and both times the floor was wet with salt spray. At high tide with a heavy surf the floor must be well flooded. A little water drips slowly from the roof but leaves no deposit there. On the wet floor small, flower-like stalagmites about 2 inches in diameter and 2 inches high have formed. These have beautiful, wavy, scalloped cups on the outside and in the center of the cone there is a slight crater-like depression. They are minervite, a phosphate not heretofore recorded from California.

Gnano deposits cover extensive areas on South Farallon, but if they have been exploited, no reference to the fact has been found in the brief search of the records that was made. The principal accumulation is on the terrace at the west end of the island; it is probably a foot deep, but may be more in some places. Marine shells are found on the gnano, scattered over the surface, and even up to the high points of the hills. Many of these are from deep water, that is 25 to 50 fathoms. Some were so recently deposited that opercula were still present in the shells. A possible explanation of this strange phenomenon is that the shells were eaten by small fishes, which in turn were captured by cormorants as food for their young. These birds are bountiful providers, and often bring in more food than the young can eat. The fishes accumulate about the nests and decompose, leaving bones and any hard objects they might have swallowed.

Other erratics, too, are scattered far and wide on the island, from the highest points to water line. These are pebbles of jasper, in all respects similar to those found on any beach or in any stream in California where the adjacent rocks are the so-called Franciscan chert. These pebbles are well rounded, and range in size from half an inch to 2 inches in diameter; many of them are slightly polished. There is no definite explanation for their occurrence, but three possibilities may be suggested.

The pebbles may have been transported to the island for use in construction projects. There can be no doubt that materials for concrete structures have been landed in this manner, because there is an abundance of such gravel about the habitations. Much of it is not chert but has the appearance of such a mixture as might have been secured at, for instance, Coyote Creek in Santa Clara Valley—although there are many other places in the vicinity of the bay where it might have been obtained. However, this method of transport would not account for the presence of the pebbles on the west end of the island where, so far as the records show, there has been no habitation. That the egg collectors covered every accessible foot of South Farallon there can be no doubt, and this is attested to by the presence of sawed bones of meat animals, the bones being the thickness usual in preparation of steaks; but these hardy workers would not have been disposed, it would seem, to scatter pebbles over their trails. These bones, along with other refuse of the sea, may possibly have been carried ashore by the birds, but this would not be a plausible explanation for the presence of the pebbles.

It is also possible that Franciscan chert or a conglomerate made up of debris from this formation may be close at hand, but is now submerged. If this be true, however, there is no definite proof. Blankenship stated that the outlying rock called Sugarloaf is composed of conglomerate. In May of 1949, Sugarloaf was almost inaccessible, and exploration was limited to an examination with a 6X field glass from fairly close range. From this observation the rock appeared to be granitic, differing in no way from the main part of the island.

A third possibility is that the pebbles were swallowed by marine mammals—fur seals and sea lions—as is their habit, and then disgorged when they came on land. When South Farallon was occupied by more than 200,000 of these animals, they must have ranged over most of the area. The fur seals especially are excellent rock climbers and land travelers—on Alaskan islands early drives as far as 12 miles were commonplace. This may seem to be a far-fetched theory, but it is within the realm of possibility. At any rate, the presence of these foreign pebbles emphasizes the great need for additional geological studies, especially submarine investigations, off San Francisco's front door.

There is no hint in any literature as to the nature of the rocks of Middle and North Farallon. Nor is anything known of the bottom at the "Potato Patch" just off the entrance to the Golden Gate and between the various Farallons, except the depth.

A few years ago, the California Division of Fish and Game, with the vessel *N. B. Scofield*, Captain Weseth, Commanding, did some exploring for marine life on Cordell Bank, 30 miles west of Point Reyes. At that time a small fragment of weathered, coarse-grained "granite" very similar to that of South Farallon was broken off bottom and brought up by a dredge; however, it has not yet been studied in detail by a petrographer.

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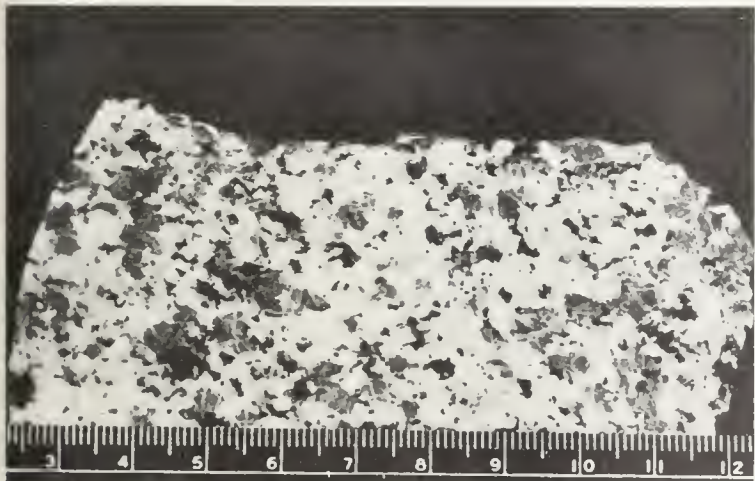


FIG. 17. A representative surface of fresh granite. Scale in millimeters.

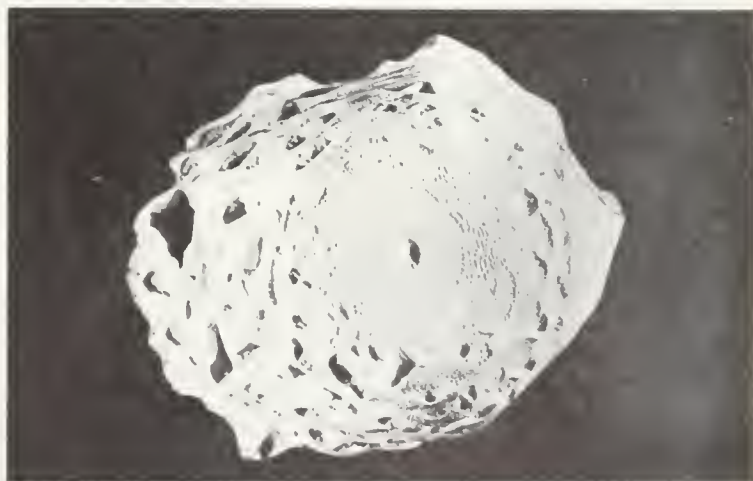


FIG. 18. Minervite, a phosphatic mineral, found as incrustations and stalagmites below the wash of the surf on sea walls and in caves. Mineral determined by M. Vonsen.



FIG. 19. Looking north toward Point Reyes across South Farallon Island and its summit lighthouse. The Golden Gate is toward the extreme right skyline. *Photo by U. S. Coast Guard.*

## UNUSUAL MINERALS OF THE BAY AREA

BY RICHARD A. CRIPPEN, JR.\*

For the nature lover who chooses mineral collecting as a hobby, there are always two important questions: where to go, and what to seek. It is the hope of the author that some aid in answering these questions, as they apply to the bay region, will be given in the following pages.

To find occurrences of some of the rare species in the field may require search over quite an area. In this search, some knowledge of geology, and the recognition of such generalized rock types as igneous, sedimentary, or metamorphic will aid the collector, as some minerals are found only in certain rocks. Geologic and topographic maps are available for much of the bay area; these may be of assistance in the search for outcrops of certain rock types. The geologic maps accompanying this guidebook have been generalized from such maps, but the necessary omission of many small rock bodies, because of the small scale, restricts their usefulness to the collector.

The ordinary minerals common to most areas are not listed in this paper; only those that are of special interest are included. Some were found many years ago, in mines now long abandoned; others are of rare or single occurrence, such as the manganese minerals of the Alum Rock Park boulder; still others are so unusual for the area in which they are reported to occur that they need verification.

The lists of mineral occurrences in each county were compiled largely from *Minerals of California*, Division of Mines Bulletin 136. A few species discovered since publication of Bulletin 136 are also included.

*Alameda County.* Numerous iris agate nodules have been collected from certain volcanic rock outcrops in the Berkeley Hills. The development of chalcedony in exceedingly thin concentric layers, which produces the rainbow colors in thinly sliced iris agate, is a rare phenomenon.

Gold has been found in some of the thin quartz veins in the north Berkeley Hills. Two specimens showing small gold masses, found near Summit Reservoir, may be seen in a jeweler's store near Shattuck and Vine Streets, Berkeley.

A small amount of cinnabar has been found in the silica-carbonate rock pinnacle at the end of Poppy Lane in Berkeley.

Glaucofane is common in the Franciscan rocks of California, but is a rare mineral elsewhere in the world. Blue glaucofane schist outcrops at several places in Berkeley north of the campus of the University of California, and also in the southern part of Alameda County.

A number of hydrous sulfate minerals—alunogen, boothite, chalcantite, copiapite, epsomite, melanterite, and pisanite—have been reported from workings of the old Leona and Alma pyrite mines in east Oakland. The location, once called the Laundry Farm, is on Mountain Boulevard north of Mills College. Some of these minerals have been collected recently in the old tunnels. Once the mines produced pyrite from massive bodies for the manufacture of sulfuric acid. Some chalcopyrite, pyrrhotite, native copper, gold, and silver occurred with the pyrite. From 1925-29 more than 300,000 pounds of copper were produced, but the gold, which assayed about \$2.00 to \$2.50 per ton, could not profitably be extracted. The rust-stained but light-colored rock in the open cuts is volcanic and is called the Leona rhyolite. Similar rock, the Northbrae rhyolite, outcrops in Berkeley in Cragmont Park and Indian Rock Park.

Manganese minerals, chromite, and magnesite can be collected at several old mines in the mountainous country south of Livermore. In this region of Franciscan rocks one may find crystals of quartz which appear almost cubic, with chamfered corners. This odd habit seems characteristic of the quartz crystals that develop in open vugs of quartz veinlets in sandstones and basalt of the Franciscan formation, and has been encountered in several different regions of Franciscan outcrops. It results from over-development of alternate terminal faces nearly at right angles to one another, and the lack of prism faces. The reason for such crystal growth is not known.

### *Alameda County minerals.*

- |                  |                    |                   |
|------------------|--------------------|-------------------|
| 1. Actinolite    | 16. Copper         | 30. Natrolite     |
| 2. Agate (iris)  | 17. Enstatite      | 31. Pisanite      |
| 3. Alunogen      | (bronzite)         | 32. Psilomelane   |
| 4. Analcime      | 18. Epsomite       | 33. Pyrite        |
| 5. Anaxite       | 19. Galena         | 34. Pyrolusite    |
| 6. Aragonite     | 20. Glaucofane     | 35. Pyrophyllite  |
| 7. Barite        | 21. Gold           | 36. Rhodochrosite |
| 8. Bementite     | 22. Halotrichite   | 37. Rhodomite     |
| 9. Boothite      | 23. Hydromagnesite | 38. Stibnite      |
| 10. Calcite      | 24. Inesite        | 39. Talc          |
| 11. Chalcantite  | 25. Kämmererite    | 40. Vivianite     |
| 12. Chalcopyrite | 26. Kröhnkite      | 41. Wollastonite  |
| 13. Chromite     | 27. Lawsonite      | 42. Zaratite      |
| 14. Cinnabar     | 28. Magnesite      | 43. Zircon        |
| 15. Copiapite    | 29. Melanterite    |                   |

*Contra Costa County.* Metacinnabar, the black mercuric oxide, makes one of its rare appearances as the ore of mercury at the Mount Diablo mine on the northeast flank of Mount Diablo. Specimens of the brilliant black mineral may be found as stringers or as drusy crystals lining pockets in the broken rock of the open cuts. Stibnite, marcasite, and some cinnabar are also found here.

\* Supervising Geological Draftsman, California State Division of Mines.

*Contra Costa County minerals.*

1. Actinolite	12. Diallage	23. Potash alum (kalinite)
2. Albite	13. Diopside	24. Psilomelane
3. Anaxite	14. Enstatite	25. Pyrolusite
4. Anthophyllite	15. Epsomite	26. Römérite
5. Apatite	16. Fluorite	27. Rutile
6. Barite	17. Glaucophane	28. Siderotil
7. Chalcopyrite	18. Halotrichite	29. Sphene
8. Chrounite	19. Lawsonite	30. Stibnite
9. Cinnabar	20. Marcasite	31. Tremolite
10. Copiapite	21. Melantherite	32. Zaraité
11. Crossite	22. Metacinnabar	

*Marin County.* Lawsonite, named for Andrew C. Lawson of the University of California, was first found on Tiburon peninsula and described by P. L. Ransome in 1895. Since then it has been recognized elsewhere in northern California and also in Europe. The Tiburon locality is in the hills north of the railroad trestle which crosses the road to Tiburon about 2 miles east of U. S. Highway 101.

Good lawsonite crystals have been found in some of the numerous outcrops of muscovite, glaucophane, and actinolite schist, which border or lie on serpentine. Many of the lawsonite crystals here have a habit which is rare among orthorhombic minerals, being elongated parallel to the opposite prism faces *m*. (110). The other pair of *m* faces form blunt chisel ends on the long, rectangular sectioned crystals. Weathering changes the pale blue tint of lawsonite at this locality to gray or grayish pink.

Some of the glaucophane schist outcrops are cut by veins of massive white albite, and excellent albite crystals are found in vugs of some of the seams. They are tabular, have many crystal faces, and show simple albite twinning, and sometimes polysynthetic striations on the basal cleavage.

A rare mineral of the borate group, called camsellite, is found near Stinson Beach. It is a hydrous magnesium borate, white and fibrous, that has been reported only from this locality and from British Columbia. It occurs with carbonates in serpentine.

*Marin County minerals.*

1. Albite	11. Chalcopyrite	22. Prehnite
2. Actinolite	12. Chromite	23. Psilomelane
3. Andradite	13. Epidote	24. Pumpellyite
4. Alunogen	14. Glaucophane	25. Pyrolusite
5. Apophyllite	15. Graphite	26. Pyrrhotite
6. Axinite	16. Hydromagnesite	27. Rutile
7. Calcite (manganocalcite)	17. Jasper	28. Sphene
8. Calomel	18. Laumontite	29. Tale
9. Camsellite	19. Lawsonite	30. Tremolite
10. Chalcedony	20. Muscovite	31. Wollastonite
	21. Nephrite	

The zeolite laumontite was found by the writer between "pillows" of the large pillow basalt exposure along Nicasio Creek east of Point Reyes Station. The mineral is more or less altered, which is

often the case with laumontite, and the small white masses of intergrown bladed crystals are rather crumbly.

Perhaps the most interesting mineral discovered in Marin County in recent years is the blue nephrite jade found by M. Vonsen on his property southwest of Petaluma. The small jade lenses are in serpentine. Although it is somewhat opaque, the fine blue color and excellent polishing quality of this unusual jade make it very attractive.

*Napa County.* Several minerals have been found in Napa County that have not been found elsewhere. Many of the rare species, however, were unusual finds in some of the old mines now inaccessible to collectors. The Manhattan quicksilver mine at the north tip of the county is a notable locality for finely banded chalcedony. Thick ledges of white, brown, and gray material in wavy but parallel bands were found both on the surface and in the mine.

*Napa County minerals.*

1. Aragonite	19. Epsomite	37. Napatite
2. Argentite	20. Erythrite	38. Opal
3. Arsenopyrite	21. Fibroferrite	39. Posepynte
4. Barite	22. Galena	40. Potash alum
5. Botryogen	23. Gypsum	41. Proustite
6. Calomel	24. Hohmannite	42. Psilomelane
7. Chalcedony	25. Hydromagnesite	43. Pyrrargyrite
8. Chalcocite	26. Jamesonite	44. Pyrolusite
9. Chalcopyrite	27. Knoxvillite	45. Quartz
10. Chromite	28. Magnesite	46. Redingtonite
11. Chrysotile	29. Marcasite	47. Riebeckite
12. Cinnabar	30. Melantherite	48. Silver
13. Copiapite	31. Mendozite	49. Smaltite
14. Copper	32. Mercury	50. Stibnite
15. Coquimbite	33. Metacinnabar	51. Tale
16. Crednerite	34. Millerite	52. Voltinite
17. Curtisite	35. Mirabilite	53. Wollastonite
18. Deweylite	36. Morenosite	

*Sacramento County.* Most of Sacramento County is within the central valley, which is a comparatively poor mineral collecting region; but the eastern portion of it extends into the foothills of the Sierra Nevada, where Tertiary sediments and Jurassic serpentine and metamorphies are found. Doubtless these formations contain many mineral species, but so far these occurrences have not been recorded.

*San Francisco County.* Apophyllite, datolite, lilac diopside, gyrolite, pectolite, prehnite, and wollastonite, which are comparatively rare in California, have been found at Fort Point in San Francisco County. Prehnite, cream to brownish in massive form, has only recently been identified. The lilac-colored diopside occurs in small irregular masses and seams in a fine-grained green metamorphic rock. J. J. Kinrade, a San Francisco jeweler, found this unusual pyroxene, and some was cut for gems before 1910. It has a dense microcrystalline structure and polishes well. Specimen material has been collected recently from the Fort Point locality. Another gem material, kin-

radite, was named for Kinrade, who found it at Lands End about a mile northeast of the Cliff House. This varicolored spherulitic jasper is similar to that from the Morgan Hill region in Santa Clara County. Jaspers of this kind were probably derived from Franciscan chert by metamorphic recrystallization.

*San Francisco County minerals.*

- |                |                      |                  |
|----------------|----------------------|------------------|
| 1. Apophyllite | 10. Datolite         | 18. Mercury      |
| 2. Aragonite   | 11. Diallage         | 19. Pectolite    |
| 3. Barite      | 12. Diopside (lilac) | 20. Prehnite     |
| 4. Brucite     | 13. Enstatite        | 21. Psilomelane  |
| 5. Calcite     | 14. Gyrolite         | 22. Pyrolusite   |
| 6. Chalcedony  | 15. Hydromagnesite   | 23. Quartz       |
| 7. Chromite    | 16. Jasper           | 24. Sphene       |
| 8. Cinnabar    | (var. kinradite)     | 25. Wollastonite |
| 9. Curtisite   | 17. Magnesite        | 26. Xenotlite    |

*San Joaquin County.* A very few mineral species—bementite, gypsum, inesite, psilomelane, pyrolusite, and rhodochrosite—have been reported from San Joaquin County, and these only from the manganese mines. In the southwestern corner of the county Franciscan sandstone, shale, chert, basalt, serpentine, and metamorphics are found, and it is probable that a number of mineral species common to these rocks will some day be added to the list.

*San Mateo County.* Three rare quicksilver minerals, calomel, eglestonite, and montroydite, are associated with cinnabar, mercury, opal, quartz, and dolomite in joints and veins in brown silica-carbonate rock, about 2 miles west of Redwood City. Montroydite was found as minute acicular red crystals in vugs in the dolomite.

Silica-carbonate rock in itself is of considerable interest. Weathered brown outcrops of this material, which consists of various proportions of the silica minerals opal, chalcedony, and quartz, with calcium, and calcium-magnesium carbonates, are encountered throughout the Coast Ranges in areas of Franciscan rocks, as replacements of serpentine. It is called "mercury rock" by miners, and aptly, because cinnabar and liquid mercury so commonly occur in it. Hot alkaline water rising through sheared and crushed serpentine in fault zones performed the replacement and at about the same time, in many cases, deposited mercury and cinnabar. Portions of unweathered silica-carbonate rock sometimes provide attractive cutting material in the form of colorless to green opal, or chalcedony, some of which is flecked with brilliant vermilion.

*San Mateo County minerals.*

- |                |                    |                 |
|----------------|--------------------|-----------------|
| 1. Analcime    | 7. Cinnabar        | 12. Margarite   |
| 2. Apophyllite | 8. Eglestonite     | 13. Mercury     |
| 3. Calomel     | 9. Galena          | 14. Montroydite |
| 4. Celadonite  | 10. Hydromagnesite | 15. Silver      |
| 5. Chalcedony  | 11. Lawsonite      | 16. Sphalerite  |
| 6. Chromite    |                    |                 |

*Santa Clara County.* More unusual mineral species are known from Santa Clara County than from any other bay area county. The remarkable assemblage of manganese minerals found in a single great boulder in Alnm Rock Park is still one of the mineralogical mysteries of California. For many years the boulder was thought to be a meteorite, and it was one of the park's attractions. It was sacrificed in 1918 to the critical need for manganese ore, of which it made several tons. At that time, Dr. A. F. Rogers of Stanford University identified several manganese minerals in the broken ore, which were not previously known from California, and described the new mineral kempite (manganese oxychloride). No similar material has been found, and it is presumed that the boulder, constituting all of one unique deposit, was part of some rock mass now completely eroded away.

A curious mineral occurrence was reported in 1904 from the Coyote Creek region—free gold in red garnets in eclogite. Eclogite is the name given to omphacite (a pyroxene) studded with garnets; it occurs in highly metamorphosed zones in Franciscan rocks, ordinarily near intrusive bodies.

Zaratite, a rare hydrous nickel carbonate was found in the New Almaden mine; it occurred as thin emerald-green coatings associated with galena and sphalerite.

A remarkable specimen of orbicular dolomite from the Coyote Hills was presented to the Division of Mines Exhibit by the late L. Ph. Bolander, who discovered a number of rare and interesting mineral occurrences. This material is in shades of buff and yellow, and a sawn surface reveals rosettes of delicate radiating crystals.

*Santa Clara County minerals.*

- |                    |                    |                   |
|--------------------|--------------------|-------------------|
| 1. Alabandite      | 19. Cuprite        | 38. Mercury       |
| 2. Alleghanyite    | 20. Deweyite       | 39. Metacinnabar  |
| 3. Almandite       | 21. Dolomite,      | 40. Pilinite      |
| (with free gold    | orbicular          | 41. Psilomelane   |
| in eclogite)       | 22. Epsomite       | 42. Pyrite        |
| 4. Apatite         | 23. Fluorite       | 43. Pyrochroite   |
| 5. Apophyllite     | 24. Galena         | 44. Pyrolusite    |
| 6. Aragonite       | 25. Gauophyllite   | 45. Quartz        |
| 7. Arsenopyrite    | 26. Glaucophane    | 46. Rhodochrosite |
| 8. Azurite         | 27. Gold           | 47. Rutile        |
| 9. Barite          | 28. Gyrolite       | 48. Siderite      |
| 10. Bementite      | 29. Hausmannite    | 49. Sphalerite    |
| 11. Bornite        | 30. Hydromagnesite | 50. Sphene        |
| 12. Braunnite      | 31. Jarosite       | 51. Stibnite      |
| 13. Cassiterite    | 32. Jasper         | 52. Tephroite     |
| 14. Chalcedony     | 33. Kempite        | 53. Tiemannite    |
| 15. Chalcocopyrite | 34. Lawsonite      | 54. Valentinite   |
| 16. Chromite       | 35. Magnesite      | 55. Zaratite      |
| 17. Chrysocholla   | 36. Malchite       | 56. Zoisite       |
| 18. Cinnabar       | 37. Margarite      |                   |



*Solano County.* About 4 miles north of Fairfield and  $1\frac{1}{2}$  miles west of Highway 40 is the Tolenas Springs region, reached by trail up Soda Springs Creek. Extensive deposits of calcite and aragonite have been precipitated as banded travertine from the spring water, a process which is still going on. The travertine or onyx marble is mostly light colored, but brown banding in some of it produces attractive stone for cutting into small decorative objects. Analysis of the spring waters made in 1888 showed a preponderance of sodium chloride, sodium carbonate, calcium carbonate, and magnesium carbonate, and minor amounts of boron, potassium, and iodine compounds.

*Solano County minerals.*

- |             |             |                 |
|-------------|-------------|-----------------|
| 1. Argonite | 3. Cinnabar | 5. Metacinnabar |
| 2. Chromite | 4. Epsomite |                 |

*Sonoma County.* The Geysers in northern Sonoma County is a spectacular region of fumaroles and hot springs. It is also noted for the numerous and unusual sulfate minerals—alunite, alunogen, boussingaultite, epsomite, halotrichite, mascagnite, melanterite, tschermigite, and voltaite—produced by the emanations.

One of the numerous localities for minerals of the Franciscan metamorphics is 2 miles north of Valley Ford on the headwaters of Ebabias Creek. Outcrops here have produced some remarkable specimens of glaucophane, notably the bundles of the blue amphibole found on walls of a single large vug by M. Vonsen. Glaucophane is also found as blue stellate rosettes in a light-colored matrix of granular clinzoisite. Veins of massive and crystalline lawsonite cut the schist in places, but the mineral is quite different in form and color from the Tiburon variety. The better crystallized material is in a vein made up of slender prismatic orthorhombic crystals coalesced into slightly divergent groups, and intergrown haphazardly. They are pale greenish-gray, subvitreous, but with bright pearly luster on the excellent cleavage. Small crystals of yellow sphene and red rutile are found in the glaucophane here.

Aegirite and riebeckite in small brilliant black crystals line some of the narrow cavities in the rhyolite of the Valley of the Moon stone quarry northeast of Glen Ellen.

Tremolite is plentiful in metamorphic rocks of The Geysers region.

*Sonoma County minerals.*

- |                    |                    |                                |
|--------------------|--------------------|--------------------------------|
| 1. Actinolite      | 21. Glaucophane    | 41. Psilomelane                |
| 2. Aegirite        | 22. Graphite       | 42. Pumpellyite                |
| 3. Almandite       | 23. Halotrichite   | 43. Pyrite                     |
| 4. Alunite         | 24. Hydromagnesite | 44. Pyrolusite                 |
| 5. Alunogen        | 25. Ilvaite        | 45. Quartz                     |
| 6. Aragonite       | 26. Lawsonite      | 46. Realgar                    |
| 7. Azurite         | 27. Margarite      | 47. Riebeckite                 |
| 8. Boussingaultite | 28. Mascagnite     | 48. Rhodochrosite              |
| 9. Brewsterite     | 29. Melanterite    | 49. Rutile                     |
| 10. Cerussite      | 30. Mercury        | 50. Sphene                     |
| 11. Chalcedony     | 31. Metacinnabar   | 51. Stilbite (var. stellerite) |
| 12. Chalcopyrite   | 32. Montroydite    | 52. Sulfur                     |
| 13. Chromite       | 33. Nopalite       | 53. Tiemannite                 |
| 14. Cinnabar       | 34. Natrolite      | 54. Tremolite                  |
| 15. Clinzoisite    | 35. Nephrite       | 55. Tschermigite               |
| 16. Crocidolite    | 36. Opal           | 56. Tschermigite               |
| 17. Curtisite      | 37. Orpiment       | 57. Voltaite                   |
| 18. Edingtonite    | 38. Pectolite      | 58. Zoisite                    |
| 19. Epidote        | 39. Pickeringite   |                                |
| 20. Epsomite       | 40. Potash alum    |                                |

*Yolo County.* Mineral collecting in Yolo County is practically limited to the northwest corner, where Cretaceous and Jurassic Franciscan rocks occur. Most of the listed species were found in the mercury mines. Metacinnabar was the principal ore at the Reed mine.

*Yolo County minerals.*

- |             |                 |              |
|-------------|-----------------|--------------|
| 1. Cinnabar | 3. Idrialite    | 6. Sulfur    |
| 2. Fluorite | 4. Marcasite    | 7. Tremolite |
|             | 5. Metacinnabar |              |

**Selected References**

Persons who desire more detailed information on California minerals and collecting localities are referred to Division of Mines Bulletin 136, *Minerals of California*, by Joseph Murdoch and Robert W. Webb, published in 1948. In this publication minerals species and localities are conveniently arranged by alphabet and by county, respectively.

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## HIGHWAYS AND BYWAYS OF PARTICULAR GEOLOGIC INTEREST

BY OLIVER E. BOWEN, JR. \*

### SAN FRANCISCO NORTH TO GUALALA VIA STATE HIGHWAY 1

State Highways 1 and 101 coincide from the southern traffic tributary of the Golden Gate Bridge to the junction point of the Mill Valley Road. The bridge approach by Highway 1 is along Park Presidio Boulevard; by 101 it is via Van Ness Avenue, Lombard Street, Richardson Avenue, Marina Boulevard, and the Presidio viaduct.

Few places in the United States are as replete with both historical background and geological features as the Golden Gate and vicinity. On both sides of the strait, numerous military installations form one of the principal bastions of the western sea frontier. As far back as 1776 the military value of Fort Point was recognized by Anza, who marked it for a fort site. The Spanish fort, Castille de San Joaquin, built in 1776 under the direction of José Moraga, was taken over by Bear Flag insurgents under John C. Fremont in 1846. Fort Winfield Scott was built in 1854, partly from ruins of the older Spanish fort. The present military reservation embracing several square miles includes Fort Winfield Scott and the Presidio grounds; the latter include part of the grounds of the Panama-Pacific International Exposition of 1915. Across the Golden Gate from Fort Winfield Scott are Forts Barry, Baker, and Cronkhite.

If one approaches the Golden Gate Bridge on a foggy day he can easily understand why the bay entrance went undiscovered for so long a period after the initial occupation of California; the entrance is particularly difficult to distinguish when viewed from a few miles at sea. The first ship to enter San Francisco Bay was Juan de Ayala's *San Carlos*. The event took place in 1775, six years after Portolá's scout, Ortega, had discovered the entrance during a land expedition.

The geologic history and features of the Golden Gate as well as the human history just touched upon are varied and complex. The mouth of San Francisco Bay is a drowned river canyon eroded by the ancestral Sacramento River. It is not a fault feature and it is not the result of volcanism—two widely circulated popular concepts. Both bay and strait owe their existence to either a subsidence of the land or else a rise in sea level which first took place in mid-Pleistocene time, perhaps  $1\frac{1}{2}$  million years ago. The geologic history of the Golden Gate vicinity has been one of alternate sinking and uplift over several geologic epochs. This rise and fall has, of course, been complicated by warping of the land surface into folds and by large-scale faulting. In terms of geologic time San Francisco Bay is a short-lived feature

because of the large amounts of detritus dumped into it by the various river and stream systems that it drains.

Bedrock on both the San Francisco and Marin County sides of the Golden Gate is complex and tricky from an engineering viewpoint. For example, the south pier, which supports the bridge, is based in serpentine, a rock of low strength. Careful geological and engineering research involving the structure of the serpentine mass and the form of the submarine land surface had to be done before it was deemed safe to build the bridge at its present site. At the northern end of the bridge the rocks are somewhat contorted basalt, chert, and sandstone, together with smaller amounts of shale and other sedimentary rocks. Each change in lithology and bedrock structure had to be taken into account in designing the bridge.

After crossing the Golden Gate, the route lies through lofty road cuts exposing various rocks of the Franciscan formation. At the east side of the bridge ramp are conspicuous outcroppings of red chert interbedded with thin bands of red clay shale. These red cherts are typical of the Jurassic Franciscan formation in the bay area. Most of the chert carries microscopic fossils called radiolaria.

Just before the highway tunnel is reached, road cuts expose dark-gray, coarse sandstone interbedded with some black shale and both red and greenish-white chert. A prominent reef of light-colored chert underlain by basalt protrudes from the soil cover on the west side of the highway three-tenths of a mile south of the tunnel. Black basaltic intrusions disrupt the continuity of the beds in several places. The aforementioned rock association of sandstone, shale, chert, and basalt is common in the Franciscan formation of both San Francisco and Marin Counties.

Immediately north of the tunnel the road for several hundred yards passes through excellently developed blackish-green pillow basalt which is crisscrossed by calcite veinlets. Pillow structure, which is merely the tendency of volcanic rocks to break along ellipsoidal joints to give a pillow-like surface, is commonly developed when molten lava flows out upon the floor of a sea or lake. The pillow basalts of Marin County are supposedly submarine flows which became interbedded with marine sediments and now are part of the Franciscan formation. Not all basalt in the Franciscan is pillowed and most was probably intruded into the sediments in the form of dikes and sills rather than deposited with sediments in the form of flows.

Six and three-tenths miles north of the Golden Gate Bridge toll station, Highway 1 leaves Route 101 and goes westward toward Mill

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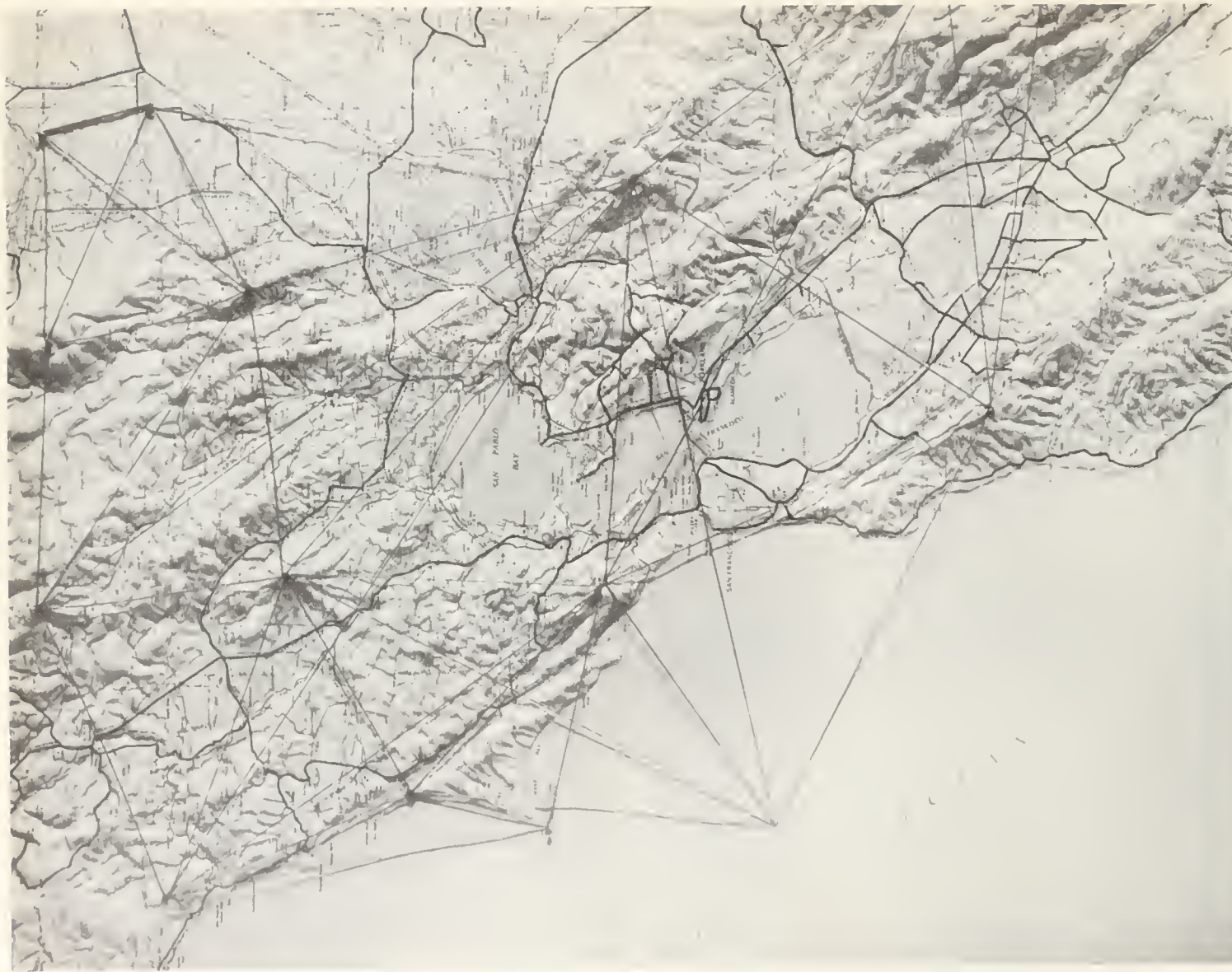


FIGURE 1. (See page 317 for description.)

FIG. 1. Earth movements in California caused by deformative forces in the earth's crust, particularly those expressed by the San Andreas and related faults, have been measured by precise surveys made at different intervals of time since the earthquake of 1906. The nature of these movements is determined by means of primary and secondary networks of triangulation stations strategically arranged along the coast of California from the latitude of Fort Ross to the Mexican border. In southern California the networks are also extended to cover the San Andreas fault zone as it traverses the Mojave Desert, San Bernardino Mountains, and Imperial Valley. Figure 1 is a photograph of a plastic relief model which shows the position of the triangulation net in the San Francisco Bay area. The geometrical pattern of straight lines represents the lines of sight used in establishing the relative changes of position between various points in the bay area and the points of intersection of the lines represent the location of major triangulation stations. The irregular heavy-line pattern is the main highway system. Surveys made in 1947 by the U. S. Coast and Geodetic Survey give positive evidence of a slow, continuous movement of the coastal area west of the San Andreas fault, relative to the area east of the fault. This outer coastal area is now moving northwest at an annual rate of five centimeters per year and has been displaced a total of three meters since 1880, the date of the first precise surveys. *Photo by U. S. Coast and Geodetic Survey; details regarding earth movement from "Horizontal Earth Movements, Vicinity of San Francisco, California," by C. A. Whitten, Trans. Am. Geophysical Union, vol. 29, no. 3, June 1948, and "Horizontal Earth Movement in California," by C. A. Whitten, Jour. Const and Geodetic Survey, April 1949.*

Valley. The turnoff is via Richardson's Slough Bridge. Before dropping down to the beach resorts bordering the ocean and Bolinas Bay, a paved road branches off to the northwest which leads to Muir Woods National Monument and Mount Tamalpais State Park. The junction point of this road with Highway 1 is 3.7 miles from the Highway 101 junction point. Muir Woods is a 395-acre reserve of Coast redwoods given to the federal government in 1908 for a national monument by William E. Kent. Some of the trees reach 300 feet in height and 18 feet in diameter. The largest tree is estimated to be 4000 years old. Mount Tamalpais State Park embraces 725 acres of partly wooded hill land of which the 2604-foot West Peak of Mount Tamalpais is the highest point. The mountain is a prominent landmark from many points near San Francisco Bay. On a clear day one can see the Farallon Islands to the west, Mount St. Helena to the northeast, Mount Diablo and the Sierra Nevada to the east, and Mount Hamilton to the southeast. The old Mill Valley and Mount Tamalpais Scenic Railroad, built in 1896 to serve tourists, has been superseded by a motor road which extends to within a quarter of a mile of the summit. The old railroad bed is still visible.

From the Muir Woods road, Highway 1 winds down a canyon to the floor of Frank Valley through Franciscan sandstone terrain. Near the last turn after the road goes up Frank Valley, a side road turns off to Muir Beach, a public park. Travelling up Frank Valley to the bridge, an extensive series of prominent reef-outcrops of chert may be seen to the east of the highway. Unlike the thin-bedded red chert of Marin peninsula, this grayish-green chert is massive and erosion-resistant. It is almost white on weathered surfaces. After crossing Frank Valley, Highway 1 winds up a ridge through more Franciscan rocks

containing lenses of light-gray limestone. Limestone is comparatively rare in the Franciscan of Marin County and this is one of the few areas in which it outcrops close to a main road. Between Muir and Stinson Beaches the route lies along an exceedingly rugged coast line having a very narrow rocky beach. The road stays several hundred feet above the ocean and on clear days affords fine views of the coast line above and below San Francisco. Numerous landslide forms may be seen along the steep coastal slopes. Four and one-half miles northwest of the Muir Beach junction serpentine is exposed in a road cut. A short distance down the slope is a small lens of black Franciscan limestone which weathers to a white color.

Eight-tenths of a mile farther north, an old quarry has been driven in red chert similar to the rock found north of the Golden Gate Bridge. Interbedded with the chert are thin partings of black manganese oxide ore. The black material was originally deposited as the manganese carbonate mineral rhodochrosite. Near-surface oxidation has changed the light-colored carbonate to the black oxide.

Fine views of Bolinas Bay with its well-developed bay-mouth bar may be had from the quarry vicinity. Bay-mouth bars are built up from sand scoured from the beach floor by the waves. Sedimentation by streams and waves will eventually fill Bolinas lagoon to form a marsh and finally a local coastal plain, unless further faulting on the San Andreas rift disrupts the cycle. Bolinas Bay lies directly above the San Andreas fault zone, Bolinas and Tomales Valleys being of typical rift type. The San Andreas fault is not a single break in the



FIG. 2. View northwest across part of Marina district and the Old Palace of Fine Arts, showing Golden Gate Bridge (1948). *Photo courtesy San Francisco Chronicle.*



FIG. 3. Pillow basalt in the Franciscan formation exposed along the Arroyo San Antonio, Marin County. Lava of similar appearance is well exposed in road cuts 1.1 miles north of the north end of Golden Gate Bridge. Pillow-shaped joints probably were caused by contact of molten lava with water. *Photo by Olaf P. Jenkins.*

earth's crust but rather is a series of roughly parallel fractures, the ends of which may be braided or else arranged en echelon.

Stinson Beach is located on Bolinas Lagoon near the junction of the sand bar with the mainland. It is a resort town affording boating, water sports, clam digging, and kindred recreational activities. Across the bay from Stinson Beach is the town of Bolinas situated well above the ocean and commanding a fine view of the San Francisco peninsula. The Bolinas vicinity is interesting to geologists and paleontologists because of the fine exposure of the Pliocene Merced formation. Shales exposed in the sea cliffs of Bolinas Beach contain numerous tiny fossils called foraminifera. Most foraminifera or "bugs," as oil men call them, can be seen only with the aid of a microscope; but many in the Merced formation are the size of a pin head, or slightly larger, and may be seen with the naked eye or hand lens. Bolinas had its beginning as a settlement well before 1850 when it was a sea-otter hunting center. Later the Bolinas-Tomaes area became a vast lumbering district and Bolinas was the site of a lumber-shipping wharf and shipbuilding facilities. The timber was eventually exhausted and Bolinas subsided to the picturesque resort it now is. Now one would never guess that the Bolinas and Tomaes Valleys were once heavily timbered—hardly a stump of a timber tree is visible along Highway 1. Bolinas town is reached via a side road which joins Highway 1 at the head of Bolinas Lagoon.



FIG. 4. Old stone church at Tomales damaged by the earthquake of April 18, 1906. *Photo from J. C. Branner collection, courtesy Stanford University.*



FIG. 5. Skippers Ranch, Olema, Marin County, April 1906. The low scarp in the middle ground, part of the 270-mile break produced along the San Andreas fault zone in 1906, can be seen cutting the fence line and cow barn. *Photo from J. C. Branner collection, courtesy Stanford University.*

Between Stinson Beach and the Bolinas road junction, Highway 1 winds along the shores of Bolinas Lagoon. The rocks are largely Franciscan sandstone and intrusive basalt; some coarse talus-breccia remnants of Quaternary age may be seen lying on the Franciscan bedrock.

A quarter of a mile north of the Bolinas road junction the highway rises onto a bench or low hill through a grove of eucalyptus trees. Road cuts at the edge of the bench expose pebble conglomerate which is probably a part of the Merced formation. This is the only exposure of rocks other than those of the Franciscan formation between Bolinas Bay and Point Reyes Station.

One and two-tenths miles north of the Highway 1—Bolinas road junction (in the mouth of an arroyo) a handful of frame buildings are all that remain of the hamlet of Woodville, known in pioneer days as Dogtown. One mile east of Woodville are a group of copper deposits which were mined in the sixties and again in 1918. The Bolinas mine is the largest of the workings, having a number of shafts and laterals of various sorts leading from them. The ore minerals were principally chalcopyrite and malachite. Ore specimens are still taken from the old mines from time to time. Cheteo Mining Company, a San Francisco firm, produced 22,500 pounds of copper in 1918, presumably from the Bolinas mine in the Woodville district.

Four and one-half miles south of Olema, a limestone quarry and the ruins of several lime kilns are located in the gulch of Olema Creek. The spot is one-eighth of a mile west of the highway and is not visible from it. Both quarry and kilns are deeply shaded by alders, bay trees, and Douglas firs, and one large Douglas fir has grown up through one of the kilns. There has been a great deal of speculation as to whether the kilns were built by Russians, Spanish, Mexicans, or Americans, but the kilns are now known to be American and to date from the early fifties. The complete story of the kilns may be found in another chapter of this book. The limestone in the quarry is pink to gray in color, fine-grained, well-bedded, and in places, cherty. In most respects it is similar to the limestone mined at Permanente, Santa Clara County, for cement.

In numerous places along Highway 1 between Bolinas and Tomales Bay evidences of faulting are present. Within a strip of land a mile or more wide, landslides, sag ponds, side-hill ridges, steep-sided aligned hills, and disrupted drainage systems may be seen on every side. Some of these features are partly obscured by vegetation, but many are plainly exposed. Rocks found along the road are apt to be crushed and deeply weathered; a few moderately undisturbed rock cuts in serpentine, weathered basalt, shale, and sandstone, all Franciscan, are exposed between Bolinas Bay and Olema.

Olema is a small village in the heart of Marin County's dairyland. The name most probably originated as a contraction of the Indian

word *olemaloke*, translated "Coyote Valley." Olema, like Bolinas, is identified largely with early-day lumbering, although it was a part of the old Mexican grant of Rancho Punta de los Reyes, dating from 1843. One of its most distinguished residents was Judge James McMillan Shafter, State Senator in the seventies and one-time Regent of the University of California. Olema is the junction point of Highway 1 and the Sir Francis Drake Highway, the latter extending from Greenbrae on Highway 101 to Point Reyes.

One-tenth of a mile north of the Olema crossroads, an oiled country road turns off to Bear Valley Ranch. In the vicinity of the ranch buildings a displacement of 21 feet was measured on the San Andreas fault at the time of the San Francisco earthquake of 1906. Two of the old monuments placed there to record possible later movements on the fault may still be seen, one on either side of the road. North of Bear Valley Ranch (the Bear Valley road connects with the Inverness road) the trace of the 1906 movement may be seen on the hillside just east of the road. The trace is clearly marked by slides, sunken areas, and, in places, by a fairly well-defined trench. The side trip over the Bear Valley Ranch road is one of the best places close to San Francisco where very recent faulting may be studied.

Continuing north from Olema, Highway 1 follows the eastern edge of Tomales Bay. The Sir Francis Drake Highway coincides with Highway 1 for 2 miles. It then turns northwestward to follow up the western edge of Tomales Bay through the picturesque wooded country surrounding Inverness.

Point Reyes Station, located 22 miles north of Olema, was formerly a butter- and produce-shipping point on the San Francisco and Cazadero line of the now-abandoned Northern Pacific Railroad. The first shipment from the town was made in 1874 when the line was known as the North Pacific Coast Railroad. Point Reyes Station now marks the beginning of a series of dairying and recreational areas arranged along the coast of Tomales Bay as far as Keyes Creek Canyon. It is built upon sands and gravels of the Pleistocene Montezuma formation, but there are no good outcrops. The land surface is a partly dissected marine terrace lifted above sea level in late Pleistocene or Recent time.

North from Point Reyes Station, Highway 1 crosses low rolling country devoted to dairy farming. To the east the rugged peak of Black Mountain rises from the coastal plain. Black Mountain is an intrusive mass of basalt and diabase included in the Franciscan formation. At several points along the highway, road cuts expose buff sands of the Montezuma formation. Franciscan sandstones and greenstones protrude through this thin Pleistocene alluvial cover in many places. As one travels northward the Pleistocene rocks become patches on the old surface worn in Franciscan rocks. At some places along the



FIG. 6. The Sonoma County coast line south of the mouth of the Russian River, showing numerous sea stacks or newly eroded islets and the prominent coastal terrace. Two stacks developed on the continental shelf at the time of a former stand of the sea can be seen upon the coastal plain in the right background.

shores of Tomales Bay in this vicinity molluscs can be dug from Pleistocene terrace material.

A few miles north of Point Reyes Station the route veers west to the edge of Tomales Bay and dips in and out of the gulches which cut the coastal terrace at bay's edge. Numerous resorts and boating centers are strewn along the bay, as well as fishing piers and oyster-digging grounds. The oyster beds are commonly fenced in by long rows of stakes. The beds were seeded with oysters imported from Japan. The coastal plain is devoted to cattle and sheep grazing, and some truck gardening in stream bottoms.

Thirteen and one-half miles north of Point Reyes Station, Highway 1 leaves the Tomales coast and follows the estuarine mouth of Keyes Creek. Tide water penetrates several miles up the creek bottom. Walker and Keyes Creeks join at Walker Creek bridge and the main channel follows Walker Creek from that point. As far as the town of Tomales the route lies through mixed Franciscan rocks of no particular interest—the exposures are weathered sandstone and shale. One-tenth of a mile southwest of the Tomales-Petaluma road junction a fault zone of unknown magnitude crosses the road. Within the zone sandstones and shales have been milled to fragmental material of variable coarseness.

The town of Tomales located near the head of Keyes Creek had its beginning in a country store built in 1852. Tomales once was served by a steamer, which landed near the mouth of Keyes Creek, and by the now-liquidated North Pacific Railroad. The surrounding countryside is devoted largely to grazing. The origin of the name Tomales is in dispute; there are those who claim it to be derived from the Indian word *tamal* meaning bay, and others who favors the Spanish dish *tamale* as the more probable source.

Beginning at Tomales, an oiled road turns west; it connects Highway 1 with the privately owned resort called Dillon Beach. Dillon Beach, located 4 miles from Tomales on picturesque Tomales Bay is delightfully situated among sand dunes opposite Point Tomales. Cabins are available for public use and there is a small museum. The spot was once thickly inhabited by Indians, as numerous shell mounds will attest. There is also a fossil plant locality (pine cones) in the vicinity. About 2½ miles from Tomales the Dillon Beach road passes outcrops of coarse conglomerate of the Pliocene Merced formation. Dillon Beach also may be reached by surfaced road from Valley Ford.

Between Tomales town and Valley Ford the route lies across dry, rolling country. The present land surface has been worn down from more lofty hills of Franciscan bedrock. Hills and thin patches of unconsolidated or poorly consolidated sands and gravels of Plio-Pleistocene age have been deposited upon this old bedrock surface and in turn have been largely removed by erosion.

Valley Ford, in the heart of the Marin-Sonoma dairyland, was first settled sometime in the sixties and was so named because of a well-known crossing of Estero Americano. The Estero Americano, like Keyes Creek, is affected by tide waters for several miles upstream. The stream itself now carries far less water than formerly because its tributaries have been diverted for irrigation, and because much of its watershed has been removed by conversion of lands from a natural to a cultivated state. A mile and three-tenths west of Valley Ford, just east of the junction of Highway 1 and the Bodega road, small outcrops of gabbro intrusive into the Franciscan formation may be seen in fields south of the road. To the west of this locality Plio-Pleistocene sandstone may be seen lying on a ridge with Jurassic Franciscan outcropping in gulches low down on the ridge. The unconformity between these two rock groups may be found by scouting the gulches south of the road junction.

Between the Highway 1-Bodega road junction the route passes down Cheney Creek Canyon through mixed Franciscan rocks largely sandstone, chert, and shale. The section of rocks exposed is much like the one along Keyes Creek but the exposures are somewhat better.

At the mouth of Cheney Creek, Highway 1 emerges onto the lovely Sonoma County coast. To the northwest there is a fine view of Bodega Head, an erosion-resistant remnant of quartz diorite, the last exposure of basement rock of granitic type to be seen in place northward along Highway 1 from San Francisco. A number of other isolated remnants or stacks of bedrock may be seen offshore from Bodega Head. Numerous stacks of at least two erosion periods are to be seen farther up the Sonoma Coast. To the northeast of Bodega Head is a series of sand dunes partly covered by vegetation. One branch of the San Andreas fault passes beneath Bodega Bay close to the resort area; another



FIG. 7. The Sonoma coast just south of the Russian River, showing two generations of sea stacks. The farthest stack is an islet in the present sea; the nearer two were islets in a former stand of the sea when the present coastal plain was below sea level. *Photo by Olaf P. Jenkins.*



FIG. 8. Sinuous estuary near the mouth of the Russian River. The meandering course of the river across the present rugged terrain indicates that the river is very old, that it was developed on a landscape much more subdued than the present one, and that its erosive power remained strong enough to keep the course open even through the rise of the Coast Ranges to their present height. *Photo by Olaf P. Jenkins.*

branch passes close to the last of Bodega headland and Mussel Point. There is no quartz diorite east of the San Andreas fault; its presence at Bodega Head is undoubtedly the result of an ancient uplift of a seaward block along the ancestral San Andreas fault zone. The recent movements on the San Andreas have been largely horizontal.

Bodega Bay, now a popular yacht harbor and resort area, is protected by a well-developed bay-mouth bar as well as by Bodega Head. However, owing to its relatively small size and depth and to the strong cross-winds which commonly blow, the bay is usable only by vessels of very shallow draft. It was discovered in 1775 by Juan Francisco de la Bodega y Cuadra, a Spaniard. Archibald Menzies' ship, a part of the exploration party of the Englishman, Captain George Vancouver, visited the bay in 1793. Menzies is supposed to have named Bodega Rock "Gibson Island." In 1809 Kuskoff, an agent of the Russian-American Fur Company, established temporary settlements at Bodega and at Kuskoff, 6 miles inland in Salmon River Valley, for the purposes of fur-trading and supplying agricultural products to the Alaskan colonies. Kuskoff left, but returned in 1811 and established more permanent settlements. These had been abandoned as Russian outposts by 1841. There is now no sign of Russian influence at Bodega Bay, and Kuskoff is nothing but a few piles of rubble.

Two and one-half miles north of the resort area of Bodega Bay, Highway 1 crosses Salmon Creek estuary at the Salmon Creek resorts. Salmon Creek estuary has formed behind a strongly developed sand-bar thrown up by opposing forces of ocean waves and river currents. From the seaward side of this bar southwestward to Mussel Point is broad Salmon Creek Beach. This is part of a series of public beaches acquired by the State Division of Beaches and Parks in 1934 and collectively known as Bodega-Sonoma Coast State Park. This series of beaches extends from Bodega Bay to the mouth of the Russian River. Parking, camping, picnicking, and trailer space are provided at many points along the 5-mile stretch of coast. The rugged sea-cliffed coast line is very picturesque and the group of public beaches are finding increased favor as vacation spots.

The Marin-Sonoma coast and the shoreline northward into Humboldt and Del Norte Counties has long been the stamping ground of sports and commercial fishermen. During fishing seasons little else is heard but fishing talk in the public places along Highway 1. The estuaries and larger streams afford fine salmon, shad, and steelhead fishing in season, and surf and rock fishing are engaged in throughout most of the year. Crabs and surf fish are obtainable with small drop-nets at various places along the coast. Oysters are harvested from beds in Tomales and Bolinas lagoons, and cockles, piddocks, and abalones are taken at various places. Marine fish of many kinds are obtainable in large numbers in and about Bodega Bay.



North and east of Salmon Creek estuary, well-developed wave-cut terraces at several different levels indicate the position of former stands of the sea. There have been many fluctuations in sea level along the northern California coast since Pliocene time. East of the narrow terraced coastal shelf, rugged hills carved into Franciscan bedrock rise abruptly to form the rugged backdrop that is characteristic of most of the northern California coast.

Opposite Portuguese Beach, 2.2 miles north of Salmon Creek estuary, Indian shell mounds or kitchen middens may be seen where highway excavations have exposed them. These consist largely of masses of seashell fragments, but Indian artifacts occasionally are picked up.

North of the entrance to Shell Beach several isolated monoliths stand above the coastal plain. These once were isolated islets or stacks in a former stand of the sea. Numerous stacks protrude above the present level of the sea which is 100 feet below the level of the coastal terrace on which Highway 1 is built. Thus, two generations of similar marine-eroded features exist almost side by side.

After traversing the narrow Bodega coastal plain Highway 1 winds down to the level of the Russian River; the bridge crossing is at the Bridge Haven store. The junction point of Highways 1 and 12 is at the north end of the bridge. Highway 12 connects with Sebastopol and Santa Rosa through the famous resort country of the Russian River. The Russian River is a fisherman's paradise, yielding fine catches of silver and king salmon, steelhead, shad, and striped bass in season.

Roadcuts close to the junction of Highways 1 and 12 expose coarse brown sandstone and grit of the Franciscan formation. The rocks are unusually coarse for the Franciscan and somewhat resemble some of the Cretaceous rocks north of Fort Ross. Resistant ridges of Franciscan rocks trend at a slight angle to the present coast line so that the shoreline diagonally truncates the ridges. Most of the streams of the Sonoma Coast have been developed since the formation of the ridges, but the Russian River is a notable exception. Its sinuous course through the western part of the Coast Ranges cuts directly across the structural and topographic trend. The rise of the folds and fault blocks which outlined the present ridges is thought to have been slow enough to allow the major Russian River to keep its ancestral course, whereas stream systems having lesser eroding power were disrupted by the structural adjustments of the earth's crust and new systems adapted to the new conditions formed.

Jenner-by-the-Sea is situated on the Russian River estuary 1.4 miles from Bridge Haven. The name is derived from the Elijah K. Jenner family which came to the vicinity from Vermont in the sixties. It is the last of the resort spots on the Russian River, river and ocean meeting 1 mile to the west of town.

Opposite Jenner is Penny Island, a broad, low sand bar in the Russian River estuary. It is inhabited only by sea birds, but is occasionally visited by boatmen and fishermen. The sand spit at the mouth of the Russian River is equipped with a jetty that was designed to keep the estuary open for shallow-draft coastal fishing vessels. However, shoal water has developed outside the end of the jetty and the estuary is no longer useful as a harbor for anything except small craft. A movement is under way to lengthen the jetty and deepen the channel so that the estuary can be used as a harbor for fishing fleets.

Half a mile west of Jenner is the cafe and store called Rivers End. Its glass-enclosed dining room, located 75 or 100 feet above the water, affords a fine view of the estuary and mouth of the Russian River, as well as the rocky coast beyond.

Half a mile up the highway from Rivers End the highway has been cut through massive, deep-blue glaucophane-garnet rock of unusual beauty. Glaucophane is a blue soda-amphibole mineral found in only a few parts of the world; in the California Coast Ranges, however, the mineral is common near intrusive serpentine contacts in the Franciscan formation. At the crown of the ridge, above the conspicuous roadside glaucophane exposures, is a rounded, barren, rock outcrop made up in part of glaucophane but containing also garnet and the grass-green soda-pyroxene, omphacite. This mineral association is rare and is thought to have formed by alteration of very deep-seated rock originally consisting of garnet and pyroxene. The eclogite, as garnet-omphacite rock is called, is thought to have reached the surface from the inner crust along great thrust faults, partial alteration to glaucophane having taken place at some time during its rise. Selected specimens containing green pyroxene, red garnet, and blue glaucophane are very popular among rock collectors. Glaucophane-bearing Franciscan rocks are also exposed south of the Russian River in the hills opposite Penny Island. Nine-tenths of a mile northward along the highway from the glaucophane locality prominent chert and pillow basalt outcrops appear east of the road. These also belong to the Franciscan formation.

A rugged, primitive area begins at Russian Gulch and extends indefinitely northward. The narrow coastal plain disappears and the mountainous ridges rise abruptly from the ocean floor. Highway 1 hugs the edges of the steep slopes and horseshoes in and out of the gulches for a distance of 6 miles before coming out onto the coastal terrace near Fort Ross. Canyons and highlands are covered with mixed coniferous and broad-leaved forest consisting principally of redwoods, deciduous oaks, firs (*Pseudotsuga taxifolia*), bay trees, madroñas, buckeyes, myrtles, and California nutmegs. Sheep-grazing and lumbering are the principal occupations along the northern Sonoma County coast and the long, low, stake sheep-fences and their meadow-like enclosures are a characteristic part of the landscape.

from Fort Ross to Stewarts Point. The rocks making up the rugged terrain between Russian Gulch and Fort Ross are weathered sandstone and shale of the Franciscan formation; exposures are poor and parking is difficult along the narrow, winding road. At the top of the grade above Russian Gulch, limited parking space will allow the tourist to take in the fine view southward down the rock-studded coast.

Five miles north of Russian Gulch and 3.6 miles south of Fort Ross the first evidences of the proximity of the San Andreas fault may be seen to the west of the highway. Between Bodega Head and this point the trace of the fault has been submerged beneath the waters of the Pacific Ocean. The fault feature first noticed in travelling north is a pond-filled depression or sag pond perched almost at cliff-edge a few hundred yards west of the highway. One-tenth of a mile farther north the San Andreas fault zone is exposed in road cuts. Both Franciscan and Cretaceous rocks on either side of the main trace have been crushed and sheared into one another, forming a blackish or brownish nondescript material termed gouge by geologists. The disturbed zone is several hundred feet wide. North from this point for a distance of 4 or 5 miles the work done by the fault upon the landscape is readily discernible. Perhaps the most easily recognized features are the discontinuous line of sag ponds and their associated jumble of earth mounds.

Eight-tenths of a mile northeast of Fort Ross there is a remarkable group of fault features all found within a square mile or two. In addition to the conspicuous sag ponds and mounds, stake sheep fences have been offset 10 to 15 feet, trees have been knocked down, and streams have had their courses completely disrupted. At one spot a large redwood tree has been split in two, with each part still standing on opposite sides of the partly filled fault crevice. In most places, however, the crevices made by the 1906 slip have been completely filled and are covered with grass or brush. Although Fort Ross is rapidly being restored and one would not now realize it, the old buildings were largely demolished in the earthquake of 1906. The quaint Creek Orthodox Church chapel was one of the most badly damaged.

To the geologist, one of the most striking results of San Andreas faulting between Fort Ross and Point Arena is the sharp demarcation between Cretaceous rocks of the Chico formation and Jurassic rocks of the Franciscan; to the east of the fault the rocks are entirely Jurassic; to the west they are Cretaceous or younger. Not only do the rocks differ in age and character on opposite sides of the fault, but folded structures have vastly different trends. To the east of the fault the regional structure trends north-northwest at a small angle to the coast line; to the west many of the fold axes are almost at right angles to the coast.

The site of Fort Ross was set aside as a state historical monument in 1906 and the restored commandante's house has been made into a museum attended by a curator and staff. Other buildings as well as the stockade and blockhouses are being reconstructed in accordance with carefully preserved historical records.

Fort Ross was completed in 1812 under the direction of Ivan Kuskoff (or Kuskov), an official of the Russian-American Fur Company, and at one time consisted of an enclosed stockade, two blockhouses equipped with cannon, and 59 miscellaneous buildings. It was built to serve as a center for the sea-otter fur trade, as an agricultural center for supply of the Alaskan colonies, and as a center of trade with Spanish California. Russians and Spanish clashed over the very lucrative sea-otter traffic and the Spanish rather effectively closed San Francisco Bay and environs to Russian-equipped Aleut hunters. The Spanish were apprehensive of Russian territorial encroachment and officially did everything possible to suppress trade with Fort Ross.

Owing to the rapidly diminishing sea-otter take, unsatisfactory trade relations with Mexico (which by then had gained independence from Spain), the advent of the Monroe doctrine, and political turmoil at home, the Russians withdrew from California in 1841, selling their Fort Ross holdings to J. A. Sutter of gold-rush fame. Sutter moved nearly everything to Sacramento Valley, including thousands of head of livestock; but because of business misfortunes during the gold-rush period, he never made use of either the fort or the fine land holdings adjacent to it. A very comprehensive account of the Russian occupation of California may be found in California Historical Society Bulletin, Special Publication No. 7, published in 1933 and obtainable at most libraries.

North of Fort Ross a terraced coastal plain similar to the one adjacent to the Bodega-Sonoma Coast parks widens out. In contrast to the sparsely vegetated watercourses that cross the Bodega plain, the Fort Ross plain is crossed by numerous forested gullies along which coniferous trees extend all the way to the cliff line. The entire coastal plain was once heavily forested with redwood and fir timber, but logging and farming have cleared it of its forest cover. Sheep pastures are everywhere and the stake fences wander in all directions. There are numerous coves sheltered by rocky headlands. Some of the beaches are merely rocky platforms cut by the waves. Curious rock structures outlined in hard strata are revealed at low tide, and the predominant variety of seaweed, which grows in colonies on the rocky beaches, is then exposed. These colonies commonly stand in miniature groves like coconut palms on the skyline of some far-off atoll.

Rocks exposed on the beaches and sea cliffs are coarse sandstones, cobble and boulder conglomerates, and dark shales, largely of Upper Cretaceous age. They are fossiliferous in some places along the Fort



FIG. 9. Restored stockade and blockhouse at Fort Ross, Sonoma County. Fort Ross, dedicated by the Russians under Kuskoff in 1812, finally passed into the hands of J. A. Sutter in 1840s, and thence into oblivion, after Sutter's empire vanished in the gold rush. Photo (1949) by Bill Young, courtesy *San Francisco Chronicle*.

Ross-Point Arena coast, but the fossil localities are not well known and the fossils have not been adequately studied. Fossil sea shells have been found in the rocks of Salt Point, Stillwater Cove, Havens Neck (2 miles north of Gualala), Anchor Bay, and at a gulch near the sea cliff 1 mile north of Gualala. Ammonites were recently found near Anchor Bay for the first time by members of the University of California Paleontology Department.

Two and seven-tenths miles north of Fort Ross is a sawmill equipped with an unusual overhead tramway for moving logs and lumber. The rig consists of two lofty poles supported by guy wires, a long steel cable suspended between, and slings attached to pulley blocks. The loaded slings were towed along the cable between the pole supports by means of the pulley blocks and smaller tow ropes or cables. Although the rig is now obsolete, the lofty cableway is a landmark for several miles along Highway 1.

Seven and a half miles north of Fort Ross, Highway 1 passes through the Kruse Rhododendron Reserve, a state park devoted to conservation of the prolifically flowering shrubs. The large azalea-like plants, many of which grow 6 or 8 feet tall, are masses of color during the late spring.



FIG. 10. Detail of one of the restored blockhouses at Fort Ross, showing cannon ports and massive timber construction. Spires of the restored Greek Orthodox Church at extreme right.

Beginning 8.6 miles up Highway 1 from Ocean Cove store or 14.9 miles north of Fort Ross, roadcuts for several miles afford a close-up look at the coarse Cretaceous rocks of the Gualala group. Cobble and boulder conglomerates are common, these being interbedded with sandstone, shale, and grit. Debris in the conglomerates and sandstones is predominantly granitic but pebbles and cobbles of black chert, quartzite, and dense, dark-colored volcanic rocks are present. Some large fragments of shale and sandstone are also present. Boulders of granodiorite up to  $2\frac{1}{2}$  feet in diameter are common in some of the conglomerate strata, and in one place a sandstone boulder 10 feet in diameter is still in place in the matrix with which it was deposited. Just south of Stewarts Point and the Highway 1—Skaggs Springs road junction, Cretaceous strata strike directly across the road at right angles to the shore line. Resistant strata form bold headlands and deep coves have been worn into the less resistant rocks between. Thus the configuration of the shoreline is controlled directly by the arrangement of the strata.

Stewarts Point is the junction place of Highway 1 and a very picturesque woods-road across the northern Coast Ranges to Geyserville; it connects with Skaggs Springs, Annapolis, and the Kashia Indian Reservation, and with ranches and logging camps in the interior. The



FIG. 11. The Greek Orthodox Church at Fort Ross as it appeared right after the earthquake of April 18, 1906. Photo from J. C. Branner collection, courtesy Stanford University.



FIG. 12. Restored Greek Orthodox Church at Fort Ross, in 1935. Photo by Dan R. Hull, courtesy San Francisco Chronicle.

road is paved most of the way but the western end is rough owing to passage of heavy logging trucks.

Stewarts Point is an old lumber town from which lumber was shipped by sea via a long wooden trestle. The lumber mill and trestle are long since idle, but the town is still identified with lumbering in the interior. The region was first settled in the sixties.

The Gualala River, which empties into the Pacific 10 miles north of Stewarts Point, is the largest watercourse between the Russian River and Point Arena. The lower reaches of its course have been controlled predominantly by the San Andreas fault, the trace of which the stream follows for many miles. It is the only stream in the northern Coast Ranges whose course parallels the coast line for any great distance before debouching into the sea.

The town of Gualala, located on the banks of the river, was a booming lumber town in the sixties and has been identified with the lumber business ever since. Haywood and Harmon's Walhalla steam mill shipped 4,000,000 feet of lumber during the year 1867, which must have been a record figure in mass production for those days. The white frame New England style hotel erected in 1903 is still popular during the fishing and tourist seasons, the adjacent Gualala River affording fine salmon and steelhead-trout fishing. There is no agreement as to the origin of the name Gualala. Some historians hold that it is the Spanish version of the German *Walhalla* of Wagnerian fame; others consider it to be derived from the Pomo Indian word *Walali* meaning "where the waters meet"; and still others believe the word may have been derived from the name of a one-time Indian chief. Gualala is situated in magnificently scenic country and is bound to find increasing favor as a recreational spot.

#### SAN FRANCISCO SOUTH TO DAVENPORT VIA STATE HIGHWAY 1

South through San Francisco from Golden Gate Bridge, State Highway 1 follows Park Presidio Boulevard, Nineteenth Avenue, Junipero Serra Boulevard, and Alemany Boulevard. The coastal route may also be reached by way of the Cliff House and Ocean Beach over Great Highway which connects with the northern part of State Highway 5. Highways 1 and 5 intersect opposite Thornton Beach just south of the Lakeside Country Club grounds.

Between the intersection of Highways 1 and 5 and Mussel Rock, Highway 1 keeps a sinuous course well above the shore line through soft sedimentary rocks, principally sands of the Plio-Pleistocene Merced formation. The formation is not well exposed along the highway and a much better idea of the stratigraphic section may be held by walking along the beach. There the formation may be seen to consist of buff sands and clays with interbeds of pebbles and shells. The prevailing dip of the Merced beds as far as Mussel Rock is north-



FIG. 13. Pioneer cemetery overlooking the sea north of Fort Ross. The earliest gravestone, dated 1854, marks the burial place of Christian Ruoff, a native of Wurttemberg, Germany.



FIG. 14. Sonoma County coast between Fort Ross and Plantation. Rugged sea cliffs, pine-dotted coastal terrace, and stake sheep fences are typical of this part of the California coast.

east, the rocks being part of a synclinal or trough-shaped structure which has been disrupted by various faults such as the San Andreas, San Bruno, and other parallel faults related to the San Andreas system.

Three-tenths of a mile north of the gulch opposite Mussel Rock, locally known as Fog Gap, the San Andreas fault crosses Highway 1 and passes out to sea in the direction of Bolinas Bay. The fault zone is not apparent in road cuts nor are there conspicuous topographic forms close to the highway. Toward the beach, however, the rift forms become pronounced and haphazard hummocks and sunken areas finally culminate at cliff's edge in a huge landslide which resulted in part from earth movement during the San Francisco earthquake of 1906. A little scouting about on foot also will reveal sunken areas and soil ridges strung out in a southeast direction; they become very pronounced along State Highway 5 (Skyline Boulevard).

Mussel Rock and its adjacent stacks or islets consist of erosion-resistant greenstone basalt belonging to the Franciscan formation. The weathered equivalent of the rock may be seen in road cuts along the highway south of Mussel Rock. Closely associated with the basalt are chert beds; both are products of marine volcanism.

In the sea cliff and on the hilltop north of Mussel Rock, at the end of a prominent ridge, the tilted basal beds of the Merced formation lie on an eroded surface worn on greenstone. The basal beds are considered to represent an old soil horizon developed under a forest floor, as they contain pine logs, coal, pine cones, and miscellaneous vegetable debris. Above the coal-bearing basal beds are sandy strata with upper Pliocene marine fossils showing that the forested area sank below sea level from a low and rather marshy coastal plain and became a shallow marine embayment. The slide marking the trace of the San Andreas fault has obscured the Merced sequence situated stratigraphically above the fossil-bearing Pliocene beds, but north of the slide Pleistocene plant fossils are present in the Merced formation. It is therefore partly Pliocene and partly Pleistocene in age, and as no erosional break has been found between the Pliocene and Pleistocene horizons on the San Francisco peninsula, the stratigraphic relation between the two parts of the formation is presumed to be gradational.

Between Mussel Rock and San Pedro Point is a series of recently developed subdivisions and beach resorts. The first of these, Pacific Manor, is built high above the ocean on an old marine terrace. Sharpe Park Village adjoins a 480-acre park given the City of San Francisco by Mrs. Honora Sharpe. The park has been enhanced by a municipal golf course nicely situated on the banks of Laguna Salada. Rockaway Beach, bordered by rocky promontories, is an undeveloped beach open to the public.

The northern promontory of Rockaway Beach is made up principally of the Calera limestone member of the Franciscan formation.



FIG. 15. Coast line between Purisima and Tunitas Creeks, San Mateo County. In the sea cliffs in the left background siltstone of the Mio-Pliocene Purisima formation may be seen in contact with Quaternary terrace alluvium.

A large quarry has been driven into it from which crushed rock has been produced for more than 50 years. The dense, siliceous, gray limestone makes good road metal and concrete aggregate and the quarry is conveniently situated. An interesting feature of the limestone is the presence of numerous sub-microscopic remains of animals called foraminifera. They are barely recognizable with the naked eye, but are fairly prominent under the hand lens, where they look like glassy pinheads. Another large exposure of foraminiferal limestone may be seen in road cuts on the inland side of the highway directly south of the quarry.

A few hundred yards south of the limestone outcrops just mentioned is a broad crushed zone in Franciscan shale, sandstone, and greenstone. These crushed basement rocks are overlain by 50 to 100 feet of Quaternary terrace sand and gravel which does not appear to have been disturbed. The crushed zone marks an old fault which was probably active before the terrace was deposited. The fault may be related to the Pilarcitos fault, which is believed to pass down the center of San Pedro Valley approximately under Lake Mathilde. The Pilarcitos fault is a major structural feature, predominantly of thrust type, along which Franciscan rocks have been crushed against the resistant granitic mass of Montara Mountain. Erosion along the crushed zone of the Pilarcitos fault has served to further accentuate the original ruggedness of Montara Mountain.

Fertile San Pedro Valley is a truck-gardening area famous for artichokes. As the San Francisco suburban area is rapidly expanding southward, San Pedro Valley may well become residential rather than

rural. One of the temporary base camps of the Portolá expedition was in San Pedro Valley; discovery of Point Reyes from a vantage point on Montara Mountain was the spur which urged the expedition toward ultimate discovery of the Golden Gate and San Francisco Bay. The Sanchez adobe, headquarters of Rancho San Pedro, established in 1837, still stands near Pedro Point at the mouth of San Pedro Valley.

South of San Pedro Valley massive Montara Mountain extends to the water's edge. Undercutting of this resistant mass by the waves has produced an exceedingly steep and lofty escarpment along the shore line from San Pedro Point to the valley opposite Halfmoon Bay. Leaving San Pedro Valley, the sinuous route climbs the side of a canyon through shales of Cretaceous age for nine-tenths of a mile. The shales then give way abruptly to a boulder conglomerate composed largely of granitic rubble, but containing Franciscan sandstone, limestone, and greenstone cobbles, together with some Sur



FIG. 16. Artichoke fields near the mouth of San Gregorio Creek, San Mateo County. These are familiar parts of the landscape between Halfmoon Bay and Pescadero Creek Canyon.

series schist. The conglomerate is clearly unconformable with the underlying shale and belongs to a different formation. Cretaceous fossils have been found in the shales beneath the boulder conglomerate at Pedro Point, and enough fossils have been taken from above the conglomerate east of Devils Slide to establish the fact that the section above the conglomerate is Eocene or Paleocene. Although the entire sedimentary series lying between the Pilareitos fault and the Montara granitic mass has long been called Martinez (?), a considerable part of the belt has been found to be Upper Cretaceous.

Close to the southwest of the prominent road cut exposing the boulder conglomerate, a low-angle fault of small displacement cuts sandstones and gravels of the Martinez formation. Its apparent dip is about  $30^{\circ}$  toward the ocean but the direction of movement is uncertain.

Half a mile farther south along the highway a large zone of thrust faulting is exposed in cuts east of the roadbed. The fault disrupts sandstone and shale of the Martinez formation. The zone



FIG. 17. Three sharply contrasted formations each separated by an unconformity as seen in a road cut on Highway 1 half a mile north of the Pomponio Creek Bridge, San Mateo County. Badlands at the top of the picture are eroded in soil developed from sandy Quaternary alluvium; the gravelly layer below is somewhat older terrace material; and the channelled, cross-bedded lowermost member that contains the white diatomite is part of the Purisima (Mio-Pliocene) formation. The peculiar distribution of the diatomite layers is the result, in part, of sea-floor slumping in mud. Rock was deposited near a beach.



FIG. 18. Detail of the slumping and crossbedding in diatomaceous mudstone and diatomite seen in figure 17. Road cut on Highway 1 half a mile north of Pomponio Creek.

dips  $30^{\circ}$  -  $35^{\circ}$  N. and the overthrusting movement was southwest toward the ocean basin.

Four-tenths of a mile farther south conglomerate sandstone forms the lower beds of the Martinez formation. These are adjacent to a strongly disturbed area several hundred yards wide in which two slivers of Upper Cretaceous shale have been sheared into the basal beds of the Martinez formation. Higher up on the mountain basal Martinez beds have been deposited on an irregular surface of weathered granodiorite. The depositional surface itself dips northeast because of warping and tilting of the various segments of the Montara Mountain block. The typical granodiorite of Montara Mountain, of which only weathered specimens are obtainable, is a coarse-grained granitic rock composed predominantly of sodic plagioclase feldspar and quartz with smaller amounts of orthoclase feldspar and biotite. It contains hornblende in some localities. The quartz content is unusually high.

Devils Slide is a chute-like rock slide kept precipitous by wave undercutting on the beach below. The roadbed is cut across it so that

its original height has been lessened, but it still extends several hundred feet from road to beach, and the rock retaining wall is not a good observation spot for the timid.

South of Devils Slide 1.2 miles, pegmatite dikes a few inches thick stand out in relief from the more weathered quartz diorite matrix. These contain much more potash feldspar than the matrix rock and are exceedingly coarse grained.

In the vicinity of the McNee Ranch, 1.6 miles south of Devils Slide, a well-developed wave-cut terrace may be seen. It is now more than 75 feet above the present stand of the sea, showing that fluctuations in sea level have been great in this area. This old seashore extends to the outskirts of Montara village.

Montara is partly a beach resort and partly a flower-growing community. It sends millions of blooms to metropolitan florists each year. On nearby Montara Point a Coast Guard fog whistle and U. S. Navy radio compass station are maintained.

Between Montara and Moss Beach, road cuts expose buff sands of the Plio-Pleistocene Merced formation. On the ridge which bounds the coast west and northwest of Halfmoon Bay, gently folded Merced sediments are exposed in sea cliffs and on the beach itself; the fold axes roughly parallel the coast. The eastern side of the ridge is bounded by a segment of the San Gregorio fault, the fault being well exposed on the beach and sea cliff at Moss Beach, San Gregorio.

Moss Beach and Seal Cove are the last of the beach resorts which center about Montara Point. Upper Pliocene rocks of the Merced formation exposed at Moss Beach give a fine picture of ancient shallow marine deposition and of fold and fault structures. The Merced formation here consists of a heterogeneous assemblage of greenish sandstone, siltstone and clay, pebble conglomerate and shell beds, predominantly beach and mud-flat deposits. Except for their color and folded condition, the Merced deposits are much like those forming on Moss Beach today, or those seen in the recently uplifted marine terraces lying above the Merced. At low tide a small but complete trough-shaped fold or syncline can be seen on the wave-scoured beach. A fault contact (San Gregorio fault) between the Merced formation and granitic rocks is well exposed in the sea cliff. Beyond Moss Beach the road crosses a low divide and passes down the coastal plain which widens out from Pilarcitos Valley back of Halfmoon Bay. Halfmoon Bay Airport, which caters largely to private planes, and the villages of Princeton, El Granada, and Miramar, are all situated at the edge of the Halfmoon Bay truck gardening district.

The coast plain in the vicinity of Halfmoon Bay is devoted almost entirely to truck gardening and dairying. The town of Halfmoon Bay is famous for its artichokes and prides itself on being the artichoke capitol of California. The Halfmoon Bay vicinity was first visited by men of the Portolá expedition in 1769. The town had its

beginning in the early forties as parts of two land grants made respectively to Tiburcio Vasquez and Candelario Miramontes. The village that developed around the haciendas of these men was known as Spanishtown long after it was laid out or plotted in 1863. The name Halfmoon Bay was largely established during the twentieth century.

Although in deep water and somewhat protected by Pillar Point, Halfmoon Bay itself is too exposed to make a first-class harbor without development of breakwater facilities. Preliminary work is now being done on a series of small harbors up and down the California coast which could adequately house California's fishing fleets as well as provide water shipping points for various products such as lumber produced along the sea coast. Halfmoon Bay is one of the harbors which will be developed under this program. In spite of the exposed nature of the harbor, tankers have taken oil from Halfmoon Bay piers near Princeton for several decades. It has also been used by whalers, trading vessels and, it is whispered, by rum runners!

There are good exposures of massive limy sandstone in several open cuts east of the road, 4.1 miles south of Halfmoon Bay Airport or 1.3 miles north of Halfmoon Bay town. The Vaqueros formation is lower Miocene in age and is famous for its abundance and variety of marine fossils. Vaqueros fossils are not plentiful, however, at this locality.

Six and three-tenths miles south of the Pilarcitos Creek road junction in Halfmoon Bay, Highway 1 winds in and out of a gulch along which the Mio-Pliocene Purisima formation is exposed. The formation there consists predominantly of buff to gray sandstone and siltstone, but brown clay shales are a common part of the formation as seen in the sea cliffs to the west and northwest of this locality. The shales exposed in these sea cliffs are very fossiliferous and the marine sea shells found in the shale are much like those appearing on the beaches of the vicinity today. Many of the Pliocene fossils fall out of the sea-cliff shales and become mingled with Recent shells. The shells of these two vastly different ages when mixed together would be difficult for the casual observer to separate, if it were not for the sand and clay which usually adheres to the fossil shells.

Oil has been produced in small quantities from the lower part of the Purisima formation in a belt extending southeast from near the mouth of Purisima Creek to the town of La Honda, located 7 miles east of San Gregorio. Oil from the Purisima formation has an exceptionally high gasoline content, but none of the wells so far have produced in notable quantity. Oil has been trapped in a series of asymmetrical arched structures at depths of 1500 to 2400 feet. As sustained production from most of the wells is between 5 and 8 barrels per day, and as present production costs are high, most of the wells are idle at present.





FIG. 19. White diatomite strata in the Mio-Pliocene Purisima formation in the sea cliffs at the mouth of San Gregorio Creek, San Mateo County.

At the mouth of Martins Creek, where Highway 1 approaches close to the coast line, steeply dipping, complexly folded Purisima shales may be seen in angular unconformity with 30 feet of Quaternary terrace alluvium. Limited exposures of Purisima sandstones and shales may also be seen along the road as far as San Gregorio Creek. Half a mile north of San Gregorio Creek bridge a series of badlands produced by rain-wash in soft Purisima (?) silt and clay makes an interesting study in erosion. Just beyond the badlands area where the road begins to drop down to the level of San Gregorio Creek, a series of dark-brown shales and thin sandy beds appears in long road cuts. The series is somewhat different from the Purisima formation farther north, but has been mapped as such on the Santa Cruz folio.

The mouth of Coyote Creek west of San Gregorio is the approximate point at which the San Gregorio fault passes out to sea. This large fault, active in late geologic time, cuts the edge of the continent in a southeasterly direction from Coyote Creek to the eastern shore of Año Nuevo Bay. It is another of several faults in the Coast Ranges along which both vertical and horizontal movements apparently have taken place.

Just north of the Coyote Creek Bridge a road joins Highway 1 that connects with the old oil fields of Bellvale and La Honda, and ultimately with Skyline Boulevard north of Portola. The road between La Honda and Skyline Boulevard crosses a section of Miocene rocks of the Monterey and Vaqueros formations which have been extensively intruded by diabasic volcanic rocks.

San Gregorio, now a farming center, was once proposed as a mission site by Fray Crespi of Portolá expedition fame. Its handful of farmhouses bears little hint of the former presence of the Spaniards. Three and a half miles south of San Gregorio is Pescadero, which lies at the confluence of Pescadero and Butano Creeks. A large estuary

separated from the ocean by a broad sandbar and sand dunes forms a pleasant setting for the village, first settled by Spanish Californians in the early fifties. Antonio Buelnos' Rancho San Gregorio grant dates from 1839.

Diatomite beds in the Purisima formation are well exposed in the sea cliff north of the small estuary at the mouth of San Gregorio and Coyote Creeks and in broad road cuts along Highway 1, four-tenths of a mile north of Pomponio Creek. In the latter locality masses of diatomite are irregularly distributed in cross-bedded clays and silt where their haphazard arrangement appears to result partly from sea-floor slumping of soft muds with which the diatoms accumulated, and partly from filling of an irregular pattern of submarine channels.

Pescadero Beach is a picturesque recreational area adjoining the town on the southwest. Adjacent Pebble Beach is a favorite collecting spot for rock hounds. Small agate, jasper, and other chalcidonic quartz pebbles may be picked up, some of which are suitable for polishing. Some of these pebbles were derived from vein materials in the Franciscan formation; others are from complex metamorphic rocks much older than the Franciscan formation, the source of which is not known.



FIG. 20. Mudstone and siltstone of the Purisima (Mio-Pliocene) formation in road cuts along Highway U. S. 101 near Sargent on the southern border of Santa Clara County. Marine deposits pictured here lack the crossbedding seen in the Purisima formation exposed near San Gregorio Creek, and presumably were deposited farther from shore.

Three miles south of Pescadero are Arroyo de los Frijoles dam and lake. The lake is also known as Lake Lucerne. It is the water supply for the farming area lying between Pescadero and Pigeon Point. On the coastal apron south of Lake Lucerne are two conspicuous marine terraces, one 50 to 75 feet above the present stand of the sea, and the other more than 300 feet above sea level. Seen from the coastal highway, the deeply gullied hills at and southeast of Lake Lucerne do not seem particularly unusual; but from the high ground behind, or from the air, the land surface reflects a complex history of stream development. Several periods of regional uplift and numerous differential movements of the two blocks on either side of the San Gregorio fault must have taken place to produce the present haphazard stream pattern. The former drainage system of San Gregorio

Highway 1. Cretaceous rocks also form stacks or islets offshore from Pigeon Point lighthouse. Both Pigeon Point and Año Nuevo Point are equipped with navigation lights. Pigeon Point also has a radio receiving station operated by the Civil Aeronautics Bureau.

Both Franklin Point, located midway between Pigeon Point and Año Nuevo Point, and Año Nuevo Point are attractive dune-covered spots; in fact the entire beach between Pigeon Point and Point Año Nuevo is a fine place for wayfarers to wander. There are many acres of dune-covered lowlands around Point Año Nuevo, and patches of Monterey cypress and Monterey pine are scattered about inland from the dunes. Still farther inland the hills become thickly wooded with Monterey pine, as the highland about Ben Lomond is approached.

A short distance south of Point Año Nuevo the coastal plain ends and Highway 1 hugs the mountainside for nearly 2 miles. The southern end of the San Gregorio fault trace on land is at the end of the coastal plain, the fault passing out to sea at that point. The oversteepened mountainside along which the road is cut appears to be an eroded fault scarp now considerably modified by marine erosion. Good exposures of weathered buff sandstone of the Monterey formation may be seen in the numerous road cuts along the steep mountainside. Farther south, the sandstones are succeeded by opaline chert and shale, the prevailing rock in the Monterey formation as it crops out near Davenport. Davenport, the home of Santa Cruz Portland Cement Company, lies on a coastal plain similar to the one south of Pescadero. The plain is terraced, at least two former stands of the sea being represented. The earliest settler in the Davenport area was Captain John Davenport, a whaler. Whales were exceedingly plentiful off the Monterey and Santa Cruz coasts during the first half of the nineteenth century and whaling was a lucrative venture as late as the eighties. The crystalline limestone deposits, which are scattered through the Ben Lomond Mountain country from Davenport to Santa Cruz, were exploited as early as 1851, when lime for brick mortar came into demand in California. Prior to the gold-rush period, adobe or frame construction had been the rule. Since 1851, millions of dollars have been realized from the limestone deposits found near Davenport and Santa Cruz. These limestones are rather coarsely crystalline and commonly are associated with mica schists of the Sur series and with granitic rocks which have intruded the schist and limestone roof pendants.

Davenport centers around the plant of Santa Cruz Portland Cement Company, located at the mouth of San Vicente Creek. The plant utilizes limestone from a large glory-hole operation located several miles up San Vicente Creek, and Monterey shale quarried between the limestone deposits and the mill. These raw materials together with imported gypsum are the principal constituents from which the company makes cement. The glory-hole limestone operation is



FIG. 21. A southern San Mateo County landscape showing two former stands of the sea, represented by two sets of uplifted terraces (foreground and middle ground) and present sea level (right middle ground). Camera was facing southeast toward the Santa Cruz Mountains from a beach side near Pigeon Point.

Creek has been radically changed from its normal course of development, and there are portions of old valleys that no longer contain streams because their former watershed has been cut into and is now drained by some other stream. This process, known among geologists as stream piracy, commonly occurs when an old drainage system is altered or destroyed by more vigorous streams that have developed in response to some radical change that has affected the grade and elevation of the land surface. Folding, faulting, and regional tilting are the usual causes.

Between Bolsa and Pigeon Points thin-bedded shale and sandstone of the Cretaceous Chico formation outcrop in road cuts along

unique among limestone quarries. Limestone is blasted from both walls of San Vicente Canyon, drops to the floor of the canyon, falls through open shafts dug in the canyon floor to an underground storage pile and haulage way, and is mechanically loaded onto railway mine cars for transportation down the bed of San Vicente Creek to the plant. Not only is the quarry interesting from an operational viewpoint, but it is also a fine place to observe the relationships of the rock formations of the area. On the west wall of the canyon, gray, massive sandstones representing the basal beds of the Monterey formation may be seen lying on an irregular erosion surface carved on white or gray crystalline limestone and brown mica schist. The gray sandstone grades upward into thin-bedded opaline chert. Higher up in the section sandstone lenses are common in the chert, but only basal sands and opaline chert are exposed near the quarry. The Monterey formation dips toward the ocean at angles close to 20°, as if the Ben Lomond block had been tilted westward.

Beyond Davenport, Highway 1 skirts Monterey Bay through Santa Cruz and the Big Basin recreational area. There are many fine state, county, and private parks; there are also many resorts, some of which are located along the bay, others of which are back in the redwood belt. The Big Basin is almost as famous a recreational area as the Russian River strip.

#### SAN FRANCISCO SOUTH TO SARATOGA VIA SKYLINE BOULEVARD AND STATE HIGHWAY 9

The northern end of Skyline Boulevard is reached via Sloat Boulevard or along the beach via Great Highway. It passes close to the shores of Lake Merced, about which are clustered Fleishhacker Zoo, Fort Funston, Harding Park Golf Course, San Francisco State College, Lakeside Country Club, and San Francisco Golf Club. The lake vicinity is one of San Francisco's best known recreational areas. Although now a fresh-water lake, the depression was once filled by ocean water and formed a bay rather than a landlocked lake. The lake formed at about the same time and in much the same way as San Francisco Bay, that is by local subsidence of the land with attendant drowning by the sea of the local drainage system. Over a long period of years, sand brought in by ocean currents together with wind-driven sand have blocked off the bay entrance, and fresh spring water has supplanted salt water. Lake Merced was a major source of water for the City of San Francisco from 1877 up to development of the Hetch-Hetchy and similar Sierran projects; it is now only an emergency source of supply. The lake was discovered in 1774 by the Spaniard Rivera and much of it was embraced by the Mexican grant Laguna de la Merced dating from 1835.

South of the Lake Merced recreational area the lowland gives way to rolling hills and the countryside is devoted to truck gardening

and horticulture. Extensive plots of flowers which supply west-bay florists may be seen on every side except in winter months. The flower plots farther south are interspersed with dense patches of native scrub which, in summer, surpass the cultivated flowers in variety of blooms, if not in massed color.

South from the intersection of Highways 1 and 5 for a distance of 5.5 miles roadcuts expose buff unconsolidated or poorly consolidated beach and dune sands of the Plio-Pleistocene Merced formation. Where unprotected by dense native scrub, deep gullies and local badlands have been extensively developed in this soft material. Wet early-morning fogs keep the wild flowering shrubs unusually lush even in summer months.

Four and three-tenths miles south of the Highway 1—Highway 5 intersection, topographic effects of the San Andreas fault begin to be seen. Over much of its 650-mile length the San Andreas fault zone is many hundreds of yards wide, exceeding a mile in width at some points. In this vicinity the zone can hardly be less than half a mile across, and, as the road almost parallels the fault zone for several miles, its fault features are visible on either side. Haphazard, hummocky topography is first apparent, and then a number of shallow sunken spots may be seen east of the highway. The largest of these is occupied by a permanent pond fed by springs and is a hundred yards or more across. It is a pretty spot surrounded by tall Monterey eucalyptuses. The pond basin formed partly by sinking of the hillside along a fault fissure and partly by landsliding. Other small slides are present in the vicinity adjacent to cirque-like pockets from which the slide material came. Just north of the San Francisco County Prison Farm road junction, crushed rock of the fault zone is well exposed in cuts east of the highway. Much of the crushed material or gouge has been so finely milled that its original nature is no longer apparent. North of the prison farm road, rocks of the Jurassic Franciscan formation outcrop in irregular resistant patches surrounded by soil. Gray-green sandstone and pebble conglomerate are the main rock types exposed; pebbles in the conglomerate are chiefly chert and porphyritic volcanic rocks.

A mile south of the Highway 5—San Bruno road junction a series of lakes begins. These lakes, which have been substantially enlarged by dams, are a vital link in the water supply of San Francisco and neighboring cities. They are strung out in a straight line for 11 miles, occupying a narrow valley astride the San Andreas fault zone. This valley formed partly by sinking of the land surface within the fault zone and partly by action of streams working in the easily eroded crushed material of the fault zone. From the point of view of the hydraulic engineer, the rift valley is a paradox. Although the reservoirs were largely created by faulting and are fed in part by springs which issue along the fault, they are in some danger of being destroyed by the very process by which they were created. The rift produced

during the earthquake of 1906 passed directly through the dam which now separates Lower and Upper Crystal Springs Lakes; it also passed close to the southern abutment of Lower Crystal Springs Lake dam. Curiously enough, neither structure was destroyed although elements of the Upper Crystal Springs dam, which was made of earth, were shifted as much as 8 feet. At the north end of Lower Crystal Springs Lake, a 44-inch water main that crossed the fault trace diagonally was telescoped more than 4 feet. No serious damage was done to vital Lower Crystal Springs Lake dam, a concrete structure, which now is largely responsible for impounding waters of both Upper and Lower Crystal Springs Lakes. The once-damaged Upper Crystal Springs Lake structure is now used principally as a causeway on which Highway 5 crosses the lake area.

Between the northern end of San Andreas Lake and the Crystal Springs Golf Course, road cuts are largely in buff sand of the Merced formation. Here and there the road passes through rocks of the underlying Franciscan formation, or else outcrops of hard Franciscan rocks may be seen in fields adjoining the road, where they stand out from the softer soil and Merced formation cover. Many of these exposures stood as low hills at the time the Merced formation was being deposited and were buried under Merced debris. Sandstone, greenstone, basalt, and some red chert are the principal rock types thus uncovered.

One and six-tenths miles south of the San Bruno road junction, California Division of Highways Historical Marker 27 commemorates a stopping place of the Portolá expedition of 1769. At that time the floor of the valley was dotted with small lakes or ponds and the ridge west of the valley was covered with a dense forest of oak, redwood, bay, and madroño trees. Although many of the redwood trees have been logged off and waters of San Andreas reservoir now cover the valley floor, much of the original charm of the place still remains. The City of San Francisco maintains the lake area and adjoining wooded country as a game refuge and watershed, and traces of old logging operations have largely been obscured by new growth.

Nine-tenths of a mile south of Crystal Springs Golf Course red Franciscan chert is exposed in cuts on the west side of the highway. The individual chert beds are 1 to 2 inches thick and alternate with thin bands of dark-red shale. The chert contains remains of marine microscopic animals called radiolaria which were caught in chemically precipitating silica at a time when volcanism was active on the sea floor. The silica and the red iron oxide of the shale was poured into the water from hot springs issuing from fissures in volcanic belts.

Two-tenths of a mile farther south a long belt of serpentine begins; this is exposed in almost all road cuts as far south as the Lower Crystal Springs Lake dam. The rock is commonly full of fractures and slip surfaces which are highly polished. Serpentine so polished has

been termed slickentite by geologists. Some specimens that have not been sheared and polished show a groundmass of granular dark-green serpentine crossed by a network of thin, pale green chrysotile (fibrous serpentine) veinlets, which give a delicately reticulated effect. Most Coast Ranges serpentines are alteration products of igneous sills, dikes, and the like, which were intruded into Franciscan marine sediments in late Jurassic time. Pseudomorphs or surviving outlines of the original pyroxene crystals remain, but the crystals have been completely replaced by serpentine. At Lower Crystal Springs dam the serpentine belt ends abruptly just short of the north abutment; the south abutment of the dam is anchored in Franciscan sandstone which is well exposed in roadcuts. The fresh rock is grayish green, weathering to buff or brownish hues. Franciscan sediments outcrop in numerous places along roadside and lake shore between Lower and Upper Crystal Springs Lake dams, but the last mile is largely through serpentine, much of which has been brecciated by action of the San Andreas fault. Sharply marked narrow terraces mark former stands of the lake.

West of Upper Crystal Springs Lake dam the road crosses a narrow belt of gravel and alluvium belonging to the Plio-Pleistocene Santa Clara formation. The Santa Clara formation is probably equivalent to part of the Merced formation. It lies unconformably on the Franciscan formation and occupies part of an old depositional basin which has been largely obliterated by erosion and faulting along the San Andreas rift. Roadside exposures of the Santa Clara gravels are poor.

Seven-tenths of a mile west of Upper Crystal Springs Lake dam is the entrance to Skyline quarry where crushed rock is produced. The quarry faces are driven in a thoroughly brecciated limestone lens of the Calera member of the Franciscan formation. The limestone fragments showing in the face of the south quarry are all smaller than one's fist, indicating how powerful the crushing forces were. The quarry operators have been able to take advantage of the crushed condition of the limestone in producing aggregate, and material savings in processing must be realized because of this shattering action of the San Andreas fault.

Six-tenths of a mile south of Skyline quarry a series of broad road cuts exposes more faulted and jumbled Franciscan rocks. Large sandstone and shale blocks are distributed haphazardly among areas of serpentine, basalt, limestone, and gabbro. The latter is a white and green altered granitic rock which originally was intruded into Franciscan sediments along with the peridotite now serpentinitized. Original relationships between the several rock types in the road cuts is confused by fault movements also related to the San Andreas rift. As the road continues to climb the ridge away from the fault zone, the strata are less disturbed and parts of fold structures are discernible.



FIG. 22. Fault contact between interbedded shale and sandstone of the Monterey formation and massive sandstone of the Vaqueros-Temblor group just south of Skeggs Point on State Highway 5. The line of fracture is irregular and indistinct, but passes diagonally across the center of the picture and cuts off the shale strata.

At the top of Cahil Ridge, Highway 5 turns abruptly southeast and diverges from Pilareitos Creek road which connects with Halfmoon Bay. Road cuts near the road junction are in Franciscan shale and sandstone, but a dirt road turns west to Hilltop quarry, where a small limestone lens has been quarried for crushed rock.

For 2 to 3 miles southeast along Highway 5, road cuts expose only weathered Franciscan sandstone, shale, and a few basalt intrusives. Slightly farther south, fine-grained weathered buff sandstone may be seen poorly exposed here and there in low road cuts. Where bedding is apparent, dips in the sandstone are low as if the ridge top followed the axis of an arch. The sandstone is the weathered equivalent of Miocene rocks better exposed farther south.

Three and five-tenths miles from the Halfmoon Bay road junction, massive gray sandstone reefs stand out from the soil cover a few hundred yards west of the road. The sandstone is coarse grained and composed predominantly of granitic debris. Although originally mapped in the U. S. Geological Survey Santa Cruz folio as part of the Vaqueros formation of lower Miocene age, the sandstones have since been referred to the Temblor formation (middle Miocene) by some authors. To avoid confusion, rocks of this group will be referred to as Vaqueros-Temblor in this guide.



FIG. 23. Large concretions in Vaqueros-Temblor sandstone on State Highway 5 1.8 miles south of the Woodside road junction. The mineral concentration in the concretions is iron oxide.

Four and three-tenths miles from the Halfmoon Bay road junction the trace of a small thrust fault may be seen in road cuts east of the highway. Massive sandstone has been thrust over shale at a low angle, the apparent line of thrusting being eastwest with overthrust force from the south. The fault is probably not a major structural feature but is nicely exposed and gives some idea of the kind of forces which have affected the area.

Just south of the thrust fault locality a heavily wooded region begins which is typical of Skyline Drive and the San Francisco peninsula in general. The forest is a mixed coniferous and broad-leaved one in which the Coast redwood, Douglas fir, madroño, bay, big-leaved maples, and tan bark oak are the predominant trees. Many of the best redwoods have been logged off, but scattered monarchs many hundreds of years old remain, and smaller second-growth trees are plentiful. The madroño with its bright red, smooth bark and glossy green leaves is a very striking tree; and the fuzzy yellowish-green new growth of the tan-bark oaks lends these trees a pseudo-inflorescence in late spring and early summer. Wooded areas in this vicinity are finding increasing favor as sites for rustic cabins, as well as for more pretentious summer homes.

As the more heavily wooded parts of the hills tend to have deeper soil cover, and as road cuts north of the Woodside road junction are

not very extensive, Vaqueros-Temblor rocks are not as conspicuous along this section of Highway 5 as they are farther south.

Seven miles southeast of the Skyline Drive-Halfmoon Bay road junction, King Mountain Road, coming from Woodside and Redwood City, and Tunitas Creek road, connecting Highway 5 with Highway 1 on the coast, join Skyline Drive. Five and four-tenths miles down King Mountain Road is historic Woodside Store, a frame structure built in 1854 to serve the sawmills and mill hands of the local lumbering district. The property, first taken over by San Mateo County in 1940, now houses a local-interest museum. A commemorative monument and plaque, State Historical Marker 93, has been erected close to the road by the California State Centennials Commission and San Mateo County.

Four-tenths of a mile southwest of the Woodside-Tunitas Creek road junction lofty road cuts expose thin-bedded siliceous shales which contain fossil microscopic plant remains called diatoms. The tiny porous remains lend a punky character to the shale. This rock is typical of the Monterey formation in the Santa Cruz Mountains as well as in other parts of the Coast Ranges. The locality marks the first appearance of the Monterey formation as one travels southbound along Skyline Drive. Toward the eastern edge of this series of large road cuts, a jumbled face of rocks marks part of the major Pilarcitos fault. East of the fault rocks are Vaqueros-Temblor sandstones; west of it only Monterey rocks outcrop for a considerable distance. The Pilarcitos fault is of thrust type farther north, but at this point probably is vertical with downthrow to the west. South from this locality the highway winds along almost parallel to the fault as far as Skeggs Point. The road cuts are mainly in steeply dipping Monterey diatomaceous cherty shale, but the road crosses into massive white Vaqueros-Temblor sandstone at one point.

Skeggs Point affords a fine view across Santa Clara Valley and the Mount Diablo Range. Ample parking space is provided for normal traffic conditions. On a clear day Mount Diablo, Mount Hamilton, and other peaks of the range can readily be seen, as well as Stanford University, San Jose, the various bay bridges, and other points in and adjacent to Santa Clara Valley. A brass plate arranged like a sun dial and set into a monument has arrows which point to principal spots of interest. A U.S. Geological Survey bench mark records an elevation of 2315 feet for Skeggs Point.

Less than a hundred yards southwest of Skeggs Point a well-exposed, sharp anticline or arched fold in Monterey shale may be seen in road cuts west of the highway. A small tongue of white sandstone has been brought up in the axis of the fold.

Half a mile south of Skeggs Point, a single giant Coast redwood dwarfs the other forest trees. It is well over 17 feet in diameter above the flared base and has been estimated to be 1500 years old. There are

few redwoods that large in the Coast Ranges south of San Francisco. The plot of ground upon which the tree stands has been set aside as a county park.

For 4 miles the road winds through white sandstones and brown diatomaceous and organic shales of Miocene age. This sector of the highway passes through a section of rocks transitional between the Vaqueros-Temblor and Monterey formations, which grade into each other. The demarcation line between the two is difficult to draw without use of microfossils and no recent work has been published on the rocks of the region.

Three and eight-tenths miles south from Skeggs Point is the intersection of the Corte Madera-La Honda road with Highway 5. The resort town of La Honda, located in redwoods 7 miles southwest from the Highway 5 junction and almost midway between that point and San Gregorio on the coast, is in the middle of an area prospected for oil during the period 1925-35. None of the wells were successful, although showings of oil and gas were observed in some of them. One well reached a depth of 3140 feet. Small amounts of oil were produced at Bellvale, 5 miles west of La Honda, but never in paying quantities. The petroleum-bearing rocks of both fields were sandstones of the Pliocene Purisima formation.

For 2 miles south of La Honda road junction, Skyline Boulevard winds through massive buff-weathering Vaqueros-Temblor sandstone. One and two-tenths miles south of La Honda road intersection, rocks of this formation have been folded into an arch or anticline. Observing the directional trend and tilt of the rock strata, one notices that they first dip toward the west, then flatten and become nearly horizontal, and finally dip toward the east. Unlike the small fold near Skeggs Point, the complete arch is too large to be visible in a single road cut or series of cuts, and must be inferred from change in dip of segments of exposed strata.

Two and four-tenths miles beyond La Honda intersection, an irregular intrusion of massive, dark-brown diabase is exposed on both sides of the road and may be seen intruding punky, brown diatomaceous shale and brown siltstone of the Monterey formation. Most of the rock has been altered from its original crystalline condition to a nondescript crumbly material, but oval and spherical boulder-like pockets of unaltered rock remain. Fresh specimens consist predominantly of glassy, lath-shaped plagioclase feldspar with black patches of augite filling the spaces between the feldspar laths. The diabase is upper Miocene in age and may be found in the Coast Ranges intruding the Monterey formation and older rocks. Along Highway 5 it may be seen in intrusive contact with both Vaqueros-Temblor and Monterey rocks south over a distance of about 10 miles from the locality just described. In the Langley and Mindogo Hills to the north and east of La Honda, basalt and diabase intrusions contain inclusions of

Eocene sediments carried up from somewhere below by the intruding molten rock.

Half a mile south of the most northerly diabase locality, or 2.9 miles south of La Honda road intersection, a section of thin-bedded buff siltstones and brownish diatomaceous Monterey shales appears in road cuts on both sides of the highway. Many of the shaly strata contain numerous fish scales and other fossil debris. Three and two-tenths miles farther south more thick-bedded brown diatomaceous shale is interbedded with thin-bedded blue-black organic shale containing fragments of wood, and some thin strata of white sandstone. The beds at this point are nearly flat and may mark the axis of a major structure. The black shales may be stratigraphically close to the base of the Monterey formation as they grade into massive Vaqueros-Temblor sandstone.

Seven and four-tenths miles southeast of La Honda road intersection is the junction point of Highway 5 with the Alpine Creek and Page Mill roads. The latter connects with Los Altos and Mountain View on the east. Alpine Creek road connects with both Pescadero and San Gregorio on the coast route. Along the Pescadero Road is situated the 310-acre San Mateo County Portolá Memorial Redwood Park, one of the fine recreational areas which abound in or close to the Big Basin of Santa Cruz County.

For a distance of almost 6 miles, Skyline Boulevard winds along the ridge top of the Sierra Morena through well-exposed grayish-white to brown sandstones and black and brown shales of Miocene age. Although mapped in the U. S. Geological Survey Santa Cruz Folio as Vaqueros formation (lower Miocene), these mixed rocks probably represent a transitional phase between Vaqueros-Temblor rocks and the Monterey shales. They seem more closely related lithologically to the Monterey formation in this general area than to the massive Vaqueros-Temblor sandstones. Five and nine-tenths miles south from the Alpine Creek Road junction or two-tenths of a mile south of the Saratoga Summit Ranger Station, Skyline Boulevard makes a sharp curve through a V-shaped notch. On the east side of the highway and at the north end of the notch is a coarse grayish-white sandstone much like the typical Vaqueros-Temblor rocks commonly seen north of La Honda road, but containing numerous small fragments of seashells. To the west of the highway is a crushed zone made up of large fragments of sandstone and smaller ones of shale, diabase, and other materials. A large fault passes through close to the notch in a northwesterly direction with the downdropped side west of the notch. The shell-bearing sandstone most probably belongs stratigraphically below the shales which outcrop west of the notch but have been brought up to the same topographic level by fault movements.

Highway 5 ends at its junction point with Highway 9, the latter being the mountain road connecting Santa Clara Valley points with

the San Lorenzo River resort country and Santa Cruz. A paved road continues on down Castle Rock Ridge and finally connects with Highway 17 and Los Gatos.

Turning east toward Saratoga on Highway 9 the road descends the ridge through heavily wooded country. For the first 2½ miles numerous road cuts offer cross-sections of Vaqueros-Temblor rocks. High up on the ridge shaly strata are present in considerable thickness but lower down sandstones make up nine-tenths of the exposed rocks. The shaly sections are transitional between Vaqueros-Temblor and Monterey formations, and the sections predominantly sandstone low down on the ridge probably are true Vaqueros, that is, the lower part of the Vaqueros-Temblor-Monterey sequence. Diabase intrusions may be seen at two points, nine-tenths and 1.9 miles, respectively, from the Skyline Boulevard terminus.

Three miles toward Saratoga Springs from the terminus of Skyline Boulevard an area of disturbed rocks is apparent for a distance of nine-tenths of a mile. No structure is apparent and a great deal of coarse fragmental material is mixed with finer rock particles and soil. The San Andreas fault zone is close by on the east, but the fragmental rocks are most probably landslide material rather than fault breccia. Two-tenths of a mile southeast of the jumbled area weathered sandstones (presumably Vaqueros-Temblor) again outcrop and four-tenths of a mile farther on interbedded conglomerates and sandstones are exposed on the right side of the road. The loosely cemented pebbles consist predominantly of granite and greenstone with some Sur series (?) quartzite. The conglomerate strata may be near the base of the Vaqueros-Temblor section.

One and one-half miles above the Long Bridge resort Highway 9 passes through a narrow hidden valley tributary to Campbell Creek. In this valley thrifty orchards are interspersed with groves of redwoods and maples. Between the orchard area and the bridge across Campbell Creek, interbedded brown sandstones and shales outcrop discontinuously on the right-hand side of the road. These may belong to the San Lorenzo formation (Oligocene) or they may be a sliver of pre-Tertiary rocks brought up along the San Andreas fault.

Long Bridge, over which Highway 9 now crosses Campbell Creek, is built near the site of an old toll-road bridge over which lumber was shipped in early days. The present stone and concrete structure is the gateway to the Long Bridge picnic grounds, a privately owned area heavily shaded by native trees and open to the public.

Seven-tenths of a mile below Long Bridge is the old Masson Winery established in 1852 and still in operation. Between the Masson Winery and Long Bridge, landslide debris and soil obscure the rock sequence, but the area is undoubtedly underlain by Franciscan sandstone and shale.

Historic Congress Hall was located not far from Congress Mineral Springs, discovered in the early fifties by Ferd Caldwell. Congress Hall was built in 1865-66 by wealthy private interests and soon became a famous public resort. Although Congress Hall burned about 1904, the springs vicinity has served as a resort intermittently ever since. Peninsular Railroad Company operated an electric railway which connected the resort with the Southern Pacific lines through Santa Clara Valley. The springs issue from fractured Franciscan sandstone. The spring water is mineralized principally with sodium chloride and sodium carbonate, and smaller amounts of sodium sulfate, iron carbonate, and calcium carbonate.

The rock crusher for the Saratoga quarry stands next to the highway 1.4 miles west of Saratoga. The plant has produced crushed rock for the county of Santa Clara for more than 20 years. The rock processed is a hard gray sandstone from the Franciscan formation.

The town of Saratoga, nicely situated in oak-covered foothills of the Santa Cruz Range, was first laid out in the early fifties by Martin McCarthy, and for 9 years was known as McCarthysville. The town was resurveyed in 1863 and much of the land came under the control of Charles McClay who renamed the town Saratoga from the New York resort of that name. Saratoga is now part of an increasingly exclusive residential area stretching between the business districts of Saratoga and Los Gatos. The oak-covered foothills of the Santa Cruz Mountains offer one of the finest natural suburban landscapes in the San Francisco Bay region.

#### SAN FRANCISCO TO SACRAMENTO VIA U. S. HIGHWAY 40

Highway 40 begins in the heart of San Francisco at the corner of Tenth and Bryant Streets, the junction point with U. S. Highway 101. Highways 40 and 50 coincide from San Francisco to the Oakland end of the Bay Bridge. Within the mainland limits of San Francisco, bedrock is exposed along the route only below the approaches to the bridge. There, various excavations have exposed weathered brown sandstone and darker brown shale of the Upper Jurassic Franciscan formation. The outcrops are uninteresting and it is difficult to park in the vicinity.

Travelling toward Yerba Buena Island on the lofty automobile deck of the bridge, the panorama of San Francisco Bay, its islands, and surrounding hills, forms a landscape of unusual beauty and interest. The bridge passes over the center of the Embarcadero or dock area of the port of San Francisco, with its long rows of ships of many nations. A few miles south of the bridge the travelling cranes in the naval repair shipyard at Hunters Point can be seen. This area was a beehive of activity during World War II. Across the bay from the Hunters Point repair yard is a large group of military installations and the Port of Oakland. The Alameda Naval Air Station, Oakland Army Base, and Oakland Naval Supply Depot are all in this group.



FIG. 24. An oblique aerial view of the Ferry Building and Fleet Landing at the foot of Market Street, San Francisco, taken in 1950. Photo by Barney Peterson, courtesy San Francisco Chronicle.



FIG. 25. The old Ferry Building, photo taken about 1886. A "new" cable car is in the middle of the picture, the older horse-drawn carriages in the left background. Paving-stone streets like the one in the foreground are still in use in some parts of San Francisco. Photo courtesy San Francisco Chronicle.





FIG. 26. West garrison of Camp Reynolds, Angel Island, as it was in the early 1850s. *Photo from an old drawing, courtesy San Francisco Chronicle.*

To the north of the bridge, small, bleak Aleatraz Island, covered by the buildings of the federal penitentiary, may be seen in the middle ground; lofty Angel Island is in the background. Franciscan rocks similar to those seen in Yerba Buena Island or on the San Francisco peninsula outcrop on both of these islands, and Franciscan rocks underlie the muds of most of San Francisco Bay. The bay itself is a river valley into which the Pacific Ocean has encroached. Local subsidence or sinking of the land which outlined the present configuration of the bay took place in Pleistocene time so that geologically speaking the bay is a young physiographic feature.

Yerba Buena Island, or Goat Island, is the midway anchor point of the bridge. Yerba Buena takes its name from an aromatic vine-like herb much in demand by both Indians and Spanish in early days, for medicinal purposes. Americans who visited the island in 1840 found it

overrun by goats introduced by the Spanish—hence the nickname Goat Island. Yerba Buena is deeply shaded by eucalyptus trees introduced into California from Australia. The original vegetation consisted principally of low shrubs, vines, and grass; a few live oaks were present on the northern side of the island. Franciscan sandstone and shale are well exposed on the southwestern side of the island, especially near the western entrance to Yerba Buena tunnel. Sandy strata tend to stand out from the less resistant shales, and the sedimentary sequence is thus distinctly outlined. A narrow, rocky beach surrounds the island and man-made Treasure Island adjoins it to the north.

Treasure Island, begun in 1936 and completed in 1938, was first the grounds of the Golden Gate International Exposition of 1939. Later it served as a base for the various trans-Pacific Clippers of Pan American Airways. During World War II, the island was taken over

by the Navy Department, and it still serves as a naval installation. The island was built simply by forming a rock jetty or retaining wall of requisite size and then pumping sand and mud dredged from the bay into the enclosure. Salt was removed from the dredged material by leaching with fresh water.

Highways 40 and 50 diverge at the Oakland distributary of the bridge and Highway 40 coincides with Eastshore Boulevard as far as Richmond. Northbound traffic traverses the edges of Oakland, Emeryville, Albany, and Richmond, in that order. For several miles the route lies upon land reclaimed from tidal marsh, and man-created estuaries form a park area over part of the distance. An ever increasing amount of tideland is being reclaimed by earth fill on the bay side of the highway. One and one-half miles north of the junction of Highways 40 and 50, Highway 24 joins Eastshore Boulevard. Highway 24 cuts across the Berkeley Hills to the vicinity of Mount Diablo and then turns northeast toward Sacramento. Along this route the stratigraphy, structure, and lithology of the Berkeley Hills are beautifully exposed.

A short distance northeast of the Golden Gate Fields race track is the rounded, tree-covered landmark known at various times as Signal Hill, Cerrito de San Antonio, Cerrito Hill, Albany Hill, and Skunk Hill. The name El Cerrito is the oldest, and is preferred over all others. Like Yerba Buena Island, El Cerrito Hill is covered with eucalyptus trees except on the north side where there is a fine stand of native live oaks. Weathered Franciscan sandstone is extensively exposed in a large quarry on the west side of the hill. Elsewhere, bedrock is covered by soil mantle. Franciscan sandstone, shale, and basalt are also exposed in a series of road cuts a quarter of a mile north of El Cerrito Hill, but these rocks are too deeply weathered to be representative of the formation.

One block east of the intersection of Highway 40 (there called San Pablo Boulevard) and MacDonald Avenue in Richmond is a good ex-



FIG. 27. Ferry boats in front of Yerba Buena Island in the early 1900s. Anchor and tunnel of the San Francisco-Oakland Bay Bridge seen in figure 28 are located on the island at a point just above the right pilot house of the nearer ferry boat. *Photo courtesy San Francisco Chronicle.*



FIG. 28. West entrance to Yerba Buena Island tunnel on the San Francisco-Oakland Bay Bridge, photographed about 1938. Rocks above the concrete portal are sandstone of the Upper Jurassic Franciscan formation. The sandstone and shale of Yerba Buena Island, through which the tunnel was driven, did not prove strong enough to support themselves while such a large opening was being driven, so a narrow arch-shaped slice was first taken out and ceiling supports were put in as the driving of the tunnel progressed. *Photo courtesy California Toll Bridge Authority and San Francisco Chronicle.*

posure of Franciscan chert. The chert is yellowish-white to red in color, and is thin-bedded and crumpled. Veinlets of quartz and carbonate minerals crisscross the formation. This is one of the few outcrops of Franciscan (Upper Jurassic) chert that resemble the chert and cherty shale of the Monterey (Miocene) formation, and which may be mistaken for them. A number of interesting metamorphic minerals may be found in schists near bodies of serpentine a quarter of a mile east of the aforementioned chert locality. The author has collected good actinolite, glaucophane, antigorite, and garnet from hillside exposures between Cutting Boulevard and MacDonald Avenue.

Continuing northward, Highway 40 passes over low bay-margin land through the municipalities of Richmond and San Pablo. Prior to the advent of the white man this area was rather thickly populated Indian country. Kitchen middens or shell mounds representing ancient and pre-Spanish Indian camp grounds have been found in several places between Albany and San Pablo, notably at Stege, which is a small way station on the Southern Pacific Railroad. After the coming of the Spanish, the region became part of Rancho San Pablo, the domain of Don Francisco Castro. Castro first lived in the vicinity in 1826 and had explored it as early as 1823, but the grant was not confirmed until after his death in 1831. Remains of two adobes built by members of the Castro family still stand. One is included in the restored building now occupied by El Rancho Restaurant at the junction point of San Pablo and Panhandle Boulevards in Albany. The other is in San Pablo at the intersection of San Pablo Boulevard and Church Street.

After leaving the town of San Pablo, Highway 40 crosses the northern extremity of San Pablo Ridge and passes through the San Pablo oil-tank farm. At the summit of San Pablo Ridge a series of road cuts exposes the first sediments of the Mio-Pliocene Orinda formation to be seen along Highway 40 eastbound. Poorly consolidated buff to whitish-gray silt, clay, and pebble conglomerate crossed by white caliche seams (thin stringers of calcium carbonate deposited in cracks by evaporation) make up the bulk of the formation at this point. The Orinda formation is widely distributed through the Berkeley Hills and in some places consists dominantly of coarse conglomerate. It represents river floodplain deposition on a continental land mass—not marginal marine deposition. Although fossils have not been found close to Highway 40, a great many have been collected from the Orinda formation in the bay area, so that a dependable age determination has been possible. Bones of horses, camels, and other vertebrates have been found, as well as many varieties of freshwater mollusks and ostracods. These indicate a lower Pliocene age for at least part of the formation.

The San Pablo tank farm of the Standard Oil Company, located a mile or two east of the town, affords storage facilities for crude oil coming into the great Richmond refinery from the central valley and

for refined products coming from the refinery. The large metal tanks occupy several square miles of rolling hill country and create a rather bizarre skyline on an otherwise pastoral landscape.

Half a mile beyond the most easterly tanks of the farm a long road cut exposes a good section of Orinda continental deposits. Like the less-well-exposed beds to the west of the tank farm, the Orinda here is composed of interbedded whitish-gray to buff sandstone, siltstone, clay shale, and pebble conglomerate, poorly indurated and strongly folded. The beds strike N. 55° W. and dip 75° to 80° N. Debris eroded from the pre-existing Franciscan and Monterey formations is readily identifiable in these rocks. Sandy and pebbly layers tend to be crossbedded on a small scale, a common feature of river floodplain deposits.

Half a mile northeast of the aforescribed road cut, a small hill or ridge rises abruptly from beside the south shoulder of Highway 40. A quarry face from which road fill was taken may be seen on the west side of the hill. The major Hayward fault passes through in a northwesterly direction close to the western base of the hill and displaces rocks of the Pliocene Orinda formation against the Claremont member of the Miocene Monterey formation. The Hayward fault is a very large structural break that can be followed from San Pablo Bay to a point a few miles southeast of the town of Gilroy in southern Santa Clara County, a distance of more than 100 miles. The hill also marks the first outcrops of Miocene rocks to be seen by persons northbound on Highway 40. In the rock quarry on the west side of the hill are good exposures of white diatomaceous shale interbedded with a few thin bands of siltstone. The shale contains not only the microscopic remains of diatoms, but also includes large numbers of molds and casts of small sea shells. The Miocene Claremont formation is, therefore, of marine origin, in contrast to the Orinda formation, which was deposited on land lying above sea level. The Claremont member of the Monterey formation is several million years older than the Orinda.

One and four-tenths miles east of the shale quarry are several good outcrops of white diatomite, a rock composed almost entirely of the siliceous remains of diatoms. The diatomite is light in weight, crudely bedded, and contains numerous fish scales and fish bones. The diatoms are too small to be seen in a hand specimen, but are readily identifiable under the microscope. Diatomite is best exposed on a low knoll north of the highway. Half a mile farther east the roadway drops down to the village of Pinole which is situated in a narrow valley bounded by faults. The faults follow in a northerly direction close to the base of the hills on either side of the town. The rocks lying beneath the soil cover in this vicinity are composed of fragmental material blown from the vent of an ancient volcano that was active in Pliocene time. The rock is best exposed along Highway 40 near the town of Rodeo. A high road-cut escarpment just west of Pinole



FIG. 29. A typical exposure of Pinole tuff (Pliocene) on San Pablo Bay half a mile west of Oleum, Contra Costa County. Volcanic ash layers are interbedded with sandy strata and lenses of coarse fragmental white pumice. Camera facing northeast. Carquinez Strait is behind the neck of land.



FIG. 30. John Muir home (April 1951) at Muir Station on the Franklin Canyon road (State Highway 4) two miles south of Martinez, Contra Costa County. California's great naturalist spent many of his declining years in this spacious house and grounds, and in them many of his great works were penned.

exposes greenish-buff, crudely bedded shale belonging to the Tice member of the Monterey formation. It strikes roughly parallel to the road and dips toward the north. Two oval concretions several feet in diameter are conspicuously developed in the shale on the north side of the road. Concretions form by migration of any of several water-soluble mineral materials toward a central point, followed by concentric deposition of crystalline material about that point. Iron oxide, calcium carbonate, calcium sulfate, and barium sulfate are materials which commonly are precipitated to form concretions. Round or oval concretions are most common, but these may coalesce to form weird shapes. The nature of the forces which cause migration of chemicals toward focal points to form concretions is not known.

The town of Pinole receives its name from Rancho El Pinole, the grant first made to Ignacio Martinez in 1829. Pinole is a name borrowed by the Mexicans from the Aztecs and signifies a meal ground from various grains or other seeds. Together with most other towns along San Francisco Bay, Pinole received its greatest growth during the last two decades, and is therefore identified more with post-war population increases than with the romance of the Spanish period.

Between Pinole and Rodeo various sandstone and shale members of the Monterey (middle Miocene) and San Pablo (upper Miocene) formations are exposed in road cuts and railroad cuts which more or less parallel the highway. A large exposure of the Rodeo shale member of the Monterey formation may be seen in the railroad cuts just west of the junction of Highways 40 and 4, a mile east of Pinole.

The town of Rodeo, situated on San Pablo Bay at the mouth of Rodeo Creek, was a camp site of the Pedro Fages expedition which explored much of Contra Costa County in 1776. Like San Pablo, Rodeo is situated close to installations of the oil industry and its interests are largely concerned with oil and with water transportation on San Pablo Bay. Miocene and Pleistocene beds in the vicinity of Rodeo are full of marine molluscan fossils and the area is a favorite invertebrate fossil collecting ground. Fossil sand dollars have even been found in Rodeo at the intersection of Third Street and Pinole Avenue! Railroad cuts along the bay from Rodeo to Oleum are also favorite spots for fossil collectors.

Half a mile east of Rodeo, a road cut exposes white rhyolite tuff composed principally of pumice fragments blown from a volcano. The tuff is very soft, porous, and light in weight. It occupies a syncline or downwarped fold which trends roughly west-northwest. It was deposited on the Miocene marine sediments, which outcrop nearby, during Pliocene time, after earth movements had brought the old sea floor above sea level.

Strung out for several miles along the highway east of Rodeo are the oil tanks and refinery installations of Union Oil Company's Oleum refinery. The bay front area from San Pablo to Crockett is attractive to heavy industry because of its deep-water dock facilities and convenient rail service. The area is served by both Southern Pacific and Santa Fe Railroads. In addition to the Union Oil installations and the Standard Refinery previously mentioned, the great Selby Smelter of

the American Smelting and Refining Company is located on the bay front northeast of Rodeo. Its 605-foot white smoke-stack is a landmark visible for many miles. Operation of the Selby smelter dates from 1885 when the first blast furnaces were blown in by the Selby Smelting and Refining Company. The Selby Company was later purchased by American Smelting and Refining Company, the present operators. The plant processes ores from all over the world, as well as from California. In addition to production of metals, much of the plant's blast-furnace slag goes to insulation manufacturers who re-fuse and then blow the molten slag into rock wool or fibre glass.

Half a mile west of the southern anchor point of the Carquinez Bridge, lofty road cuts expose strongly disturbed sediments which mark the trace of the Franklin thrust fault. The Franklin thrust diagonally crosses the highway in a northwesterly direction and causes rocks of Cretaceous age to be thrust up and over rocks which are many millions of years younger; in this case Upper Cretaceous rocks of the Chico formation have ridden up and over rocks of Tertiary age (Miocene Monterey and Paleocene Martinez). Within the fault zone the rocks are crushed and contorted, and bedding is nearly everywhere destroyed. Because of the disruption of the original rock structure by the fault, the Division of Highways has had to face some of the road cuts in the vicinity with concrete to prevent landslides.

Carquinez Strait, crossed by Highway 40 via the lofty, narrow Carquinez Bridge, joins San Pablo and Suisun Bays. It is the outlet



FIG. 31. Channeled, cross-bedded early Quaternary or late Tertiary tuffaceous sands on the Benicia Grammar School grounds, Benicia, Solano County. Camera facing east. A pronounced unconformity or old erosion surface (accentuated by upper dashed line) may be seen at the level of the tops of the basketball backboards; the lower channeled, cross-bedded rocks have been planed off by erosion and the upper flat-lying beds added during a later period. A second unconformity is also evident (lower curved dashed line) between the channel filling and lower rocks into which the channels were cut. A deposit of white pumice stands out at the extreme right of the picture, and cross-bedding, which is a common feature of stream and beach deposits, can be seen to the left of the white pumice.

for waters of both Sacramento and San Joaquin Rivers, which merge at a point a few miles northeast of the town of Pittsburg. Cretaceous molluscan fossils may be collected along the north bank of Carquinez Straits, a short distance east of the north end of the bridge. From the north end of Carquinez Bridge to well beyond Vallejo, the road-bed traverses a belt of Cretaceous marine sedimentary rocks which have been deformed into a series of broad folds whose axes trend northwest. Road cuts expose incomplete cross sections of these structures, whose directional trends can be traced across the landscape because of resistant strata which protrude above the soil cover. The strata consist predominantly of well-bedded brown sandstone and clay shale, but in some places the shales weather to a distinct blue-black color.

Vallejo, home of the Mare Island Navy Yard, is largely by-passed by Highway 40. General Mariano G. Vallejo planned to found a town near the present site as early as 1830, but the plan was not carried out until 1850. General Vallejo attempted to establish the town as the state capitol and for two short periods in 1852-53 it did serve as such. The Navy Yard was established in 1853, and is one of the first constructed on the Pacific coast.

Nine-tenths of a mile beyond the junction of Highways 40 and 48 a major fault cuts off the Cretaceous section and brings up a mixed group of Upper Jurassic Franciscan rocks. The fault crosses the highway in flat country, so that the fracture zone is only apparent in a few obscure road cuts of limited size. A few hundred yards south of the highway, on the hillside above the valley floor, an old quarry exposes steeply dipping contorted red chert. This rock was originally formed by chemical precipitation of silica introduced into sea water by volcanic activity. Remains of star-shaped microscopic marine organisms (radiolaria) found in the rock show its marine origin. Other quarries and surface outcrops in the vicinity expose serpentine and silica-carbonate rock as well as gray-green sandstone. Serpentine is the hydrated, altered product of peridotite intruded after the cherts and sandstones were deeply buried. Silica-carbonate rock is the product of alteration of serpentine by the rise of carbonate-rich water along an old fracture system. Veinlets of green, microcrystalline quartz called chrysoprase are common in silica-carbonate rocks in a quarry situated close to the highway near the top of the ridge.

A few hundred yards down the other side of the ridge, rocks exposed in the road cuts change abruptly from serpentine and mixed Franciscan rocks to brown sandstone and shale of probable Cretaceous age. The break marks the crossing of another major fault. The ridge just passed is, therefore, a horst or upthrown fault block. Slightly more than a mile east of the fault last mentioned, the rocks exposed are light-colored, poorly lithified sandstones of Eocene age. Near the

bottom of the grade landslides can be seen on both sides of the road. The relation between these and the rocks to the west is not known.

Highway 40 continues northeastward down American Canyon, largely through sandstones of Eocene age, and then passes across the alluvial plain toward Fairfield.

The junction point of State Highways 40 and 12 (the Santa Rosa road) is at the confluence of Jameson and American Canyons 7 miles west of Fairfield. Jameson Canyon serves as a pass for both the Jameson Canyon (Santa Rosa) road and the Southern Pacific Railroad. A mile farther toward the northeast, Highway 21 (from Benicia) joins Highway 40. On the plain to the east of this junction point are several buttes of flow lava and fragmental material (tuffs) blown from ancient volcanoes. The rock of the largest of these buttes is quarried at the Cordelia quarry for crushed rock, and a crusher is in operation on the southern end of the butte, but a lofty road cut at the north end of this butte exposes white tuffs only. The volcanic rocks have been named the Sonoma volcanics; they are Pliocene in age. Continuing northeast over the Fairfield plain, the Fairfield by-pass, completed in the summer of 1949, allows the heavy Sacramento traffic to escape the congested part of town.

Fairfield, the county seat of Solano County, lies in the heart of a rich agricultural district devoted to fruit orchards and livestock grazing. The town dates from 1859 and has been the county seat from its inception; it was named from the birthplace (Fairfield, Connecticut) of its founder, Capitan C. H. Waterman.

Northeast of Fairfield, the route crosses a series of northwest-trending parallel ridges partly buried by alluvium. In these low ridges, and in the more rugged country to the north, the strike and dip of the folded strata can plainly be seen for some distance across the landscape. The thick beds of weather-resistant sandstone are easily followed with the eye, some for several miles. The most westerly ridge consists of Cretaceous strata; those to the east consist of Eocene strata which lie on top of the Cretaceous. The entire section is folded into several synclines and anticlines.

Four miles beyond the eastern turnoff to Fairfield (or 1 mile west of the Vacaville road junction) is an historic adobe structure on part of which a more recent frame shed has been erected. This is the ruin of the Juan Felipe Demitrio Peña adobe built in 1842 on the old Los Putos Spanish grant. The latter was given jointly to Manuel Cabeza Vaca and Juan Felipe Peña in 1841. The nearby town of Vacaville was named in honor of the Vaca family.

There are no rock outcrops in the Sacramento Valley until the vicinity of Rocklin, near the Sierra foothills, is reached. The valley rocks are covered with Pleistocene and Recent alluvium and soil. The subsurface structure is essentially synclinal and most of the dips recorded in drilled wells are gentle.



FIG. 32. Elkhorn Ferry, near Woodland, Yolo County, one of the few ferries operated by the State Highway Department. Ferry carries three cars. An upstream cable holds the boat on its course and the ferry is moved by cables and a power winch. *Photo courtesy San Francisco Chronicle.*

Highway 40 passes through rich farming lands which are among the most prolific in the state. The Agricultural College of the University of California, located at Davis, is only a mile or two north of the route. Across the river from the City of Sacramento, rich lands have been reclaimed from marsh by building levees. During flood periods the waters of the Sacramento River are allowed to cover these low lands, partly to ease flood damage and partly to replenish underground water supplies. Many hundreds of acres of this lowland are peat-covered and these have proven exceptionally rich. Huge tonnages of rice and other cereals are produced on peat soil. Peat has, in some places, accumulated in sufficient depth and purity to be valuable for horticultural use, and mining of California peat for that purpose is steadily increasing. Peat lands have been known to catch fire and smolder undetected for long periods, only to break forth suddenly and seriously damage crops and dwellings.

The Sacramento River system is a sportsman's paradise. Waterfowl are plentiful in season, and the rivers are well stocked with fish. Ring-necked pheasants introduced from China have increased so greatly as to be a nuisance in some places. Large numbers of boating enthusiasts ply the river systems and bayous. The Sacramento River is navigable for ships of moderate draft, and water freight still comes into Sacramento from the port of San Francisco by this waterway, in spite of the competition of truck and rail transport.

The City of Sacramento, which clusters about the State Capitol, is rapidly expanding its suburbs into the picturesque oak-covered country lying to the northeast. Initiated in 1839 as the principality of New Helvetia by Captain John A. Sutter, Sacramento experienced many of the gold-rush growing pains through which San Francisco passed. Prior to the gold rush, New Helvetia was an important supply point for overland wagon trains of the pre-gold-rush immigrants. The present town of Sacramento was laid out on Sutter's old holdings, and lots were first offered for sale early in 1849. Sutter's Fort, now completely restored and set in beautiful park grounds, stands at the corner of 26th and L Streets. Ivy-covered concrete walls 18 feet high surround the various restored buildings in which are housed relics of early days in California.

The development of the second story architecture in the older sections of Sacramento has been attributed to occasional flood rampages of the nearby American River. Stairways in these old houses lead to the second floor, where porches and entryways are developed, instead of on the ground floor. Old Sacramento enjoys the deep shade of great numbers of fine elm trees which are very welcome to tourists and residents alike during the hot summer months.

#### OAKLAND TO BYRON VIA BROADWAY TUNNEL AND MARSH CREEK ROADS

The approach to Broadway Tunnel Road may be made by way of either Ashby Avenue (State Highway 24) and the Claremont Hotel in Berkeley, or along Broadway from downtown Oakland. The Oakland-to-Byron route offers a fine close-up view of the structure in the Berkeley-Oakland Hills, and parking space is available near most points of interest.

From the Claremont Hotel, Highway 24 passes south along the base of the Berkeley Hills as far as the Broadway Tunnel Road viaduct, after which it turns east and coincides with Broadway Tunnel Road. Between the Claremont Hotel and Tunnel Road, the route lies directly above the Hayward fault zone, the latter being a major structural feature along the west side of the Berkeley-Oakland hills. The fault has definite topographic expression in some places, and commonly marks the north-south boundary between Cretaceous and Franciscan rocks. In this sector Franciscan rocks erop out west of the fault and are not seen east of it.

Seven-tenths of a mile south of Claremont Hotel a series of extensive quarry faces expose a rusty-looking volcanic rock of Pliocene age known locally as the Leona rhyolite. The fresh rock is white, bluish-gray, or greenish-gray, and has a very fine-grained porcelaneous groundmass in which small pyrite, feldspar, and quartz crystals are set. These crystals are seldom more than 1 millimeter in longest dimension, but pyrite crystals may be grouped together in metallic brass-yellow blebs. The quarries are close to the Hayward fault zone and



FIG. 33. The landslide of December 9, 1950, on Tunnel Road (State Highway 24) between Oakland and Orinda. Trees brought down in the slide and the earth moving equipment in the right foreground give some idea of the magnitude of the slide. Rock exposed in the road cut in the extreme left center of the picture is steeply west-dipping basalt of the Moraga volcanic series; rock to the right of the toe of the slide is gently east-dipping gravel and sand, probably part of the Orinda formation. Slide material was principally clay and gravel but some basalt came down too. The slide is at the axis of a faulted anticline. The State Highway Department spent almost seven months removing the slide from highway and hillside and placing drainpipes to reduce chances of another slide. The highway was almost completely blocked for several days and the temporary by-pass was a bottleneck on the heavily travelled highway for many months afterward. *Photo by Bill Young, courtesy San Francisco Chronicle.*

much of the rhyolite is badly shattered. This shattering is partly responsible for the advanced degree of weathering which most of the rhyolite shows, the broken condition allowing extensive penetration by groundwater. Another factor controlling weathering and decomposition is the large amount of pyrite the rock contains. Groundwater carrying dissolved oxygen, carbonic acid, and other soluble chemicals readily decomposes pyrite, forming sulfuric acid, iron sulfate, and oxides of iron. Sulfuric acid and iron sulfate further decompose the rock, and iron oxide is deposited in every crack to give the rusty appearance shown by most rock specimens. Unweathered specimens can be obtained, however, along Old Tunnel Road at the east end of the quarry. The lofty quarry faces from which so many millions of tons of fill rock have been taken were excavated chiefly during 1943-44 by the Macco Construction Company. The fill rock went to form dock installations at the Port of Oakland.

Approaching Broadway Tunnel from Oakland along Broadway, good exposures of rocks of the Upper Jurassic Franciscan formation may be seen in road cuts and along the ridge between Keith Avenue and Lake Temescal. The predominant rock is a greenish-gray massive sandstone cut by numerous veinlets of calcite and quartz, but some red chert, shaly layers and an occasional layer of pebble conglomerate are interbedded with the sandstone. The Franciscan formation is cut off at Lake Temescal by the Hayward fault and does not appear again along this route until Mount Diablo is reached.

East of the Tunnel Road viaduct and the Pacific Gas and Electric Company power station, rusty brown Leona rhyolite is exposed discontinuously on both sides of the road for several hundred yards. The rhyolite is then cut off by a fault which roughly parallels the Hayward

rift. The fault zone is partly obscured by landslides, but an abrupt change in the character of the rocks is noticeable. Brown, weathered rhyolite gives way to crumbled brown and black shale containing sandstone blocks and short segments of sandy strata. The shales are probably Upper Cretaceous in age, but no formational name has been assigned to them. Where structure is discernible, the Cretaceous rocks dip steeply toward the east. There are several other exposures of Cretaceous rocks west of Broadway Tunnel, chiefly massive yellowish-brown sandstone. Just west of the west portal of the tunnel, the Cretaceous rock section is succeeded by Miocene sandstone and shale of the Monterey group of formations. The contact is not exposed, but is assumed to be unconformable; that is, an ancient erosion surface separates the two rock groups.

Because of the concrete lining, the very interesting cross section through Skyline Ridge that the tunnel once afforded, is no longer visible. The Miocene sandstones and shales are succeeded by the Miocene cherts which are exposed above along Skyline Drive, and then by conglomerate, sandstone and mudstone of the Mio-Pliocene Orinda formation. Although the rock formations get progressively younger as one travels east through the tunnel, the strata all dip toward the west at angles averaging 65 degrees. It is therefore concluded that the once-horizontal series of strata has been tilted to vertical position and then overturned some 25 degrees, and that the sequence is thereby reversed from its original order.

Driving of the tunnel proved to be a very costly undertaking because of the low strength of some of the rocks encountered, because of faults, and because of the irregular distribution of weak rocks. The chert section is literally riddled with altered diabase intrusions which

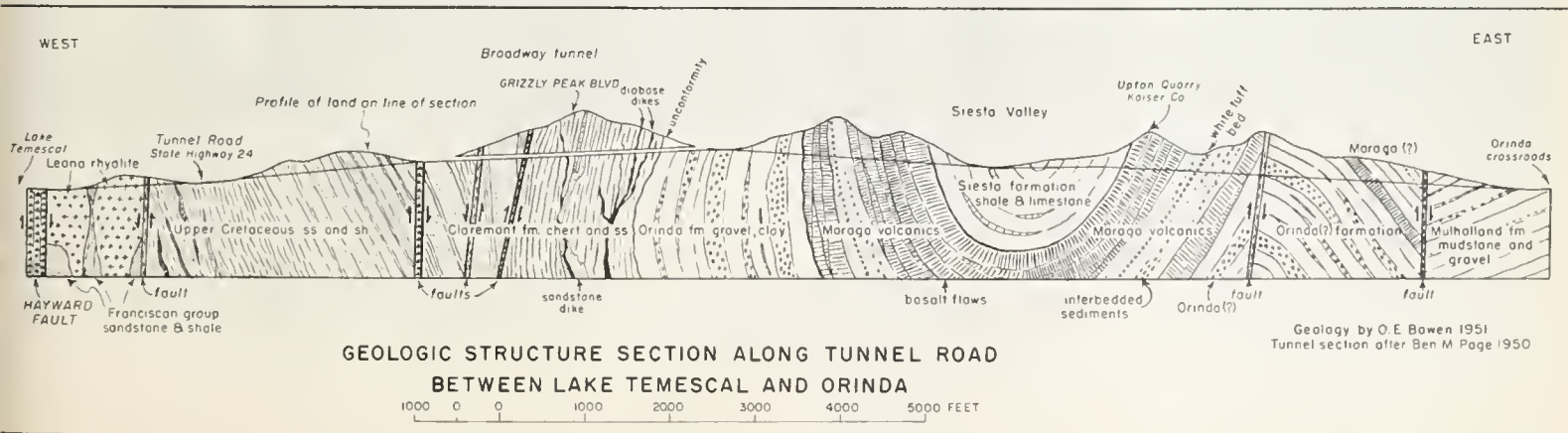


FIG. 34. Structure section along Tunnel Road.





FIG. 35. Panorama east across the Oakland Hills, Mount Diablo on the horizon and Upper San Leandro Reservoir in the foreground. Rocks in the immediate vicinity of the lake are dark marine Upper Cretaceous shale and lighter-colored sandstone; those in the grass-covered middle strip are chiefly lower Pliocene continental gravel and clay. The more rugged brush-covered ridge in the back middle distance, on which the beds faintly outcrop, is chiefly upper Miocene marine sandstone and shale. Mount Diablo itself is a piercement of mixed rocks of the Franciscan group, chiefly graywacke, greenstone, and chert. Tilted Miocene and Pliocene beds are exposed south of the mountain, Eocene and Cretaceous beds to the north and east. *Photo by Commercial Photo and View Company, courtesy East Bay Municipal Utility District.*

behave much like clay, and two fault zones, probably representing segments of the Wildcat fault system, produced landslides. These fault zones are located approximately 430 and 760 feet, respectively, from the west portal of the tunnel. In general, the rocks encountered underground were weaker than was indicated by a study of their surface exposures.

Passing out of the tunnel to the east, dark red and yellowish clays and greenish gravels of the nonmarine Orinda formation may be seen in road cuts on both sides of the highway. These strata, like those through which the tunnel has been driven, trend roughly north, but are standing vertical. This attitude is maintained in the Orinda formation for a quarter of a mile, and then the sedimentary rocks are succeeded by a thick series of basalt and andesite flows locally called the Moraga formation. The Orinda and Moraga rock groups are Mio-Pliocene in age; that is, they began to be deposited at the end of the Miocene epoch and continued to be deposited during lower Pliocene time. The Orinda formation has yielded a good many scattered fossil bones of land mammals that serve as time markers. The contact of the Moraga lava flows with the Orinda formation is marked by a bright red zone, the result of the baking action of hot lava.

Eastward along the route the basalt flows slowly change attitude and show decided though steep dips to the east. Dips gradually become less and less in that direction, as the trough of a U-shaped fold is approached. The approximate bottom or axis of this fold is the center of Siesta Valley. The Moraga volcanic series, which begins at the base with a series of dark flows, can be seen to consist of some interbeds of clay and gravel similar to those in the Orinda; but the sequence remains predominantly volcanic. Yellowish-white water-laid rhyolite tuff beds are conspicuous in several horizons, and one thick, light-colored bed of this nature forms a prominent marker easily followed even when exposures are poor. On the other side of Siesta Valley the same marker bed appears again but dips in the opposite direction. It is by such markers that the geologist is able to reconstruct major geological features, even if only parts of them are exposed.

Eight-tenths of a mile from the east portal of the tunnel the highway comes out of a canyon and crosses narrow, upland Siesta Valley, which is being drained and rapidly eroded by the west branch of San Pablo Creek. As Siesta Valley has been worn into soft sediments of the Siesta formation, and as San Pablo Creek is rapidly undercutting this soft material, great landslides have developed that encroach into San Pablo Creek Canyon from both sides of the highway. These have not moved in recent years and are somewhat overgrown; but they might move again during excessively rainy seasons. Half a mile farther east, soft material from a sedimentary member of the Moraga formation gave way on the morning of December 9, 1950, sending many thousands of cubic yards of mud down the hill and across the

road, blocking all but a single lane at the eastern shoulder of the road. Landslide forms are common all through the Berkeley Hills.

Owing to the landslides in Siesta Valley, the Siesta formation is exposed to view along the highway only at the valley borders, where the lowermost strata lap onto the resistant lava ridges. At these points the Siesta rocks resemble those of the Orinda formation, but elsewhere in the Siesta formation there are yellowish-white tuffaceous lake beds and grayish-white fresh-water limestones different from anything in the Orinda formation. The Siesta formation is lower Pliocene in age and is really part of one depositional and volcanic sequence that began at the end of the Miocene with deposition of the lowest Orinda beds and continued well into middle Pliocene with deposition of the Mulholland formation.

The rugged eastern ridge bordering Siesta Valley is made up predominantly of volcanic rocks like those west of the valley and, in fact, is a continuation of the same series; it has merely dipped under the floor of Siesta Valley and come out on the other side. The Upton rock quarries operated by Kaiser Company are driven in Moraga volcanic rocks. The road to Upton quarries leads off to the south along the east side of Siesta Valley.

After passing through the west-dipping volcanics east of the Upton road, the upturned edges of the Orinda formation should again be crossed; actually, however, they cannot be seen. Beyond the volcanic rocks a landslide covers the old road cuts; then come volcanic rocks and interbedded sediments dipping east at a low angle. The landslide obscures the crest of an arch or anticline, and the Orinda formation either has not been upwarped high enough to be exposed or else the antighinal crest is faulted.

Two-tenths of a mile west of Orinda Crossroads extensive road cuts expose yellowish and greenish silts, clays, and gravels similar to parts of the Orinda formation, and once considered to belong to that formation. However, sufficient fossil mammal bones have been found in recent years to establish the beds as younger than the Siesta and Orinda. A comparison of the structural attitudes of the younger beds and the adjacent Siesta, Moraga, and Orinda indicates that a fault must separate these rock groups even though its trace is not evident. Structural relationships will be most easily understood by looking at the accompanying cross section (fig. 34) drawn along the line of Highway 24.

Orinda Crossroads is rapidly becoming the supply and transportation center for the series of fashionable suburban districts known collectively as Orinda. Orinda Crossroads was once called Bryant, and so appears on old maps. It is the connecting point with Moraga and Saint Marys College on the south, and Orinda Village, Wildcat Canyon, and Tilden Park on the north. The Wildcat Canyon Road

winds along the edge of picturesque San Pablo reservoir for several miles.

Between Orinda and Lafayette the highway passes over gently tilted sands, clays, and silts originally mapped as part of the Orinda formation. In the light of present knowledge concerning the Mulholland fauna it appears possible that several different age groups of rocks may be included, but a section of Mulholland sediments several thousand feet thick is present. The structure is hard to follow as seen along the highway, but there are several folds.

Lafayette lies in the heart of Rancho Acalanes, originally granted to Candelario Valencia in 1834. Title to the rancho was acquired by Elam Brown, a New Yorker, in 1846. He erected buildings near Lafayette in 1847. Another prominent early settler in the vicinity of Lafayette was Nathaniel Jones, who founded Locust Farm on a subdivision of Rancho Acalanes purchased from Brown. The town itself gradually took shape during the fifties, around the present plaza. One of the pioneer churches of Contra Costa County, erected on "Golden Gate Way" about 1855, has endured through the years, although the present Community Church occupies a different site and buildings. Prior to the coming of the white man, a large Costanoan Indian village called Akalan existed in the Lafayette vicinity. The name Acalanes is believed to have been derived by the Spanish Californians from the name of this village.

Between Lafayette and Walnut Creek rock exposures are not plentiful. The Pliocene rocks are succeeded by Miocene sandstones and siltstones of no particular interest. Two large thrust faults traverse the area in a northwesterly direction, one crossing the highway in the vicinity of the Lafayette business district, the other crossing through the west edge of Walnut Creek in the vicinity of the Mount Diablo Boulevard and Dewing Lane junction point. Neither fault has discernible features close to the highway.

The vicinity of Walnut Creek was first settled by David Glass, a Pennsylvanian, in 1850; but Glass is better identified with San Ramon where he permanently settled 9 years later. James T. Walker settled in nearby Ignacio Valley in 1851. Walnut Creek town was laid out in the late fifties by Homer Shuey. Perhaps the oldest public building still standing is the old Methodist Church located on Locust Street a block north of Mount Diablo Boulevard. It was erected in 1872 on a lot which originally fronted on Main Street. The pioneer church is still active, but has been moved to a new location on Sunnysvale Avenue.

Fossil localities are numerous in both the business and residential districts of Walnut Creek. Miocene sea shells are found in sandstone exposed along Locust Street just across from the Safeway Store; in road cuts near Farmers Feed and Supply Company's establishment on Railroad Avenue; along the railroad right-of-way near the junction of Danville Highway and Rudgear Boulevard; and in countless

private yards in the Saranap district. Relics of ancient man are also found from time to time in the Walnut Creek-Concord vicinity. An Indian burial ground excavated by the University of California Department of Anthropology in 1946 at a site located at 21 Gregory Lane, Concord, yielded numerous bones and artifacts estimated to be from 1500 to 3500 years old, or possibly older. Fossils in stone have become common ornaments in Walnut Creek gardens.

The origin of the black walnut trees found along the banks of Walnut Creek is a debatable point among botanists. They are certainly pre-Spanish, and are found largely where Indians are known to have had extensive rancherias or camp sites. They are somewhat different from the southern California black walnut trees supposedly native to California, but may have developed from them from seed brought in by the Indians.

At the new Civic Center in Walnut Creek we shall leave Highway 24 and cut across Ignacio Valley to the Marsh Creek road. The turnoff is 4 blocks north of the "T" junction point of Highways 24 and 21. Much of the Ignacio Valley Road is through flourishing walnut groves which are a sea of green in summer. Beneath the trees, bright yellow fields of mustard spread like carpets in winter and in early spring before the leaves are back on the trees.

Three-fourths of a mile east of the Civic Center, the road crosses a ridge of sandstone belonging to the Miocene San Pablo group. A number of prominent ridges formed by the upturned edges of hard sandstone may be followed by the eye to the very foot of Mount Diablo. These prominent ridges also have numerous fossil localities. The strata in part are the same as those exposed in Walnut Creek, as they dip beneath San Ramon Valley into a syncline and come up again on the west side.

The ridged highland separating San Ramon and Ignacio Valleys is devoted to cattle grazing and race-horse breeding. The orderly white paddocks and green meadows of the Heather Horse Farm add an eastern touch to the western scene.

Three and three-tenths miles from the terminus of the Ignacio Valley road in Walnut Creek is the junction point of one of the two routes that lead to the summit of Mount Diablo. The other route comes from Danville on Highway 21. It is about 15 miles to the summit of the mountain by either route. Mount Diablo is a sort of geologic freak. The core of the twin-peaked mountain consists of jumbled massive rocks of the Franciscan formation which literally have been punched through the once-overlying Cretaceous and Miocene formations from below. Upturned edges of these ruptured formations flank the mountain on every side, and a large fault zone can be followed around its base. Standing by itself at a height of 3849 feet above sea level, the mountain has been a guiding landmark since the coming of the Spanish, and probably was used by the Indians long before that time.



FIG. 36. Main Street, Walnut Creek, Contra Costa County, as it was about 1915. Now the hub of one of the fastest growing areas in the east bay, Walnut Creek bears little resemblance to its leisurely past as this north view, taken approximately from the Mount Diablo Boulevard intersection, attests. *Photo courtesy Pacific Gas and Electric Company.*

In 1851 it was chosen as the principal reference point for the United States land surveys in central California, and the base and meridian lines established during the surveys pass through its summit. The summit and upper slopes of Mount Diablo became a state park in 1931, and picnicking and camping facilities have been provided. The magnificent view from the mountain top is enjoyed by hundreds of thousands of visitors each year. On a clear day, peaks in the Sierra and Cascade Ranges are readily visible, as well as distant points in the Coast Ranges such as Mount St. Helena and Mount Hamilton.

Continuing across Ignacio Valley one can see the great scars in the hills to the east that mark the abandoned quarry operations of the once-flourishing Cowell cement plant. Limestone deposits which supplied the plant originated by precipitation from hot springs and did not extend very deep into the hillside. The deposits were far more superficial than their surface area indicated, and were exhausted after 38 years of exploitation. The plant, still standing just over the hill at the village of Cowell, was constructed in 1908. The limestone, although deposited in recent time, geologically speaking, was laid down on rocks of middle Eocene age. The source of the lime-laden water from which the limestone was deposited may have been the same deep-seated volcanic source which gave rise to the quicksilver deposits on the east side of Mount Diablo.

Two miles east of the Ignacio Valley-Marsh Creek road junction, the Kirker Pass route to Pittsburg joins the Marsh Creek road. The Kirker Pass road crosses folded sedimentary rocks of Cretaceous, Eocene, Oligocene, and Miocene age; but only the blue sandstone of the San Pablo group, which gets its characteristic color from an opaline cement deposited on and between the sand grains, is well exposed along the way. San Pablo group rocks are best exposed three-tenths of a mile north of the Kirker Pass-Nortonville road junction where a series of quarries have been cut into unweathered rock.

An interesting side trip through the pioneer coal mining districts of Nortonville, Somersville, and Stewartsville may be made via the Kirker Pass road by turning right up Kirker Canyon at a point 4.5 miles from the Marsh Creek road. This route is paved from Kirker Pass to Nortonville; is a winding dirt road to Somersville; and, leaving by Markley Canyon, is paved from Somersville on to Pittsburg. Through Kirker Canyon, a V-shaped pass largely barren of vegetation, the road passes between two ridges of Eocene strata. Their dip and directional trend, or strike, is well shown by shale and sandstone strata which stand out in relief from the hillsides. In several places sandstone members contain large spherical concretions resembling cannon balls.

The site of Nortonville is now located principally by the sand-loading dock, a structure built in the nineteen-thirties long after the town had been abandoned. Hardly a vestige of the early buildings re-



FIG. 37. Aerial oblique photo of Mount Diablo, camera facing east-northeast from a point above the Black Hills east of Alamo. The indistinct beds in the foreground are upper Miocene sandstone; those prominently exposed near the middle of the photo are sandstone of middle Eocene age. *Photo by Clyde Sunderland, Oakland.*



FIG. 38. Aerial oblique photo of Mount Diablo, camera facing northeast across the San Joaquin Valley. North Peak is hidden behind the main peak. Meandering San Joaquin and Sacramento Rivers may be seen in the middle distance; the snow-capped Sierra Nevada is on the skyline. Heavy bedded sandstone in the foreground is upper Miocene in age. Other rock groups are not easily detected in this photo. *Photo by Clyde Sunderland, Oakland.*



FIG. 39. State Park building on the summit of Mount Diablo built of fossiliferous upper Miocene sandstone of the San Pablo group. Photo (1939) by Bob Campbell, courtesy *San Francisco Chronicle*.

mains, although the multicolored mine and furnace dumps are still there. Nortonville had its beginning with the opening of the Black Diamond and Cumberland coal mines in 1860, and had its heyday between 1867 and 1890. It was connected by rail via Kirker Canyon with New York Landing, located at present-day Pittsburg. Pittsburg at that time was called Black Diamond. Rising mining costs, a serious mine disaster in 1876, and increasing competition from fuels from other states resulted in abandonment of the Nortonville coal mines in 1882. Although a small amount of coal was mined at Nortonville in 1932, many unfavorable economic factors have prevented a large-scale reopening of the deposits, even though substantial reserves are left underground. White silica sand associated with the coal was mined for foundry use during the nineteen-forties, but the sand mines are also currently idle.

Leaving Nortonville, the Somersville road traverses the old mine dumps and crosses Nortonville Pass, a high saddle separating the basins in which Nortonville and Somersville were located. The old mine dumps and even the smutty coal outcrops may be seen on hillsides west of the road that drops down toward Somersville from the summit of the pass.

The only good link with Somersville's past is the forlorn yet picturesque cemetery located two-tenths of a mile down from the summit of Nortonville Pass. Few historic spots in California have been as badly vandalized as the Somersville Cemetery, but a great deal has been done by the Native Sons and Daughters of the Golden West and other organizations to restore the damaged gravestones. Most of the names recorded in the cemetery are Welsh. A few cypress trees and several bird-of-paradise plants have thrived on the cemetery grounds, but the surrounding hillsides are desolate except when springtime covers them with a blanket of grass.

The amphitheatre below the cemetery, which is formed by coalescing tributaries of Markley Canyon, is the site of old Somersville. The town had its beginning with the opening of the Pittsburg coal mine in 1860. The other principal nearby mines were the Manhattan, Eureka, Union, and Independent. The rise and decline of Somersville more or less parallels that of Nortonville, but coal mining persisted at the former until 1902. Somersville was connected by rail via Markley Canyon to Pittsburg Landing, the water-shipping point for the Somersville mines. Segments of the old railroad bed are still visible in Markley Canyon. Little remains of the town except mounds representing old building foundations and several small wooden buildings. All the principal structures have disappeared.

East from Somersville a dirt road connects with three other mining camps, Stewartsville, Star Mine, and West Hartley. Their histories are much like those of Nortonville and Somersville, but their mines did not produce a very large amount of coal. Stewartsville, like Nortonville and Somersville, had its railroad connection with water-shipping facilities. The dock was at Antioch.

The geology in each of the coal mines of the Mount Diablo district is much the same. The coal beds are invariably associated with white sandstone and impure coaly beds, all of middle Eocene age. These are essentially the same in character, were formed under similar subtropical conditions to the coal-sand-clay formations of Amador and other Sierran foothill counties, and are approximately of the same age. Many geologists consider the Mount Diablo coal measures to be part of the Ione formation of the Sierra Nevada, but the two rock groups cannot be traced continuously across the Great Valley. In the Mount Diablo district the coal-bearing strata dip northeast at angles averaging between 20 and 30 degrees. Two coal horizons were extensively mined, the Clark vein and the Black Diamond vein. The Clark vein proved most profitable because it occurred within sandstone walls which were relatively stable and did not require expensive timbering. The coal varied from 2 to 7 feet in thickness, averaging about 2½ feet throughout most of the distance mined. The Black Diamond vein, on the other hand, occurs in very dangerous ground, as there is much



FIG. 40. Aerial view of the old coal-mining town site of Nortonville taken in 1938, camera facing south toward the base of Mount Diablo. The two mine dumps in the narrow canyon to the left of the center of the photo mark the caved entrances to two of the old workings. The low brush-covered ridge to the left of the smoke stack hides the entrance to one of the adits that is still accessible. Both the brick smoke stack and the small building in the principal mine-dump area have been demolished for the brick they contained. Since this photo was taken many thousands of tons of high-silica sand were mined from weakly cemented strata to the left of and beneath the narrow canyon floor below the two mine dumps. A partly caved stope and glory hole lead from the east side of the canyon to the floor of the next canyon east. *Photo by Clyde Sunderland, Oakland.*





FIG. 41. Nortonville in the late 1870s, camera facing west across School Hill. Steepled building at the foot of the hill in the right middle ground is Nortonville Grammar School. The extensive mine dumps and trackways leading to them from the Black Diamond mine are prominent in the left foreground. *Photo courtesy W. F. Jones, San Francisco.*

elay, shale, and impure coal both above and below the good coal. Although the coal breaks free of the walls, the walls are weak, hard to support, and tend to swell upon exposure to air.

The Mount Diablo mines added very materially to the wealth of California during the pioneer period. Nearly 3,000,000 long tons of coal were mined and sold for a little more than \$15,279,000. This is a very creditable showing, more so than that of many a metal-mining district in the state. Although it is doubtful if California coal can compete with California oil as a fuel in the foreseeable future, the mineral resources of the Mount Diablo district may still be economically important. The white sand associated with the coal has been produced from time to time at Nortonville and Somersville for glass and for steel-casting and refractory purposes. The coal may again become important for conversion to wax, fertilizer, coal-tar products, and by-product fuels such as briquettes.

Leaving the Somersville vicinity by Markley Canyon, the road crosses more Eocene rocks somewhat younger than those that contain the coal measures. In the narrowest part of the canyon, good exposures of the Miocene San Pablo formation may be seen on both sides of the road. One cliffed outcrop of conglomerate contains numerous molluscan fossils somewhat like those to be seen on the rocky

California beaches today. The fossils are so close to the road that one can reach out and touch them without getting out of the car.

The Markley Canyon road ends at the Antioch-Camp Stoneman road, which in turn intersects with the Kirker Pass road south of Pittsburg.

Returning to the main route down Marsh Creek Canyon, one comes to the village of Clayton, which also had its beginning with the opening of the Mount Diablo coal mines. It acted as a junction point for traffic heading to the mines from overland points in the east bay region. The Whitney Survey party, one of the earliest to study the geology around Mount Diablo, camped near Clayton in 1862. Ninety years before, the country had been explored by the Pedro Fages party of 1772. Present-day Clayton, sheltered by a great grove of eucalyptus trees, is the home of Mount Diablo Ranch, a vast cattle and fruit holding. The postwar expansion so noticeable in towns farther west has not yet reached Clayton.

Rocks exposed between Clayton and the junction of the Marsh Creek and the Riggs Canyon road to Livermore are highly tilted brown shales and sandstones of Lower Cretaceous age. On higher ground west of the Marsh Creek road, they are in fault contact with

rocks of the Franciscan formation which make up the core of Mount Diablo.

The east and northeast slopes of Mount Diablo's North Peak remain a wooded primitive area covered with oak, buckeye, scrubby coulter pine, and chaparral. Rugged terrain of this sort extends south nearly to Livermore, and the attractive wilderness area is penetrated by a fair dirt road that follows south via the South Fork of Marsh Creek and Riggs Canyon. Happy Hollow, 2.4 miles southeast of Clayton on the Marsh Creek road, and Curry Creek Park located in Curry Canyon just off the Marsh Creek-Livermore road 6.6 miles from Clayton, offer resort facilities for those who seek vacation lands not too far from the bay cities.

Open cuts of the Mount Diablo quicksilver mine can be seen west of the road 4 miles southeast of Clayton. The entrance to the mine properties is near the Marsh Creek-Livermore road junction from which the mine buildings and workings can be seen. The mine, originally called the Ryne, was first active between 1875 and 1877. Within this period production ran as high as 75 flasks per month and between \$100,000 and \$200,000 must have been realized. Recorded production between 1930 and 1950 was slightly in excess of \$1,451,000, giving a

total production for the mine of well over \$1,500,000. Early-day workings were entirely underground and some underground mining was done in the early nineteen-thirties; these workings reached a depth of 165 feet. Since 1936, however, mining has been by large-scale open-cut methods capable of handling and processing low-grade surface ore. The ore bodies are in porous opalized serpentine of the Franciscan formation, locally called "quicksilver rock." Ore minerals are red cinnabar and black metacinnabarite, both sulfides of mercury. With only local exceptions, the ore minerals are disseminated through the opaline rock and are not conspicuous in hand specimens. The yellowish iron sulfide minerals marcasite and pyrite normally are more easily seen than the mercury minerals. Drusy and chaledonic quartz are commonly present, as well as opal. The Mount Diablo mine, although currently idle insofar as quicksilver production is concerned, is still capable of producing substantial amounts of the metal, a valuable asset during the present war emergency. Bradley Mining Company, the current lessee, produces crushed rock and fill rock of large dimensions from quarries located a mile northwest of the Mount Diablo mine.

East of Mount Diablo the route follows the course of Marsh Creek for almost 7 miles. The landscape is typical of the drier parts of the



FIG. 42. Nortonville in 1949. This is almost the same view as figure 41. Even the small brick building near the center of the picture has disappeared since this photo was taken. The tilted strata in the hillside are sandstones near the base of the Markley formation (upper Eocene). *Photo by Bob Campbell, courtesy San Francisco Chronicle.*

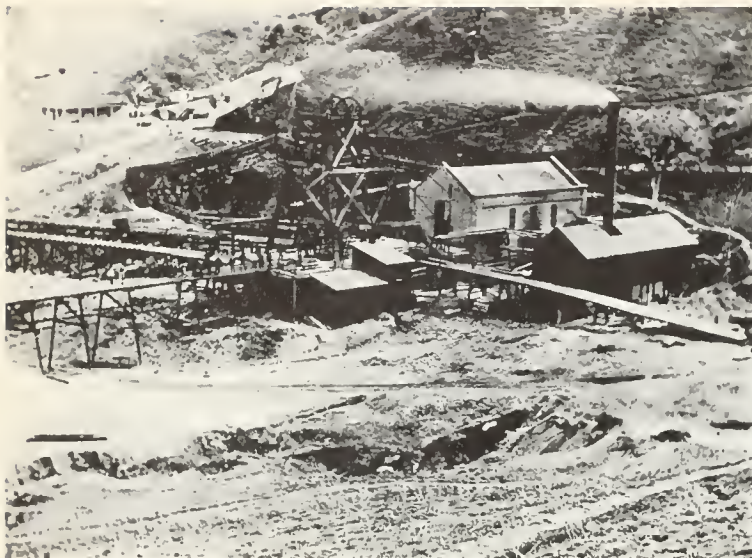


FIG. 43. Headframe, boiler house, and hoisting-engine building used to work the Black Diamond coal vein at Nortonville. The trestles were used to carry the one-ton coal cars to the bunkers. Home of Morgan Morgans, mine superintendent, is on the level spot to the left of the headframe sheaves. *Photo taken about 1880 and reproduced through courtesy of W. F. Jones, San Francisco.*

California Coast Ranges. Tall sycamore trees with their handsome mottled gray-and-white bark line the watercourse of Marsh Creek. The creek usually is dry during the summer months except for scattered pools where the white-faced cattle drink. Except for small farms in the narrow bottom-lands, cattle grazing is the chief pursuit in the region, as it has been since the days of the Dons.

The rocks seen along Marsh Creek between the Livermore road junction and the valley surrounding the John Marsh estate are principally marine clay shales and sandstones of Cretaceous age. The structure of these rocks is easily followed, as resistant sandstone strata stand out of nearly every road cut and hillside. Long hog-back ridges cross the country in a northwest direction, and the strata dip consistently east at angles varying between 30 and 40 degrees. The Cretaceous rocks are progressively younger as one travels east; the shales so prominently exposed at the northeast base of Mount Diablo are in the lower part of the Cretaceous section, whereas the top of the sequence lies in the vicinity of the John Marsh home. The entire thickness of Cretaceous rocks in this area is roughly 24,000 feet, or more than  $4\frac{1}{2}$  miles.



FIG. 44. Part of the Cumberland Hills at Nortonville, once known as the Mount Hope Slope. The large building at left center is the Cumberland Exchange; barn to the right is the company stable. Coal bunkers can be seen to the right of the brick smokestack. *Photo courtesy W. F. Jones, San Francisco.*

Intrusions of Tertiary andesite cut the Cretaceous rocks in the general vicinity of the Marsh Creek Springs Park. Deep red, weathered sections of this rock are exposed in large road cuts between the park and Mount Diablo quicksilver mine. The exact time of the igneous activity which resulted in emplacement of these dark rock bodies is not known, but the intrusions may well belong to the Pliocene volcanic epoch which produced the lavas of the Berkeley Hills.

Marsh Creek Springs Park is another of the convenient resorts that serve the Mount Diablo primitive area. It is located 6.2 miles from Clayton on the south side of the Marsh Creek road.

The John Marsh mansion, also called The Stone House, stands a short distance northwest of the junction of the Stockton-Brentwood and Byron roads into which the Marsh Creek road diverges. The entrance to the site is 17.4 miles from Clayton or 6.2 miles from Byron. The nicely preserved stone building set in a group of locust trees is a prominent landmark along the Marsh Creek road. The broad, fertile acres dotted with great white oaks which surround the mansion grounds preserve the early rancho aspect that was Spanish California, but the austere though ornate English architecture of the house itself seems out of place. Built in 1856 to please Marsh's newly won wife, The Stone House was the last word in architectural finesse and in the quality of materials used. The stone was quarried from Eocene sandstone strata found in the hills to the east of the house.

The John Marsh holdings were purchased from José Noriega in 1837; they were originally known as Rancho Los Medanos and were



FIG. 45. Part of the Somersville cemetery as it was in September 1950. Camera facing east. The main part of town, of which only a frame building or two remain, was on the tree-dotted rise in the left center of the picture. The road beyond the townsite leads southeast toward Stewartville and West Hartley, other early-day coal towns.



FIG. 46. New York Landing near the present site of Pittsburg, California, taken about 1875. This was the terminus of the railroad from Nortonville. Note the small locomotive and passenger car. Company and telegraph offices are in the frame house and the river wharf is behind the house. *Photo courtesy W. F. Jones, San Francisco.*

granted to Noriega in 1835. Marsh got along well with his Indian neighbors but was high-handed in his treatment of Americans and Spanish Californians. He was killed by a party of Spanish Californians with whom he had quarreled, in 1856. Marsh never enjoyed the fruits of his labors at The Stone House.

In the hills east of the Marsh estate, the white sandstones seen in the Mount Diablo coal fields again appear; they are continuations of the same formation, although in this locality there is little or no coal in the series. The white sandstones have been worked extensively for silica sand for glass. Several sand pits may be seen close to the Byron segment of the Marsh Creek road  $2\frac{1}{2}$  miles east of The Stone House. The largest of these, situated close to the Brentwood road junction less than a quarter of a mile south of the highway, has produced many hundreds of thousands of tons of glass sand. The sand pits were worked between 1929 and 1942 by the Silica Sand Company of Brentwood. During this period they produced nearly 600,000 tons of sand which sold for more than \$2,300,000. The deposits are by no means exhausted, and may again be utilized.

A few miles east of the sand-pit area the Byron road leaves the hills and comes out into Sacramento Valley near Byron. Byron, a small farming and fruit-growing community astride the Southern Pacific Railroad, is 2 miles north of well-known Byron Hot Springs. These springs, used by pioneers as early as 1849, have been a well-known health resort since the nineties. They issue in a salt marsh at the edge of Sacramento Valley. There are Eocene marine sedimentary rocks nearby, but no known recently active volcanic areas are anywhere near. As water from one of the salt springs issues at a temperature of 120 degrees Fahrenheit the source of the heat is a problem not fully understood. Chemical interaction between the various mineral solutions might produce sufficient heat.

The Marsh Creek route ends in Byron at its junction point with the paved Tracy-Livermore highway. It affords the best cross section of the rock formations seen between San Francisco Bay and Sacramento and, in addition, is an attractive alternate route from the bay area to central valley points.



FIG. 47. Greystone Winery of Cresta Blanca Wine Company near St. Helena, Napa County. Photo taken in early spring before the grape vines had come into leaf and before the winter-flowering mustard had been plowed under. The scene is typical of the Napa-Sonoma wine country. *Photo by Ari Frisch, courtesy San Francisco Chronicle.*

#### VALLEJO TO MOUNT ST. HELENA VIA STATE HIGHWAY 29 AND THE SILVERADO TRAIL

Vallejo is reached from San Francisco via San Rafael using U. S. Highway 101 and State Highways 37 and 48, or via Oakland over U. S. Highway 40. Vallejo is the home of Mare Island Naval Shipyard established in 1853, one of the first naval installations constructed on the Pacific Coast. General Mariano G. Vallejo planned a town at the present site as early as 1830, but the plan was not carried out until 1850. General Vallejo was very anxious to have the state capitol established in his new town and for two short periods between 1852-53, state officials and legislators did meet there. The town is built on rolling hill land overlooking San Pablo Bay, but is rapidly encroaching upon the flat land lying to the north and east. The brown shales and sandstones so commonly seen in public works excavations are of Upper Cretaceous age.

North from the intersection of Highways 29 and 48 the route follows the Petaluma and Santa Rosa line of the Southern Pacific Railroad through flat dairying and grazing country. The rolling, grass-covered hills behind, green in winter and brown in summer, are dotted with large deciduous oak trees.

Two and one-half miles north of the Highway 48 intersection are the abandoned quarries and concrete buildings of the old Standard Portland Cement Company built in 1903. The plant utilized marl and shell limestone from the Eocene Domengine formation and clay shale of Lower Cretaceous or Upper Jurassic age. It was abandoned in 1919.

One and three-tenths miles north of the junction of Highways 29 and 12, weathered light-brown sandstone belonging to the upper Miocene San Pablo group is exposed in road cuts. San Pablo sandstones form long ridges that strike off to the east; the upturned edges of the sandstone strata mark the position of a broad syncline or down-bowed structure. North of this structure at the base of prominent



FIG. 48. Old Bale Mill (grist mill) on State Highway 28 north of St. Helena, Napa County, built in 1846-47 for Dr. Edward Bale, a Napa County pioneer. *Photo by Olaf P. Jenkins.*



FIG. 49. Petrified redwood log lying in volcanic ash. Petrified Forest northwest of Calistoga, Napa County. *Photo by Olaf P. Jenkins.*



FIG. 50. Petrified redwood log, showing excellent preservation of wood structure. *Photo by Olaf P. Jenkins.*



FIG. 51. Napa Valley from near the bottom of the Mount St. Helena grade; camera facing southwest toward Calistoga. A typical view of the Napa-Sonoma countryside.

Suseol Ridge the tilted Miocene sandstones are underlain by upper and middle Eocene sandstones and shales. This folded section of marine sedimentary rocks is then overlapped by lavas of the Sonoma volcanic series, upper Pliocene in age. The dense weather-resistant lavas of this series form the tops of ridges and peaks in this area, such as Suseol Ridge to the north and Elkhorn Peak to the northeast. The Sonoma volcanics, chiefly andesite and basalt in this vicinity, are exposed in road cuts where Highway 29 crosses the western end of Suseol Ridge.

Half a mile south of Napa State Hospital the Basalt Rock Company operates quarries and plants that produce a variety of rock products, particularly concrete blocks made from pumice and lava from the Sonoma volcanic series.

The City of Napa, laid out by Nathan Coombs of Massachusetts in 1848, includes parts of three cornering Mexican land grants, Ranchos Napa, Entre Napa, and Tulucay dating from the period 1836-41. The names were all borrowed from Indian words, as the country was well peopled with Patwin, Napa, and other Indian tribes. Napa Valley is a tranquil land of orchards and vineyards set deep in the famous Napa-Sonoma wine country. The level valley land is abruptly

bordered by bold ridges of lava partly covered by gray-green trees and brush. To the east of Napa the lava flows show numerous vertical joints produced during cooling of the molten rock. These give a columnar effect to the cliffed outcrops.

Seven miles north of Napa is Yountville, on the southern border of Rancho Caymus, granted to George C. Yount in 1836. The Veterans Home of California, opened in 1881 for disabled veterans of the Mexican and Civil Wars, is located here. Three miles west of town, the State Department of Fish and Game operates a large farm for propagation of game birds.

Four miles north of Yountville is Oakville, a wine-producing center and the hub of the Oakville quicksilver-mining district. The Oakville quicksilver deposits were first discovered during the prospecting rush of 1860 and had produced \$365,000 up to 1951. The two principal mines are the La Joya and the Bella Oaks, located in 1865 and 1868, respectively. La Joya mine is situated on the divide between Napa Valley and Dry Creek Canyon, 7 miles by road from Oakville. It was last operated in 1931; an attempt to reopen, made in 1943, failed because of extensive caving in the principal tunnel. This tunnel, known at the surface as Adit No. 3, was 820 feet long and had a 400-foot drift along the principal vein. None of the workings reached deeper than a few hundred feet below the surface. The mine has produced 2017 flasks of quicksilver from cinnabar ore. The cinnabar is found in fragmented silica-carbonate rock. Ore bodies are found along steeply dipping, sheared and faulted contacts between serpentine and sandstone and shale of the Franciscan (?) group.

The Bella Oak mine, known until 1928 as the Bella Union, is a consolidation of the old Oakville and Bella Union claims located in 1868. Dumps of the old workings may be seen next to the hills west of Highway 29 as one travels north from Oakville. The mine has about 6000 feet of underground workings, but many are caved or otherwise inaccessible. The shallow mine workings were entered through tunnels and inclined shafts. As at the La Joya, mining activity at the Bella Oak has been sporadic, the last quicksilver having been produced in 1943. The total recorded production of the mine has been 1792 flasks of liquid metal, each flask weighing about 76 pounds. The ore bodies occur in a tabular body of serpentine that has been intruded into a thrust-fault zone. The fault zone dips  $10^{\circ}$  to  $35^{\circ}$  SW, except where it locally flattens or rolls.

After passing through the small vineyard towns of Zinfandel and Rutherford, the route lies through beautiful St. Helena, founded by Henry Still in 1855. St. Helena and Calistoga are on parts of Rancho Carne Humana granted to Dr. Edward Bale about 1841. Bale married a niece of General Mariano Vallejo and became a naturalized citizen of Alta California. The great dressed-stone buildings of the Beringer Brothers Winery, a landmark just north of town, are

typical of the masonry construction seen all over Napa Valley. Dozens of bridges and many of the older buildings are constructed of dressed blocks of rhyolite and rhyolite tuff quarried from the Sonoma volcanic series. The fall wine festivals popularized by vineyardists of Swiss, German, and Italian descent are as colorful as the fiesta days of Spanish California.

At roadside 3.7 miles north of St. Helena is the nicely restored grist mill built for Dr. Bale in 1846-47. It is now a park set aside by Napa County in cooperation with the Sons and Daughters of the Golden West. The site is marked by State Historical Marker 359.

Five and a half miles north of the Bale Mill is the resort town of Calistoga, famous for its hot springs, geysers, and scenery. It is situated in a lovely spot almost in the shadow of Mount St. Helena, which looms up to the north. Its hot springs support numerous health resorts and its geysers, although not as spectacular as those at The Geysers in Sonoma County, are none the less worth seeing. The geysers and hot springs are holdovers from the volcanic past that produced the lava flows and tuff beds around Mount St. Helena. Calistoga was founded in 1859 by that enterprising Mormon Sam Brannan, who established the first health resort and laid out the first vineyard.

One mile north of Calistoga on Highway 28 is the turnoff to Petrified Forest, one of northern California's most spectacular geologic oddities. Over an area of almost three-quarters of a square mile, huge petrified tree trunks of an ancient redwood forest lie half buried in volcanic ash. Some trunks are 80 feet long by 12 feet in diameter; and so perfect is the preservation in some places that nearly all the delicate wood structures can still be traced in stone. The process of petrification was accomplished by silica-laden groundwater, the silica taking the place of the wood bit by bit over many thousands of years. The tree trunks all fell in approximately the same direction and may have been blown down in an ancient volcanic blast or blasts; but the popular idea that the trees perished in some fiery cloud sweeping down from the slopes of Mount St. Helena is false. Mount St. Helena is built up of a series of folded lava flows and originated in the same way as any other fold-mountain, that is by warping of the earth's crust. It is not the root of a former volcanic vent and did not get its height from volcanic activity.

Leaving Calistoga, Highway 29 changes its general northwesterly course and heads north directly toward Mount St. Helena. Three miles north of Calistoga the road leaves the valley floor and climbs the steep, winding St. Helena grade. This was once a toll road on the old stage and wagon route to the interior of Lake County, and is on the route followed by Robert Louis Stevenson from Napa to his wilderness cabin near the Silverado mine. This is the famous land of The

Silverado Squatters, and the place where Stevenson partly regained his health during that idyllic summer of 1880.

Just above the summit of the St. Helena grade is the long, red-roofed ruin of the old Toll House Hotel. It is set in a magnificent woodland of bays, madroños, oaks, Douglas firs, etc., and should be restored for its historical significance. The old Silverado mine bunkhouse where Stevenson and his bride stayed is a short distance by trail up a ravine northwest of the ruined toll house. The site is marked by a monument consisting of a rock base and pedestal surmounted by an inscribed open book made of pink granite. The monument, placed by the Napa County Women's Club, carries the following inscription from Stevenson's own writings: "Doomed to know not winter, only spring, a being trod the flowering April blythely for awhile, took his fill of music, joy of thought and seeing, came and stayed and went, nor ever ceased to smile."

The Silverado mine is best seen from above on the Forest Service road to the summit of Mount St. Helena. The Mount St. Helena road junction with Highway 29 is four-tenths of a mile toward Middletown below the summit of the St. Helena grade. The turnoff is unmarked and a key must be obtained from the State Division of Forestry either at Calistoga or Middletown in order to gain access to the road. The road is graded but not paved. On a clear day the side trip up the mountain is well worth the effort, as one can see Mount Shasta and numerous peaks of the Sierra Nevada as well as Mount



FIG. 52. Some of the old structures at the Palisade mine northeast of Calistoga, Napa County. The mine, still in operation, is one of the few in the Coast Ranges that produce precious metals. The complex ore contains gold, silver, lead, and copper. Photo by Olaf P. Jenkins.





FIG. 53. Mount St. Helena, at the corner of Napa, Sonoma, and Lake Counties. Camera facing roughly west. The mountain is made up of folded rhyolitic Pliocene volcanic rocks of the Sonoma series, underlain by serpentine and other rocks of the Franciscan group. *Photo by Clyde Sunderland, Oakland.*

Diablo and other peaks in the Coast Ranges. Although fires have destroyed much of the forest cover on the upper slopes of Mount St. Helena, new growth is rapidly obliterating the old scars. Bold crags of gray-white to pinkish-white rhyolite stand out from the new growth in numerous places.

Two and a quarter miles up the Mount St. Helena road from its junction point with Highway 29 the dark slit that marks one of the entrances to the Silverado mine is easily seen across a gulch toward the south. This mine, also known as the Calistoga or Mount St. Helena, was first opened in 1872 and produced \$93,000 in silver and gold during 1874. Ore milled at that time ran a little more than \$40.00 per ton. In 1928 the owners estimated that 40,000 tons of \$12.00 per ton ore remained in the mine, but if so none was ever taken out. The ore is of disseminated sulfide type, occurring in milky and chalcidonic quartz gangue. Wall rocks are silicified rhyolite. The principal vein strikes approximately north and dips about 73° W. There are several smaller veins of similar attitude. The workings are accessible by two tunnels located on the sides of the gulch and a shaft sunk from high up on the ridge next to the Mount St. Helena road.

Another mine of similar type is the Palisade, located 3½ miles air-line southeast of Silverado. Although it lacks the romantic background lent the Silverado mine through the writings of Stevenson, the Palisade mine has been a far more notable producer, having returned its operators close to \$2,000,000 in silver, gold, copper, and lead, a combination of metals unique among mines of the Coast Ranges. It is reached by dirt road from a turnoff on Highway 29 located midway between Greenwood Avenue and Tubbs Lane.

Beyond the Silverado mine the road winds 6 miles to the summit of Mount St. Helena terminating at the State Division of Forestry fire lookout station. A bench mark pinpoints the convergence of three counties, Sonoma, Napa and Lake, and the 4344-foot summit commands a tremendous sweep across northern and central California. The Russian scientist J. G. Woznesenski, identified with early work on California zoology, and a Russian exploration party ascended the mountain in 1841. At about the same time Princess Helena de Gagarin, wife of the governor general of Russian colonies in North America, is said to have climbed the mountain and is frequently credited with naming the mountain in honor of her patron saint. Some historians doubt that she was the first to name it St. Helena, but at least one Russian visit was authenticated by the finding of a plate or tablet on the mountain top in 1853. A facsimile of the tablet is now part of an historical monument placed on the mountain in 1912 during the centennial observance of the founding of Fort Ross.

Wayfarers who do not mind a few extra miles will be pleased to return toward San Francisco by way of Silverado Trail, a paved highway created by Napa County in honor of Robert Louis Stevenson. In

general, The Silverado Trail follows an old wagon route used in early days. Except for the part between Calistoga and Silverado, which coincides with Highway 29, it keeps to the base of the ridge at the eastern edge of Napa Valley for almost the entire distance between Calistoga and Napa, and the traveller is spared the hustle and bustle of traffic experienced along Highway 29. Silverado Trail skirts the edges of an orchard, vineyard, and cattle-grazing countryside and parallels tree-hung Napa Creek for many miles. The handsome hand-dressed stone bridges spanning Napa Creek are marvels of craftsmanship. Road cuts at the base of the ridge offer good exposures of the widely variable rocks of the Sonoma volcanic series as well as sedimentary strata interbedded with them. White punk-like fresh-water diatomite is exposed in several places between Calistoga and Pratt Valley.

Glass Mountain, a knob overlooking Napa Valley 2½ miles north of the town of St. Helena, is made up of a variety of glassy volcanic rocks among which perlite, pumice, and obsidian are exceedingly common. These are exposed in road cuts along the Silverado Trail at its junction point with the Pratt Valley road. On the east side of the hill near the summit are a group of pits from which Indians once obtained obsidian for arrow and spear heads. The hill slope facing the Silverado Trail is heavily mantled with flakes of obsidian refuse, many of which are pieces discarded by the Indians.

The southern termination of the Silverado Trail is its junction point with State Highway 37, the Monticello road, 1½ miles northeast of the center of Napa. A trip through Napa Valley to St. Helena in either blossom time or harvest time will not soon be forgotten.

#### SIR FRANCIS DRAKE HIGHWAY

Sir Francis Drake Highway traverses the heart of scenic Marin County, extending from the bay side near the end of San Quentin peninsula to Point Reyes, a distance of 42 miles. The route was taken over as a county road prior to 1870, although it was not named the Sir Francis Drake Highway until the time of its paving and improvement during the period 1928-30. Before that time various parts of it were called the San Rafael and Olema road, Point Reyes road, and other local names. Beginning at the San Rafael-Richmond ferry road, the highway crosses to the south side of San Quentin peninsula. Rocks exposed along the highway are gray-green sandstones and brown shales of the Upper Jurassic Franciscan formation. Just east of the intersection of Sir Francis Drake Highway and U. S. Highway 101 are the plants and quarries of the Hutchinson Company and the old Remillard Brick Company. The Hutchinson Company produces crushed rock and fill rock of large dimensions using Franciscan sandstone. The ruins of kilns and miscellaneous brick buildings of the Remillard plant date from 1891; the plant once had a capacity of 12,000,000 bricks annually.



FIG. 54. Houses and houseboats along a slough near Corte Madera (1948). Marin County. Camera facing south-southwest toward Corte Madera and Larkspur. Stream valleys such as this one were partly drowned by encroachment of bay water but are rapidly being filled with detritus and will cease to be marshes in the near geologic future. Photo by Aaron Rubin, courtesy San Francisco Chronicle.

It was abandoned about 1911. Weathered clay shale from the Franciscan formation was the chief raw material used.

After crossing Highway 101, the route lies along sunbathed Ross Valley in which are situated the attractive towns of Greenbrae, Kentfield, Ross, and San Anselmo. Ross Valley was part of Rancho Punta de San Quentin granted to Juan Bautista Roger Cooper in 1840, but more commonly identified with James Ross, who settled near the present site of Ross in 1859.

On the Greenbrae hillsides above the intersection of Sir Francis Drake Highway and U. S. 101, one of the greatest historical finds of recent times was made in the summer of 1936. This was the discovery of an inscribed plate of brass believed to be the one left by Francis Drake on his world-encompassing voyage of 1579. After numerous exhaustive tests the plate has been declared authentic. If so, it is nothing short of miraculous that an article as easily transported and hidden should have been found at all. However, the authenticity of the plate seems far more certain than the precise location of the spot on which it was originally placed, or even the locality where Drake

anchored the *Golden Hinde*. It is highly probable that the plate has been moved many times. In addition to the ultimate finder, one other has come forward and claimed the original discovery spot to be on the Laguna Ranch, a locality more than 15 miles west of Greenbrae. The Laguna Ranch is only 1½ miles from Drakes Bay and 3½ miles from the mouth of Drakes Estero and, if this prior discovery account is true, would further substantiate Drakes Bay as the most likely anchorage.

The marsh land of lower Ross Valley with its sloughs and braided stream pattern is typical of submerged river valleys now almost refilled by new sediments. Similar landscapes are to be seen around San Rafael inlet and on other arms of San Pablo Bay.

The exposed hill of red rock between San Anselmo and Fairfax is deeply weathered basalt of the Franciscan formation. One and seven-tenths miles west of San Anselmo, a road turns off to the south that connects with Fairfax and the Alpine Lake and Mount Tamalpais recreational areas. Fairfax is situated on ground that was once a part of the Rancho Cañada de Herrera, granted to Domingo Sais in 1839. Don Domingo gave the 40 acres surrounding present-day Fairfax to a Dr. Taliaferro in 1849 and it then passed into the ownership of Charles S. (Lord) Fairfax about 1856, hence the present name. Fairfax, like its neighboring towns, was once on the San Francisco and Cazadero line of the Northwestern Pacific Railroad, a branch line abandoned about 1938.

Northwest from Fairfax the highway follows the floor of Ross Valley for 2 miles and then climbs the ridge that divides Ross Valley from San Geronimo Valley. Several prominent weed-grown landslides are to be seen on the north side of Ross Valley. Road cuts expose sandstone and other rocks of the Franciscan formation. An exceptionally fine section of interbedded Franciscan sandstone and shale is exposed in deep road cuts at the top of the divide, 2.6 miles from the Alpine Lake road junction. The sandstone strata contain a great deal of fragmental, carbonized plant material.

One mile west of the summit of the grade is the first of several fine redwood (*Sequoia sempervirens*) groves that are scattered along Sir Francis Drake Highway from Fairfax to Olema. The sylvan retreat called Woodaere is in this grove of trees.

One and one-half miles from Woodaere is San Geronimo, the junction point of Sir Francis Drake Highway and the Nicasio-Petaluma road. San Geronimo was a station on the North Pacific Coast Railroad as early as 1875 and had a post office as early as 1898.

On the north side of the road near Lagunita School, yellowish-brown silica-carbonate rock, an alteration product of serpentine, is exposed. Green to greenish-white masses of serpentine crop out on hillsides north of the school as well as Franciscan sandstone and green-



FIG. 55. Diatomaceous shale and siltstone of the Miocene Monterey formation on the beach and sea cliffs at Sir Francis Drake State Park near Point Reyes. The lofty light-colored banks are believed to have reminded Drake of white cliffs of his native Albion, hence his name for California, "Nova Albion." Photo by Olaf P. Jenkins.



FIG. 56. The straight beach north of Point Reyes, Marin County. Camera facing south. The long, linear beach is the result of prevailing winds, waves, and currents acting over most of the year perpendicular to the beach over a broad gently sloping continental shelf. Photo by Olaf P. Jenkins.

ish-white chert. As San Geronimo and Lagunitas Creeks have cut deeply into this mass of intrusive rocks, they are well exposed along the road. Four-tenths of a mile from Lagunitas near the confluence of Lagunitas and San Geronimo Creeks, a very coarsely crystalline green basaltic rock is conspicuous in cuts on the north side of the highway. In it are numerous glassy feldspar crystals many of which exceed half an inch in longest dimension. Some parts of the exposed basalt surface show rough pillow structures that are believed to indicate rapid cooling of the molten rock in a very wet medium; the basalt may have flowed out onto the ancient sea floor, or may have been intruded into very wet sediments.

One and two-tenths miles west of the basalt porphyry locality is Samuel Taylor State Park, situated deep in the shade of another fine stand of redwoods. The stumps of the huge predecessors of the present trees bear mute evidence of the great virgin forests that once existed there. Some of the stumps are 12 to 16 feet in diameter. Picnicking and camping facilities are available at the park the year around.

Three and one-half miles from Samuel Taylor State Park is Tocaloma, once a station and post office on the North Pacific Coast Railroad but now reduced to a handful of dwellings. Tocaloma is a name apparently derived from the Miwok Indians, and San Geronimo Creek apparently was once known as Tocalahume Creek. Excellent exposures of silica-carbonate rock may be seen north on the road just across the bridge from Tocaloma.

Leaving Tocaloma toward Olema the highway climbs a ridge consisting largely of Franciscan sandstone, and after reaching the summit passes onto open rolling country which is in the San Andreas fault zone. To the north the relatively straight shores of Tomales Bay reflect its fault origin. Peculiar haphazard landslide topography is to be seen on every side and, in contrast to the fine exposures seen to the east, and no hard rocks crop out anywhere. Across Olema Valley, the opposite ridge is of crystalline basement rocks, chiefly quartz diorite. Pendants of limestone and schist are scattered over the granitic surface, and Tertiary sediments lap onto it on the west side of the ridge.

North from Olema for 2 miles Sir Francis Drake Highway and State Highway 1 coincide; Sir Francis Drake Highway then diverges and crosses to the west side of Olema Valley whereas Highway 1 continues up the east side.

Seven-tenths of a mile northwest of Olema is Bear Valley Ranch, on which was recorded the maximum 21-foot displacement measured after the San Andreas fault movement of April 18, 1906. The turnoff to Bear Valley Ranch is one-tenth of a mile north of the Olema road-junction point. The row of four monuments placed to study later shifts along the San Andreas rift may still be seen near the ranch buildings, and 1.2 miles to the north the weed-grown line of depres-



FIG. 57. Point Reyes Lighthouse. Camera facing west toward the Farallon Islands. Rocks of the point are chiefly quartz diorite; inland the granitic basement is overlain by a thin veneer of sandstone and boulder conglomerate probably of early Tertiary age. *Photo by Ken McLaughlin, courtesy San Francisco Chronicle.*

sions, once a fault fissure, can still be located. The various San Andreas fault movements recorded during man's short stay in California have been predominantly horizontal, with the west side of the fault moving north in respect to the east side. Surface indications of fault movement at the time of the 1906 earthquake were traceable 270 miles, from Humboldt County on the north to San Benito County on the south. The entire known length of the rift zone is more than 600 miles and it most probably extends into the Gulf of California several hundred miles farther south.

Three miles northwest of Olema the Laguna Ranch road connects with Sir Francis Drake Highway. One and one-tenth miles west along the Laguna Ranch road is a very old abandoned quarry in white crystalline limestone of unknown age. It has been intruded by and is a pendant in quartz diorite the age of which is also unknown.

Between the Laguna Ranch road and Inverness the rocks are either deeply weathered quartz diorite heavily mantled with soil or else Pleistocene terrace gravels derived from the quartz diorite. Just north of Inverness, a roadside quarry exposes a granitic rock face from which fairly fresh specimens of quartz diorite may be obtained.

Inverness, widely known as one of the most beautiful resort and residence spots in Marin County, nestles against thickly wooded hillsides on the edge of Tomales Bay. The blue bay is nearly always dotted with small motor boats and sailing vessels, the Inverness coast having been a recreational retreat for bay residents for several decades. Climate and landscape are said to resemble those of the Scottish shire of that name. Inverness received its first settlers about 1889.

Just north of Inverness Sir Francis Drake Highway turns west toward Point Reyes. Two and one-half miles west of Inverness a quarry exposes a large face of quartz diorite typical of the unweathered rock in this area. Half a mile farther west are good exposures of chert and diatomaceous shale of the Miocene Monterey formation. The strata are almost horizontal, in contrast to the complexly folded rocks seen east of the San Andreas fault zone. The strength of the underlying granite may have protected these rocks from severe deformation, whereas the less competent sediments seen east of the fault would have proven a much less stable basement.

After crossing Inverness Ridge and progressing down a long canyon, Sir Francis Drake Highway comes out onto low-rolling marsh and sand-dune country that surrounds many-fingered Drake's Estero. This is almost certainly the country where in 1579 the fabulous freebooter that was Drake fraternized with the local Indians while his treasure ship was careened and repaired. Even though the estuary probably could not be entered by his ship, it must have been penetrated by the small boats as well as by parties on foot; the Indians

were anything but hostile. Another famous early-day explorer, who probably visited Drakes Bay and Estero in 1595, was Sebastian Rodriguez Cermeño, a Portuguese pilot sailing under the flag of Spain.

Ancient wrought-iron spikes and fragments of porcelain of an early Chinese period believed to be debris from the wreckage of Cermeño's ship were discovered in 1940 by University of California archeologists.

The geologic features of the Drakes Estero vicinity are many and varied. The estuary itself is a former valley system drowned by the sea either as the result of local downwarping or possibly by a general rise in sea level that may have occurred as the result of the worldwide wasting of the Pleistocene ice sheets. Drakes Estero is protected by long bay-mouth sand bars, and its narrow entrance is flanked by curved sand spits. The stream valleys the estuary occupies were cut into gently folded Miocene marine sediments, the main part of the estuary occupying the axis of a broad, gently folded, northwest-trending syncline or downwarp. Numerous fossil bones of marine mammals such as whales and seals have been found in the Miocene rocks that adjoin the southwest shore of the estuary. Passing beyond the middle finger of Drakes Estero, Sir Francis Drake Highway winds through low-rolling country across gently folded Miocene marine sedimentary rocks that are masked here and there with Recent wind-deposited sand. Blue bush-lupines and yellow bush-daisies lend summertime color to an otherwise drab and lonely landscape.

The road passes near the trans-Pacific receiving stations of the Radio Corporation of America and the American Telephone and Telegraph Company, with their lofty antennas and crisscross of wires. Farther toward Point Reyes it also passes the U. S. Naval Radio Compass Station, nestled among the sand dunes. These stations receive information from all over the Pacific and as far west as eastern Asia.

Point Reyes itself is at the end of a bold, eastward-trending ridge of hard rock. The core of the ridge is granitic (quartz diorite) but the point itself and the northern flank of the ridge are made up of coarse boulder conglomerate and cross-bedded sandstone belonging to the Laird formation. The Laird formation lies unconformably underneath the middle Miocene sediments which have been correlated with the Monterey group, and it may be Miocene or Eocene in age. Fossils have not yet been found in the Laird formation.

North from Point Reyes the shoreline of the Pacific Ocean is almost a straight line for a distance of more than 10 miles. Straight-line features are unusual along the rugged California coast, so the long, uninterrupted beach with its perpetual line of white combers and its sand-dune background is all the more spectacular. Although many linear topographic features in the California Coast Ranges are



FIG. 58. White tuff bed in Moraga volcanic series on Grizzly Peak Boulevard, half a mile north of the Fish Ranch Road intersection. The tuff is interbedded with basaltic and andesitic flows and agglomerates.



FIG. 60. Contact between conglomerate of Orinda formation and basalt of Moraga volcanic series (at the base of the small eucalyptus tree), 0.4 of a mile northeast of Fish Ranch Road intersection. Bifurcated dark zone in the vicinity of the tree, as seen in the field, is bright red as a result of action of heat and gases given off by the hot lava.



FIG. 59. A volcanic mud-flow deposit in the Moraga volcanic series on Grizzly Peak Boulevard 0.6 of a mile northeast of the Fish Ranch Road intersection. Rounded cobbles and boulders of dark lava may be seen weathering out of a finer matrix of volcanic debris.



FIG. 61. A fault zone on Grizzly Peak Boulevard 0.2 of a mile west of the Fish Ranch Road intersection. Shale, sandstone, and chert of the Claremont member of the Monterey group have been crushed and badly dislocated in a zone several hundred feet wide.

related to faults, the shape of Point Reyes Beach is not the result of faulting. It is the result of combined wave and wind deposition on a segment of the coast line that happens to face in the direction from which the strong prevailing wind blows. As the ocean floor slopes very gently seaward and as heavy surf is almost constantly at work, large quantities of sand are scoured from the bottom and thrown onto the beach whence they are readily shifted by the wind. For more than 9 months of the year the wind blows from the northwest and the average tidal current also tends to work from a northwest or southwest direction. Consequently, the surf is constantly working parallel to the beach with little cross-current or riptide activity that would tend to indent the coastline. The wind has long since filled with dune sand any former indentations or gullies that may have existed along the western edge of the peninsula.

Looking northeast from any high place on Point Reyes Ridge, one can easily see the white cliffs that some chroniclers say gave Francis Drake the inspiration for naming the land New Albion. On a clear day the cliffs are very impressive, and although the white cliffs of Dover are chalk, whereas those of Drakes Bay are bleached sandstone, chert, and diatomaceous shale of the Monterey group, the similarity may have been acute for a man who has been many months at sea! A broad, wave-cut bench is developed on stratified rocks of the Monterey group which are well exposed along the cliffs at low tide, giving a good idea of both the lithology and rock structure in the vicinity of Drakes Bay.

Point Reyes is one of the windiest spots on the California Coast and is certainly the foggiest. The wind averages 18 miles an hour throughout the year and has been known to reach 91 miles per hour. Because of the fog, and because of its proximity to the Golden Gate, Point Reyes has been a graveyard for ships. The U. S. Coast Guard maintains navigation lights and fog signals on the point as well as dock facilities for rescue craft. The long straight beach north of the point with its perpetual surf is a favorite training spot for Coast Guard rescue crews.

#### GRIZZLY PEAK AND SKYLINE BOULEVARDS

Grizzly Peak Boulevard, beginning at Golf Course Drive in north Berkeley and eventually joining Skyline Drive in east Oakland, combines magnificent scenery with a profusion of geologic features. In the wooded slopes south of the golf course area, great monoliths of dirty white rhyolite are conspicuous among the pines. They are remnants of intrusions and short lava flows which found their way to or near to the surface along fissures in late Pliocene time. Little Grizzly Peak itself is a cylindrical massif of cemented fragmental rock similar in character to the flow rhyolite, and is considered to be one of several vents which produced the rhyolite flows.

The Wildcat fault, active in recent years, crosses Grizzly Peak Boulevard between Grizzly and Little Grizzly Peaks, but its surface trace is masked by soil and brush. Grizzly Peak is a series of flows of greenish-black basaltic and andesitic lava, the upturned edges of which dip steeply to the east. Just south of the main peak the continuity of the lava horizon is interrupted by a northeast-trending fault which shifts volcanic rocks east several hundred yards. Both the rhyolite of Little Grizzly and the basalt of Grizzly Peak came into existence during the Pliocene epoch, but the rhyolite is considerably younger than the basalt and was emplaced after the basalt had been deposited, bedded with sedimentary rocks, and folded.

A still older volcanic series, separated from the Grizzly Peak group by lake-bed sediments, is beautifully exposed along Grizzly Peak Boulevard on the west slope of the ridge that rises above the head of Claremont Canyon. Coming down the hill toward Fish Ranch Road from the ridge divide, the road passes diagonally over a series of dark-colored flows piled one above the other and dipping into the hill toward the east. Many of the borders of the flows are outlined by dark red zones or by brown soil layers. The red zones are caused by chemical action of gases at the flow borders. Rocks of many of the flows are characteristically amygdaloidal, that is, their once-numerous gas holes have become filled with chalcedony, agate, onyx, and kindred quartzose materials. These cavity fillings are prized as polishing materials by lapidarists in the bay area.

A bright red zone of alteration 2 to 3 feet wide conspicuously outlines the base of the lava series. Underneath the lava is a thick series of poorly cemented cobble conglomerates which here and there contain thin lenses of red and yellow clay and silt. The conglomerate contains much debris of the Franciscan formation; it is lower Pliocene or possibly late Miocene in age. The conglomerate beds, locally called the Orinda formation, are exposed the remainder of the distance down to the Fish Ranch Road intersection, continue to be exposed for a few hundred yards west of that intersection, and then are faulted off against the cherts of the Monterey group (locally called the Claremont chert). Between Fish Ranch Road and the fault zone the Orinda formation changes character and becomes a succession of red and yellow clays rather than conglomerate.

Farther south along Grizzly Peak Boulevard a classical series of studies in structural geology is graphically exposed. Thin-bedded cherts of the Miocene Monterey group of rocks are fantastically tilted, folded and beveled at every conceivable angle. Owing to the winding course of the road through these folded strata, a very beautiful three-dimensional picture can be seen and understood.

Another very striking and unusual feature of the Miocene section of rocks seen along Grizzly Peak Boulevard south of the Fish Ranch Road intersection is the great number and complexity of the





FIG. 62. Thin-bedded chert of the Claremont member of the Monterey group (Miocene) exposed along Grizzly Peak Boulevard above the Broadway Tunnel. The height of the road cut is about 50 feet.



FIG. 63. Detail of bedding in chert of the Claremont member of the Monterey group seen along Grizzly Peak Boulevard just west of Broadway Tunnel. Some of the chert beds are separated by thin shale partings.



FIG. 64. Sandstone dikes in chert and shale of the Claremont member of the Monterey group on Grizzly Peak Boulevard 0.4 of a mile north of the Skyline Boulevard junction. The sand was probably squeezed in along cracks under great pressure, mobility of the sand being enhanced by water, petroleum, or both. The sand was cemented into sandstone after being emplaced. It was probably derived from sandy strata lower down in the Monterey section.



FIG. 65. A small fault in Claremont chert on Skyline Boulevard 1.2 miles north of the Park Boulevard intersection. Camera facing north.



FIG. 66. A redwood grove in Redwood Regional Park in the hills east of Oakland, Alameda County. The cool redwood groves draw millions of visitors annually from all over the bay area. *Photo (1947) by Commercial Studios, Oakland, courtesy The Oakland Tribune.*



FIG. 67. Lake Temescal in northeast Oakland; camera facing north-northwest toward the Campanile of the University of California. Lake Temescal park is a popular summer meeting spot for swimming, boating, and tennis enthusiasts. *Photo (1948) by Cedric Wright, courtesy The Oakland Tribune.*



FIG. 68. Tilden Regional Park east of Berkeley, Alameda County; camera facing northwest toward San Pablo Bay from Grizzly Peak Boulevard.  
*Photo (1941) by A. L. Cohen Co., courtesy The Oakland Tribune.*



FIG. 69. A California winter scene along Sausal Creek and Park Boulevard in Diamond Canyon, Oakland Hills, Alameda County. *Photo by Commercial Studios, Oakland, courtesy The Oakland Tribune.*

sandstone and diabase intrusions which cut across or have been squeezed in between the chert and shale strata. Most of the diabase dikes have been altered to a yellowish clay-rich crumbly material and do not resemble their original character. Unaltered diabase is a compact, hard, dark-colored feldspar-pyroxene rock resembling basaltic lava in general appearance, but having a different texture as seen under the microscope. Sandstone intrusions are much more conspicuous than the associated diabase dikes because they are well cemented and more resistant to erosion. Some sandstone intrusions cut sharply across the chert strata, between closely spaced parallel walls; others form large irregular lens-like masses around which the chert layers have been contorted and broken. The presence of sand intrusions is unusual but is fairly common in severely folded rocks in California. In this case the sand now seen in the dikes appears to have originated in sandy layers in other parts of the Miocene rock section. The sand undoubtedly was loose at the time of intrusion and its mobility probably was enhanced by water or petroleum or both. The strong pressures in the crust at the time the rocks were folded could have produced cross fractures into which the semi-fluid sand could be moved. Although petroleum is no longer conspicuously present in these exposed rocks some of the sandstone dikes have slightly bituminous borders suggesting that oil may once have played a part. Sandstone intrusions of all sorts may be seen along Grizzly Peak Boulevard for 4 or 5 miles but they are best seen 2.2 and 2.9 miles respectively from the Grizzly Peak Boulevard-Fish Ranch Road intersection.

No resident of the San Francisco Bay region should neglect spending some time in the magnificent series of regional parks which embrace much of the hill area from north Berkeley to south Oakland. The sylvan setting of the parks is partly the result of natural groves of redwood, madrones, and other native trees, and partly of extensive planted forests of eucalyptus and pine now several decades old. Many of the planted pine-covered slopes seem as native as the redwoods themselves, so well have they become adapted to the hill lands. Roads, bridle trails, and footpaths abound, and there is much to be seen of geological nature. All the parks are accessible from Grizzly Peak or Skyline boulevards.

#### HAYWARD AND ALTAMONT PASSES

No one who has traveled Highway 50 from Oakland to Tracy can have failed to be impressed by the complexly folded sandstones and shales exposed over Hayward and Altamont Passes. Most of the route between Castro Valley and Dublin lies through canyon topography where steeply dipping, thin-bedded, dark-brown shales and lighter brown, more thickly bedded sandstones of Cretaceous age are almost continuously exposed. These are marine sediments laid down before the Coast Ranges came into existence at a time when a land

mass lay west of the present California coast. The area now defined by the Coast Ranges lay beneath a shallow sea bordered on the west by a land mass of subdued relief and on the east by the ancestral Sierra Nevada. This once-extensive marine basin into which tens of thousands of feet of sand and mud were piled was destroyed during the Tertiary period by a series of crustal disturbances which threw the once-horizontal beds into great folds much as a pile of rugs would yield if pushed from opposite sides. The nearly vertical beds seen a few miles east of the town of Castro Valley give a fair picture of the severity of the folding, although few arched or trough-like folds are completely exposed.

The western border of this belt of Cretaceous rocks is the trace of the Hayward fault; west of this fault the rocks are the familiar serpentine, sandstone, basalt, and gabbro of the Upper Jurassic Franciscan formation exposed in hills and rock quarries around Castro Valley. Three and three-fourths miles west of Dublin the most easterly of the Cretaceous rocks give way to much younger Miocene and Pliocene formations that are too soft to be well exposed along Highway 50. The erosion surface or unconformity that separates the Cretaceous from the younger rocks is likewise not exposed. The major Calaveras fault cuts the soft rocks in a northerly direction just east of Dublin, but its trace is not evident in the flat alluvium of the valley floor.

Altamont Pass, between Livermore and Tracy, is also a fine study in structure in marine Cretaceous shales and sandstones similar to those of Hayward Pass. The folds are not nearly so acute and are much more easily followed. Wide road cuts offer good cross sections of segments of the broad folds, and erosion-resistant strata can be followed by the eye for miles across the rolling land. The crest of the principal structure, the Altamont anticline, is 4 miles southwest of Mountain House or  $3\frac{3}{4}$  miles east of the western foot of Altamont Pass. Rocks in the axial region are flat lying, but they dip to the east on the limb toward Mountain House and to the west on the limb toward Livermore. The Altamont anticline is the southern nose of a major fold that extends many miles to the northwest culminating in the great piercement that is Mount Diablo.

One and seven-tenths miles southwest of Mountain House an angular unconformity between steeply dipping Cretaceous sandstones and shales of the Panoche formation and more gently dipping conglomerate and sandstone of the upper Miocene Neroly formation is well exposed in road cuts. The lower beds of the Neroly formation are characteristically blue because of a thin glaze of blue opal that surrounds each pebble and sand grain. These bluish rocks are unlike sediments of any other formation in the bay area. In addition to their color the lower Neroly rocks are particularly interesting because they contain volcanic debris apparently derived from the Sierra Nevada.

Andesite pebbles together with sand grains derived from breakdown of andesite rocks make up the bulk of the debris in the lower part of the formation. The volcanic material is similar to that found in the Mehrten formation of the Sierra Nevada foothills and is regarded as approximately equivalent in source and age. The upper part of the Neroly seen less conspicuously along the highway toward Mountain House contains much less volcanic debris and is made up largely of soft clays and ordinary looking brown sandstone.

The Neroly formation overlaps both the Cretaceous Panoche formation so well exposed over Altamont Pass and the marine upper Miocene Cierbo formation well exposed farther south on the nose of the Altamont anticline. It represents coastal river flood-plain deposition on the margin of the receding Miocene sea and gives some record of the transitional period between Miocene conditions that were predominantly marine and Pliocene conditions that were predominantly continental in this part of the bay area.

#### HILL AND VALLEY BETWEEN HAYWARD AND SAN JOSE

East of State Highway 17, at the edge of the hills between Hayward and Niles, the effects of recent activity along the Hayward fault are conspicuous. The hills rise abruptly from the valley floor along a relatively straight line which, in this area, is coincident with the fault zone. Numerous landslides along the hill front are partly the result of fracturing and weakening of the rocks by direct fault movements and partly the result of earthquakes caused by faulting. The most striking feature, however, is the deranged drainage system shown by the stream canyons which debouch onto the plain from the hills. The trend of these canyons is more or less perpendicular to the hill front and the canyons normally would empty straight onto the valley floor. In almost every case, however, these canyons bend sharply north for several hundred yards before turning toward the bay. This effect is due partly to direct offsetting of the watercourses because of the small northward shifts of the valley block, partly to the ease of erosion in soft, jumbled fault-zone material, and partly to ridges produced by compression within the fault zone which help deflect the streams from their original courses.

The trace of the 1868 break in the Hayward fault zone passes through the gravel pits west of the town of Niles, being marked by a thin ribbon of clay gouge. The 1868 movement caused a severe earthquake that damaged buildings in the vicinity of present-day Hayward, San Leandro, and other east bay towns, but the area was sparsely populated at the time.

Niles Canyon, which cuts across the hills east of town, is a well-watered, well-wooded canyon that is a pretty drive at any time of the year. The road goes through a severely folded section of Cretaceous rocks which are a continuation of those seen over Hayward Pass along

Highway 50. Except for the fine structure section which is rather easily followed along the roadside, the rocks are monotonous marine sandstones and shales with few, if any, fossil localities or other points of special interest.

Alameda Creek, which flows through Niles Canyon, is a very old watercourse that was in existence before the rise of the hills now seen between Niles and Sunol. The crust apparently was deformed slowly enough to allow the creek to cut downward as fast as the hills rose. Such streams are called antecedent by geologists.

Close to the junction of the Niles Canyon road and Highway 17 is State Historical Marker 46, placed near the site of the grist mill built by José de Jesús Vallejo in 1850. The stone foundations are all that remain of the old building, but part of the stone aqueduct that brought water to the mill wheel from up Niles Canyon can still be seen. Vallejo's adobe stands on the grounds of California Nursery Company half a mile north of town.

West of Niles are the gravel pits at Irvington and the salt works at Newark. The Irvington pits, located a quarter of a mile and half a mile south of town at the base of the hills, are of particular interest because of the large number of Pleistocene fossil bones which have been taken from them. It is hard to believe that local animal life once included kinds now found only in Africa or Asia; but their bones are mingled with those of types now living here, and there can be no doubt as to their coexistence a million or more years ago. Bones of horses, camels, deer, antelope, and many other animals have been taken from the Irvington pits.

The vast desiccation basins in the vicinity of Newark form an extensive patchwork particularly conspicuous from the air. Newark is one of few places in the United States where solar evaporation is an essential step in separation of such products as common salt, magnesia, and calcium chloride. Wide, shallow basins gradually concentrate bay water into strong brine or bittern which is then processed by artificial evaporation and controlled crystallization.

Four miles south of Niles is tree-hung Mission San Jose. Just before entering town the road passes the beautiful walled estate owned by the heirs of E. L. Beard, the pioneer American into whose hands much of the mission lands passed after secularization in the middle 1840's. La Misión del Gloriosísimo Patriarca Señor San José was the fourteenth mission constructed in California, being founded by Padre Lasuén in 1797. The mission, only a small part of which has been restored, is to the east of the highway opposite the business district. On the mission grounds are located the Catholic church, cemetery, and convent of the Sisters of St. Dominic. One mile west of town is the burial ground of the Ohlones Indians who did most of the work of erecting the mission.

There is an interesting route east of San Jose, through the Coast Ranges hinterland to Livermore by way of East Santa Clara Avenue, Alum Rock Avenue, Alum Rock Park, Mount Hamilton, and the Arroyo Mocho. Alum Rock Park, set aside by the State Legislature in 1872, is a 629-acre tract near the mouth of oak-studded Penitencia Creek Canyon, 5 miles east of San Jose. Apart from the scenic beauty derived from its trees, springs, and queer rock formations, Alum Rock Park is interesting to geologists and mineralogists because of its volcanic rocks, mineral springs, and unusual mineral occurrences. Many of the odd-looking rock outcrops are weathered light-colored sodic lava locally called the Alum Rock rhyolite. The rock is fine grained and ranges from pinkish white to reddish or purplish, coloration being the result of iron and manganese oxide stains. Small albite feldspar crystals can be seen in the rock in some parts of the intrusion. The rhyolite is intrusive into Cretaceous rocks but is probably no older than late Pliocene and may be much younger. The numerous mineral springs vary greatly in mineral content: some are salty, some carbonated, some high in sulfates, and many are sulfurous. The minerals are probably being leached from nearby Tertiary and Cretaceous marine sediments by groundwater, and apparently are not related to the rhyolite intrusion. The park gets its name from dusty efflorescences of potassium alum that form on rock surfaces and in rock crevices in various parts of the park. A huge boulder of rare manganese minerals was found in a landslide on the park grounds during World War I, but the source rock has never been located.

From the access road to Alum Rock Park the Mount Hamilton road winds up a high ridge through soft upper Miocene sandstone of the Briones formation. Crushed areas that mark the intersection of two northwest-trending faults with the Mount Hamilton road may be seen in road cuts 1.3 and 1.65 miles up from the Alum Rock Park road junction.

After passing the reservoir in Halls Valley the road ascends a second ridge predominantly of sandstone and shale of the Franciscan formation. One and seven-tenths miles southeast of the reservoir bold dark-colored outcrops of glaucophane schist stick out of the hillside to the east a few hundred yards from the roadside. The rock is dark blue in hand specimen and consists largely of the soda amphibole glaucophane. Glaucophane-bearing rocks are widely distributed in areas of Franciscan-group rocks and generally are found close to the borders of serpentine masses. They are believed to form from a variety of different Franciscan sedimentary and igneous rocks by action of hot mineral water or water vapor related in some way to the serpentine intrusions.

In many parts of the central Coast Ranges the Franciscan formation is predominantly deformed massive sandstone in which it is hard

to find bedding and even harder to trace the structure of the beds. In Mount Hamilton and vicinity, however, Franciscan sandstones tend to be interbedded with shale and parts of folds can readily be seen in road cuts as one travels up the Mount Hamilton road.

At the summit of 4209-foot Mount Hamilton is the Lick Observatory of the University of California, completed in 1888. The observatory was made possible through the endowment of James Lick of San Francisco, and the reservation, which now consists of 3133 acres, was first set aside by Congress in 1876. The neat white buildings house a 36-inch telescope and several of smaller dimensions, together with a library exhibit hall, and research facilities. The observatory is open daily except Sunday between the hours 9-12 and 1-5; on Sunday it is open from 10-1 and 2-5. Visitors are invited to look through the telescope between 7 and 9 Friday evenings.

Mount Hamilton is the highest peak in the Mount Hamilton Range and commands a wide sweep across central California. It is the most southerly of the four principal peaks of the central Coast Ranges, the other three being Mount Tamalpais, Mount St. Helena and Mount Diablo. Mount Hamilton is not quite so prominent a landmark as the other three because the surrounding summits of mountains of the Mount Hamilton Range are also fairly high.

The paved part of the San Jose-Mount Hamilton-Livermore route ends at Mount Hamilton and the next 20 miles is over graded dirt



FIG. 70. Salt crystallizing from concentrated bay-water brine at the Leslie California Salt Company works, Newark, Alameda County. Bay water is concentrated by solar evaporation in large, shallow basins, the salt is scraped from the floor of the basins and either refined for table use or sold in crude form for various industrial purposes. Photo by Olaf P. Jenkins.



road. From Mount Hamilton east to San Antonio Valley road cuts expose shales and sandstones of the Franciscan-Knoxville group. Neither the structure nor the rock units in the area east of Mount Hamilton have ever been adequately worked out, but the Upper Jurassic section is many thousands of feet thick and is complexly folded and faulted. This part of the Mount Hamilton Range is arid and vegetation consists predominantly of Coulter pines, digger pines, junipers, and wild lilacs.

Fourteen miles by road east of the summit of Mount Hamilton, the route turns to the north up San Antonio Valley. As the northern end of the valley is approached, the bold rust-red ridge called Red Mountain looms prominently to the northeast. A series of white dumps on the western slope of the mountain mark the position of the various entrances to Westvaco Chemical's Red Mountain and Western magnesite mines. Between 1905 and 1945 these mines produced more than 800,000 tons of magnesite ( $MgCO_3$ ), and substantial reserves remained in the mines at the time they were shut down in 1944. Magnesite is used as a source of magnesium chemicals, oxychloride cement, and metallic magnesium. The white magnesite occurs as replacement veins in shear zones in a large mass of serpentinized peridotite. The ore bodies are steeply dipping, tabular, lenticular bodies, one of which was 900 feet long, 660 feet wide, and 35 feet thick. The magnesite apparently was deposited from hot carbonated water solutions that had leached magnesium from peridotite situated deeper in the crust.

At the entrance to the Red Mountain mines at the upper end of San Antonio Valley, pavement begins again and the remainder of the route to Livermore is over good paved road. Between the access road to the mines and Fourteen-Mile House in Arroyo Mocho, rocks exposed in road cuts and along the creek are typical sandstones, greenstones, manganeseiferous cherts, and glaucophane schists of the Franciscan formation. The glaucophane schists in this area vary widely in texture and mineral assemblage and apparently have been derived from metamorphism of a variety of Franciscan rocks. In addition to the numerous blue boulders of glaucophane schist which line the stream bed of Sweetwater Creek, multicolored white, yellow, and green boulders of silica-carbonate rock are seen from place to place. These contain the green chrome-mica, mariposite, and are much like some of the rocks of the Mother Lode in the Sierra Nevada. These mariposite rocks are hydrothermal alteration products of serpentine and have much the same origin as the magnesite deposits.

Numerous small manganese prospects are strung out along the Arroyo Mocho road between Fourteen-Mile House and the mouth of Arroyo Mocho. Dumps, open cuts, and short underground workings may be seen up the slope east of the road 2.6 and 4.5 miles northwest of Fourteen-Mile House. All of these manganese prospects are in red

chert, the black ore occurring in stringers and pods between the thin beds of chert.

In the bottom of the canyon 5.1 miles from Fourteen-Mile House are the large bluish dumps accumulated during driving of the Hetch-Hetchy aqueduct tunnels, first used in 1934. The Hetch-Hetchy supply system includes 81.9 miles of tunnels and 72.7 miles of pipeline. The Coast Ranges segment of the aqueduct includes a 25-mile long tunnel connected with the surface in the canyon bottoms by vertical shafts. The aqueduct is 10.5 feet in diameter and has a daily capacity of 250,000,000 gallons. It brings water from Hetch-Hetchy reservoir on the upper Tuolumne River to the City of San Francisco. The general direction taken by the tunnel as it passes beneath Arroyo Mocho is N. 75° E.

Two and one-half miles west of the Hetch-Hetchy dumps the road comes out of steep-walled, V-shaped Arroyo Mocho and onto the rolling margin of Livermore Valley. The Franciscan formation is immediately overlapped by alluvium and gravels of Plio-Pleistocene age called the Livermore gravels. For a few hundred yards on either side of the stream bed Recent terrace deposits in turn cover up the Livermore gravels.

After paralleling Arroyo Mocho Creek for another 5 miles the road terminates against the Tesla-Corral Hollow road. Along the Corral Hollow road are various mines which from time to time have produced manganese, coal, clay, and silica sand. The mines are currently idle, for the most part, and many lie beyond the counties covered in this guidebook.

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FIG. 71. One of the oddly weathered outcrops of volcanic rock (rhyolite) in Alum Rock Park in Penitencia Creek Canyon east of San Jose, Santa Clara County. The 629-acre tract, in which native trees and shrubs have never been disturbed, gets its name from dusty efflorescences of potassium alum deposited from time to time on the surface of some of the rocks by evaporation of alum-bearing groundwater. Photo by Tucker Studio, San Jose, courtesy San Francisco Chronicle.

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GLOSSARY

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## GLOSSARY

**Acidic rocks**, a term applied to igneous rocks containing abundant silica, more than 65 percent SiO<sub>2</sub>, such as granites.

**Acre-foot**, the quantity of water required to cover one acre to a depth of one foot, or 43,560 cubic feet.

**Adit**, also called a **tunnel** or **drift**. An adit, unlike a railroad tunnel which penetrates a hill and is open at both ends, may have but one surface opening.

**Aftershock**, a minor or accessory shock following the main shock of an earthquake.

**Agglomerate**, a rock composed largely or wholly of coarse fragments of volcanic rocks.

**Aggradation**, the natural filling of a stream bed or stream valley by deposition of sediment.

**Aggregate**, sand, gravel, shell, slag, or broken stone or combinations thereof, with which cementing material is mixed to form a mortar or concrete.

**Alluvium**, unconsolidated stream deposits of sand, mud, and gravel.

**Alteration** of a rock refers to a change in its chemical composition.

**Alumina**, aluminum oxide.

**Amalgam**, an alloy of mercury with another metal, such as gold or silver.

**Amygdaloid**, a cellular igneous rock containing small cavities filled with secondary minerals such as calcite, quartz, chalcedony, or some variety of zeolite.

**Andesite**, a volcanic rock composed of plagioclase feldspar together with one or more dark minerals such as augite, hornblende, or biotite.

**Anticline**, an upfold or arch of rock strata.

**Antilocaprid**, a pronghorn antelope.

**Aphanitic**, fine-grained texture of igneous rocks; individual minerals cannot be distinguished by the naked eye.

**Aplite**, a fine-grained granite occurring as dikes, consisting chiefly of quartz and potash feldspar.

**Arkose**, a sandstone rich in feldspar fragments.

**Ash**, an unconsolidated mass of tiny volcanic rock fragments deposited after being violently ejected from a volcano.

**Attitude** (of rock structures), a term including the terms *dip* and *strike*. The attitude of the flat surface of a sedimentary bed, whether inclined or not, is referred to the horizontal plane. **Dip** is its slope inclination (in degrees) from this plane, and is measured with a clinometer. **Strike** is the compass bearing on the line of intersection of its surface with the horizontal plane. The terms may also apply to faults, veins, and dikes.

**Axes of reference** in crystallography are assumed in describing the exact relative positions of the faces of a crystal.

**Axis** of a fold in bedded rocks refers to the crest line of an anticline or to the trough line of a syncline.

**Basalt**, a dark-colored, fine-grained volcanic rock, composed essentially of calcium-rich plagioclase feldspar and one or more dark minerals such as pyroxene.

**Basement complex**, the old rock floor, generally complex in structure, upon which a series of sedimentary beds has been deposited.

**Basic**, a term applied to igneous rocks, such as basalt, that are comparatively low in silica, less than 52 percent, but high in iron and magnesium.

**Batholith**, a large intrusive body of once-molten rock that has crystallized beneath a great thickness of overlying rocks. The granitic mass of the Sierra Nevada is called the Sierran batholith.

**Baumé**, a scale used to measure the relative weights of various liquids.

**Bed**, a single layer or stratum of rock.

**Bedrock**, the solid rock underlying superficial detritus.

**Bentonite**, a plastic clay derived from the weathering of volcanic tuff or ash.

**Bivalve**, an invertebrate with a double shell, such as a clam.

**Bittern**, the concentrated liquor or residual brine that remains after the first desirable salts have been crystallized out.

**Breccia**, a rock composed of angular fragments commonly cemented together.

**Chert**, a compact siliceous sedimentary rock of organic or precipitated origin.

**Clastic rock**, composed of fragments of rocks and minerals.

**Cleavage**, a property of some minerals to break along certain planes which are parallel either to actual or possible crystal faces. **Basal cleavage** is cleavage perpendicular to the longest direction of a crystal. So-called rock cleavage is better known as **jointing**.

**Cobbing**, sorting out the worthless parts of an ore by striking them off with a hammer.

**Colloid**, a substance, approaching molecular dimensions, carried by a solvent; intermediate between a soluble state and a suspended state.

**Complex**, a term sometimes used for an ancient series of rocks comprising various kinds of formations too complex in structure and composition to enable the geologist to separate them in mapping.

**Conchoidal**, shell-shaped fracture, as in broken glass.

**Concretions**, compact nodular or irregular concentrations of mineral matter in sedimentary and fragmental volcanic rocks.

**Conformable**, following in unbroken sequence; refers to sedimentary beds deposited one upon the other in unbroken sequence.

**Conglomerate**, a rock composed largely of rounded pebbles cemented by finer material.

**Contact**, the boundary between two geologic formations.

**Contact metamorphism**, a change in the chemical or physical constitution of a rock near an intrusion of igneous rock.

**Correlation**, equivalence in geologic age of two or more formations or rock units in widely separated areas.

**Country rock**, a miner's term for the rock surrounding a vein or mineral deposit.

**Cross-bedding**, a minor structure; applied especially to sands deposited by current action of water or wind, in which the minor bedding planes of deposition are oblique to the principal planes of stratification.

**Cross-cut**, a level mining operation driven across the course of a vein or at right angles to the main workings.

**Dacite**, a volcanic rock composed essentially of plagioclase feldspar and quartz, and minor amounts of potash feldspar, biotite, hornblende, or pyroxene.

**Degradation**, the general lowering of a land surface by natural processes of erosion.

**Detritus**, fragmental rock material derived by physical breakdown of surface rocks; may be transported by wind, water, gravity, or ice.

**Diabase**, an intrusive igneous rock similar to basalt in chemical composition but differing from it in texture.

**Diastrophism**, the profound process by which the earth's crust is deformed.

**Dike**, a body of rock forced in molten condition into a fissure in older rocks, and there solidified; sandstone dikes, an exception, are not molten when pushed into fractures.

**Diorite**, a coarse-grained intrusive igneous rock composed of plagioclase feldspar and hornblende, biotite, or pyroxene.

- Dip**, see *attitude*.
- Dolomite**, a carbonate rock composed predominantly of the mineral dolomite,  $\text{CaCO}_3 \cdot \text{MgCO}_3$ ; limestones, magnesium limestones, and dolomites are related chemically and physically and have much the same appearance in the field.
- Druay**, coated with minute crystals.
- Efflorescence**, fluffy or powdery mineral material; formed as a residue from evaporation of mineral water.
- Elastic rebound**, the spring back of an elastic body when a deforming force is suddenly removed.
- En echelon faults**, a series of faults arranged in parallel lines, each fault laterally offset from the others, forming a step-like pattern.
- Epicenter**, the geographical location of the point on the surface of the earth that is vertically above the earthquake focus.
- Erosion**, the wearing away of the earth's surface by natural agencies.
- Faience**, decorative earthenware as distinct from tableware.
- Fault**, an earth fracture or zone of fracture along which the rocks of one bounding wall have been displaced in relation to those of the other.
- Fault breccia**, rock broken into angular fragments by movement in a fault zone.
- Fault gouge**, finely ground rock found between the walls of a fault.
- Faunal stage**, a minor subdivision of a stratigraphic series; the presence of characteristic fossils serves as a basis for establishing the stage.
- Feldspar**, the most abundant mineral substance of igneous rocks; represents a group of minerals, silicates of aluminum and potassium, sodium, and/or calcium.
- Ferromagnesian**, containing abundant iron and magnesium; applied to dark silicate minerals, particularly characteristic of basic igneous rocks.
- Fine grained**, a rock texture in which the minerals are one millimeter or less in diameter.
- Fissure**, an extensive crack, break, or fracture in rocks.
- Flagstone**, a commercial term for rock that splits easily along parallel bedding planes or joints, and can be used for paving.
- Flint**, a dense, hard rock composed mainly of minutely granular silica; similar to chert.
- Flows and flow rocks**, volcanic rock in which minerals show a parallel arrangement produced during their emplacement.
- Fluvial**, formed by action of rivers or streams.
- Focus**, the point of origin of the initial earthquake waves of a principal earthquake.
- Footwall**, the boundary of the lower wall in an inclined planar structure such as a fault or vein.
- Foraminifera**, microscopic one-celled animals, the limy shells of which are found as fossils in rocks.
- Formation**, a rock body or an assemblage of rocks which have some character in common; applied to a particular sequence of rocks formed during one epoch; a rock unit used in mapping.
- Fossil**, any record of past life, whether it is the whole or a part of an organism, or any record of its presence left in the rocks.
- Fumarole**, a vent in the earth from which hot gases and vapors issue.
- Gabbro**, a coarse-grained intrusive igneous rock, similar in composition to basalt.
- Gangue**, the valueless minerals in an ore.
- Geosyncline**, a major downward flexure of the earth's crust in which great thicknesses of sediment are deposited.
- Glaae**, a silica melt which has cooled so quickly that crystals were not formed.
- Gneiss**, a crudely banded metamorphic rock.
- Gossan**, the weathered, iron-stained, red or brown, outcrop of a mineral deposit.
- Graben**, a trench or valley, the floor of which is bounded by faults.
- Granite**, an intrusive, coarse-grained rock consisting essentially of quartz and alkali feldspar with smaller amounts of mica and other minerals.
- Granodiorite**, a coarse-grained intrusive rock intermediate in composition between granite and quartz diorite, containing both alkali and plagioclase feldspars.
- Gravel**, an unconsolidated accumulation of rounded rock fragments predominantly larger than sand grains.
- Graywacke**, a coarse feldspathic sandstone, usually dark gray, containing bits of dark-colored minerals or rocks.
- Greenstone**, a general term for a compact, dark-green igneous rock, altered, and usually containing the mineral chlorite.
- Habit, crystal**, the characteristic shape or form, determined by growth along certain directions.
- Hanging wall**, the boundary of the upper wall of an inclined planar structure such as a fault or vein.
- Hogback**, a ridge formed by the outcropping edges of tilted strata.
- Hydrothermal**, pertaining to action of hot water or water vapor.
- Igneous rocks**, formed as a result of solidification from molten material.
- Imbricated fault zone**, a zone of closely spaced faults in which the fault wedges have been displaced so that they lap over one another like shingles on a roof.
- Inlier**, a surface exposure of an underlying rock which is surrounded by overlying rocks of later deposition.
- Interdigitate**, interfinger.
- Intrusive**, applied to an igneous rock that has been injected into older rocks; it has cooled and solidified from a molten condition under the cover of the surrounding rock mass.
- Invertebrate**, any animal having no bony spinal column.
- Jasper**, an opaque, compact, noncrystalline variety of quartz occurring in various colors, particularly red, brown, and yellow.
- Joints**, the cracks which divide rocks into blocks, without appreciable displacement of the walls.
- Kitchen middens**, refuse heaps marking a former site of Indian occupation.
- Lacustrine**, formed in a lake.
- Lava**, molten rock or rock formed by solidification of molten rock from a volcano.
- Lignite**, low-grade coal in which alteration of vegetal matter has proceeded farther than peat but not so far as bituminous coal.
- Limbs**, the two parts of a fold, one on each side of the axis; also called *flanks*.
- Lime**, calcium oxide.
- Limestone**, a sedimentary rock composed largely of calcium carbonate.
- Lithology**, the study of rocks as based on the observation of hand specimens.
- Mafic minerals**, are those which contain a high percentage of iron and magnesium.
- Magma**, molten material from which igneous rocks solidify.
- Magnesia**, magnesium oxide.
- Marble**, recrystallized limestone.
- Massive**, homogeneous, or without stratification.
- Mastodont**, a member of a group of extinct elephant-like animals.
- Matrix**, a rock mass in which a crystal, fossil, or other object is embedded; also called *groundmass*.
- Meanders**, loop-like bends in a watercourse.
- Measure, coal**, a bed or stratum of coal.
- Megascopic**, identifiable by means of the naked eye or a pocket lens.
- Meta-**, a prefix denoting that the rock has been somewhat recrystallized but not to the extent that its original character has been obliterated.

**Metamorphics**, or **metamorphic rocks**, rocks profoundly altered by pressure, heat, and solutions, usually at considerable depth in the earth's crust.

**Metamorphism**, changes in rocks due to recrystallization.

**M.g.d.**, million gallons per day.

**Mineral**, a naturally occurring substance with definite physical characteristics and a chemical composition varying within certain limits.

**Mold**, an impression made in a rock by the outside form of a fossil.

**Monadnock**, a rounded hill standing isolated above a plain; generally refers to a residual remnant of an older topographic relief.

**Monocline**, a fold in which strata dip in one direction only, other parts of the structure being horizontal.

**Monoclinic**, the crystallographic system in which crystals can be referred to three unequal axes, two of which intersect at an oblique angle, but the third is perpendicular to these two.

**Normal fault**, a fault in which the upper or hanging wall side has moved downward in relation to the lower side.

**Obsidian**, solid volcanic glass.

**Ochre**, an earthy and often impure ore of iron, usually red (hematite) or yellow (limonite), extensively used as a pigment.

**Ore**, that part of a mineral deposit from which material may be extracted at a profit.

**Oreodonts**, extinct animals which combined some of the characteristics of pigs, deer, and camels.

**Orogeny**, the process of mountain building.

**Orthorhombic system**, a system of crystallization which has three axes of unequal length at right angles to each other.

**Ostracods**, minute bivalve crustaceans.

**Outcrops**, surface exposures of bedrock.

**Overtured fold**, occurs in sedimentary beds when deforming forces are unequally applied so that the limbs are tilted past vertical; the sequence of strata on one limb may thus become inverted.

**Pediment**, a plain, usually an erosion plain, at the foot of a mountain range; the alluvial cover is generally quite thin.

**Pegmatite**, a very coarse-grained dike rock, frequently granitoid in composition.

**Pendant**, a downward projection from the roof of an intruded rock mass into the intruding igneous body.

**Penplain**, a broad plain at or near base level produced by degradation of a land mass.

**Peridotite**, an ultra-basic igneous rock composed essentially of olivine with pyroxene.

**Peperite**, a large bleb of basaltic or andesitic lava, found in marine sedimentary rocks that has become isolated from its source tongue of lava and is completely surrounded by sediment.

**Penultimate**, the last of a series but one; the next to last.

**Perlite**, a glassy volcanic rock of rhyolitic or dacitic composition, with a texture characterized by concentric or onion-like partings, resembling pearls; perlite usually contains a small percentage of water, a property which enables it to be expanded to a cellular material when suddenly heated.

**Petrifaction**, the process of replacement of fossils by mineral material.

**Petrography**, the study, description, and systematic classification of rocks, usually by microscopic means.

**Phenocrysts**, isolated crystals visible to the unaided eye lying in a finer-grained matrix of an igneous rock, particularly a porphyry.

**Pillow basalt**, a basaltic lava characterized by a peculiar structure resembling a pile of pillows.

**Planimetric map**, a map that shows the relative position of the features of a land surface but not the configuration of that surface; it does not show contour lines, as does a topographic map.

**Playa**, the flat-floored bottom of an undrained desert basin, containing flat sheets of fine sand and clay, deposited in intermittent lakes.

**Plug, volcanic**, the vent or pipe of a former volcano filled with solidified lava.

**Plunge**, the angle between the axis of a fold and a horizontal plane.

**Plutonic rocks** are crystallized from a molten or partly molten condition at great depth in the earth's crust, as contrasted with surface volcanic rocks and near-surface dikes.

**Polysynthetic**, a term used to describe the multiple parallel parts of twinned feldspar crystals.

**Porcelanite**, an impure chert having the texture and appearance of unglazed porcelain. Impurities commonly are clay or calcium carbonate.

**Porphyritic**, a rock texture composed of isolated crystals or phenocrysts, imbedded in a matrix of finer mineral material.

**Potash**, potassium oxide.

**Pumice**, a frothy, light-weight, highly silicic volcanic glass.

**Pyroclastics**, a general term for fragmental deposits of volcanic materials, including volcanic conglomerate, agglomerate, tuff, and ash.

**Quartzite**, a metamorphosed rock composed of quartz grains cemented by silica.

**Quartz diorite**, a coarse-grained igneous rock composed essentially of quartz and with minor amounts of dark minerals.

**Quartz monzonite**, a light-colored coarse-grained igneous rock containing quartz and approximately equal amounts of plagioclase and potash feldspar.

**Radiolaria**, microscopic animals commonly having a highly ornate siliceous shell covering.

**Rejuvenation**, renewal of erosion brought about by uplift of the region; also renewal of any geologic process.

**Relict**, left behind in a process of change; residual.

**Replacement**, the process by which one mineral or chemical substance takes the place of some earlier different substance, often preserving its structure or crystalline form.

**Reverse fault**, a fault in which the upper or hanging wall side has moved upward in relation to the footwall side.

**Revolution**, profound mountain-building which has taken place over a very wide area.

**Rhyolite**, a light-colored, fine-grained volcanic rock composed predominantly of quartz and potash feldspar.

**Rift**, synonymous with fault trace.

**Riprap**, large pieces of undimensioned stone used for sustaining walls, breakwaters, etc.

**Road metal**, broken stone, cinders, etc. used in making and repairing roads or ballasting railroads.

**Sandstone**, a rock composed of grains of sand held together by a cement.

**Schist**, a finely laminated metamorphic rock in which the minerals are arranged in thin layers.

**Seam**, a term often used to describe a bed of coal or other valuable mineral.

**Sedimentary rocks** are formed by deposition in water or air, and are for the most part stratified; their origin may be mechanical, chemical, or organic.

**Seismogram**, the record of an earth tremor made by a seismograph.

**Seismograph**, an instrument for quantitative recording of ground vibration.

**Shale**, compacted mud or clay, generally possessing a thinly bedded or laminated structure.



**Shear**, deformation caused by two parallel but opposing forces, which are not in line with each other.

**Silica**, silicon dioxide,  $\text{SiO}_2$ .

**Sill**, a tabular sheet of intrusive rock injected along the bedding planes of sedimentary or volcanic formations.

**Silt**, rock particles intermediate in size between sand and clay; when compacted the rock is called **siltstone**.

**Slate**, a homogeneous metamorphosed clay or shale characterized by a cleavage which causes it to split readily into thin broad sheets, not necessarily parallel to the original bedding planes.

**Slip**, the relative displacement of formerly adjacent points on opposite sides of a fault.

**Spherulitic**, small spherical structures in volcanic rocks made up of radiating crystal fibers.

**Spilite**, an altered sodium-rich basaltic rock, usually amygdaloidal.

**Stockwork**, an ore deposit consisting of a large irregular mass of rock penetrated by numerous small veins of ore.

**Stope**, an excavation underground for the removal of ore.

**Stratigraphy**, the study of arrangement of strata, especially as to position, order of sequence, and age.

**Stratum**, a layer that is separable along bedding planes from layers above and below, the separation arising from a break in deposition or a change in the character of the material deposited.

**Strike**, see *attitude*.

**Stringer**, a tiny vein.

**Syenite**, a coarse-grained intrusive rock composed principally of feldspars together with smaller amounts of mica, amphibole, or pyroxene.

**Syncline**, a trough-shaped fold in rocks in which the strata dip inward from both sides toward the axis.

**Tailing**, the refuse material separated as residue in treating ores.

**Tear fault**, an auxiliary cross-fault along which the displacement has been parallel to the strike of the main fault.

**Tectonic**, pertaining to rock structure and surface forms resulting from deformation of the earth's crust.

**Terrazzo**, a type of flooring made of small chips of rock set irregularly in cement and polished.

**Thrust fault or thrust**, an inclined fault in which the hanging wall moves up relative to the footwall.

**Triclinic system**, a crystal system characterized by three unequal axes intersecting at oblique angles.

**Tuff**, a rock formed of compacted volcanic ash or dust.

**Twinning**, the assemblage of two or more crystals, or parts of crystals, in apparent reversed position with reference to each other.

**Ultrabasic or ultramafic**, refer to igneous rock containing little or no quartz or feldspar and composed essentially of iron-magnesium silicates.

**Unconformity**, represents a break or gap in depositional sequence in sedimentary rocks; it usually represents an erosion surface cut into an older series of rocks, upon which later sediments are deposited.

**Vein**, the mineral filling of a crack or fissure in rocks; precipitation from solution, rather than crystallization from a molten mass.

**Vesicle**, a small cavity in a once-molten rock usually produced by the formation of gas in the molten mass.

**Vitreous**, having the luster of glass.

**Volcanic rocks** have solidified from a melt on or near the earth's surface.

**Vug**, a small cavity in a rock, usually lined with crystals.

**Wall rock**, the country rock bounding a vein.

**Weathering**, the gradual decay and disintegration of rocks at or near the surface, caused by subaerial influences, such as rain and frost, but especially oxidation and other chemical actions.

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