SUMMARY OF THE GEOLOGY OF THE GREAT VALLEY

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A close association exists between physiography and geology in many parts of California, and although details may vary, large contiguous areas of the State have distinctive features not shared by the adjacent terrane. These large physiographic-geologic provinces have been designated "geomorphic provinces" to indicate that the division has been made subject to the rock fabric. One of the largest and most obvious of these provinces in California is the Great Valley—the topic of the following geologic summary.

The Great Valley of California, also called the Central Valley of California or the San Joaquin-Sacramento Valley, is a nearly flat alluvial plain extending from the Tehachapi Mountains on the south to the Klamath Mountains on the north, and from the Sierra Nevada on the east to the Coast Ranges on the west. The valley is about 450 miles long and has an average width of about 50 miles. Elevations of the alluvial plain are generally just a few hundred feet above sea level, with extremes ranging from a few feet below sea level to about 1,000 feet above. The only prominent topographic eminence within the central part of the valley is Marysville (Sutter) Buttes, a Pliocene volcanic plug which rises abruptly 2,000 feet above the surrounding valley floor.

The northern portion of the valley is called the Sacramento Valley and the southern portion the San Joaquin Valley. Each of these segments is drained by the river after which the valley has been named, and these, after joining about 30 miles east of San Francisco, empty into San Francisco Bay. The southern extremity of the San Joaquin Valley, however, has interior drainage via the Kings and Kern Rivers into the depressions that in the past supported Tulare and Buena Vista Lakes.

The Great Valley has been the source of about $10 billion worth of crude oil, $2 billion worth of natural gas, and $1 billion worth of natural gas liquids. The Sacramento Valley part has yielded tremendous amounts of gas but almost no oil, whereas the San Joaquin Valley has yielded both oil and gas. Because of the differences between the two main parts of the Great Valley, and to some extent because of its size, geologists, particularly petroleum geologists, have generally studied intensively either the Sacramento or the San Joaquin Valley, but not both. As a result, relatively few reports on the geology of the combined Sacramento-San Joaquin Valley have been published. In the preparation of this article a little-known comprehensive report on the entire Great Valley by C. A. Repenning (1960) has been of great value, and almost all of the paleolithologic maps used herein are direct reproductions from his excellent report.

Geologically, the Great Valley is a large elongate northwest-trending asymmetric structural trough that has been filled with a tremendously thick sequence of sediments ranging in age from Jurassic to Recent. This asymmetric geosyncline has a long stable eastern shelf supported by the subsurface continuation of the granitic Sierran slope and a short western flank expressed by the upturned edges of the basin sediments. The basin has a regional southward tilt, which is interrupted by two significant cross-valley faults. The northernmost fault, the Stockton fault, is the boundary used by most geologists to separate the Great Valley Basin into two sub-basins, the Sacramento and San Joaquin. The other great cross-fault lies near the southern extremity of the basin and has been named the White Wolf fault.

STRATIGRAPHY

The Great Valley has been filled with a thick sequence of sedimentary rocks of Jurassic to Recent age, but the locale of the thickest accumulation of sediments varied throughout geologic time. In the Tertiary the thickest accumulation was along the western edge of the southern portion of the San Joaquin basin, about at the present position of the structural low. Mesozoic rocks, however, are thickest along the west side of the Sacramento basin, indicating that their greatest deposition was probably west of the western edge of the present valley structural trough. It appears likely that a minimum of 60,000 feet of Mesozoic sediments were laid down in the area just west of the present margin of the Sacramento Valley.

The sedimentary sequence rests on a basement floor of metamorphic and igneous rocks in the eastern half of the valley. These basement rocks, which are exposed in the Sierra Nevada foothills, are composed of Paleozoic and Mesozoic metasediments and volcanics as well as Jurassic and Cretaceous granites. Along the west margin of the valley, where the very thick Mesozoic strata are present, basement has not been observed, either in outcrop or in well bores. Recent studies indicate that the terrane lying between the central part of the valley and the San Andreas fault and containing Franciscan rocks is probably underlain by a basaltic or ultramafic basement (Bailey, et al, 1964).

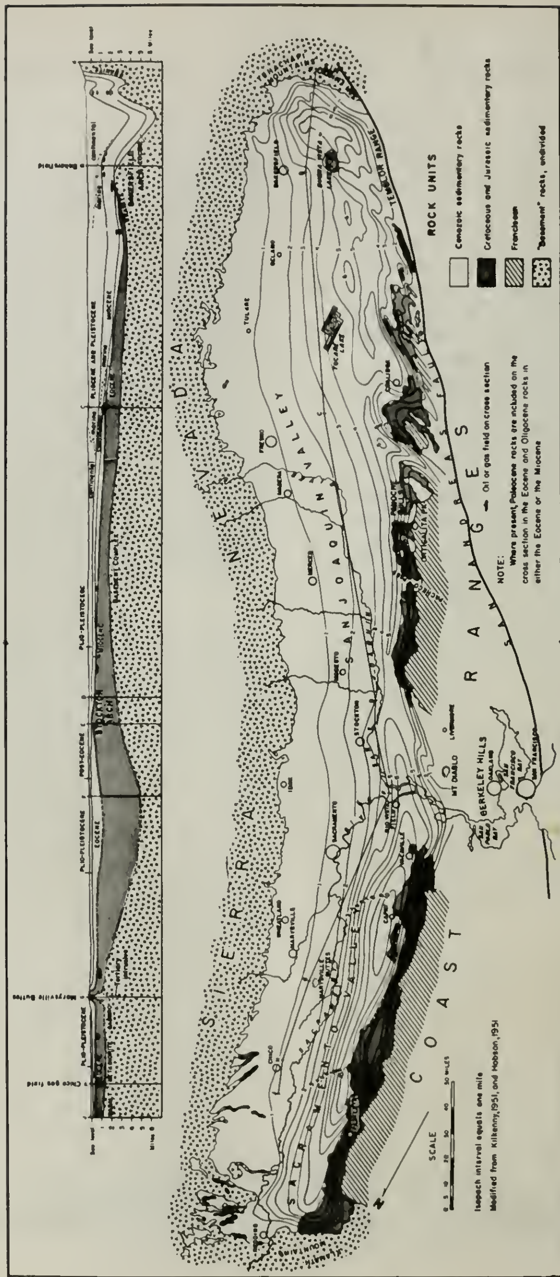

Figure 1. Map of central California showing thickness of sedimentary rocks in the Great Valley. After Repenning (1960, fig. 2).

The Jurassic, Cretaceous, and Tertiary rocks are, for the most part, of marine origin, though significant thicknesses of continental rocks are present in the Tertiary section. Through the entire sequence the rocks are almost entirely clastic, with siltstone, claystone, and sandstone, in that order, the dominant lithologic types. Except for rare occurrences, carbonate rocks are virtually absent. Volcanic rocks compose about 10 percent of the Franciscan Formation and are present in minor, though important, amounts in the Tertiary.

Cretaceous deposits make up the predominant formations in the Sacramento Valley, while Tertiary strata attain the greatest thickness in the San Joaquin Valley. The Cretaceous section is characterized by general lithologic similarities over great distances throughout the Great Valley. It is not unusual for one to be able to recognize at a glance Cretaceous sediments at localities several hundred miles apart. On the other hand, the Tertiary strata are extremely variable and rock units may change facies over very short distances.

The sediments that form the thick valley section were largely derived by erosion of land areas located to the east of the depositional trough. For the major portion of the Jurassic and Cretaceous sediments of the valley, the source area seems most likely to have been the batholiths of the Klamath Mountains and the Sierra Nevada. This hypothesis is based on the several percent of K-feldspar found in these rocks and presumed to have been derived from the granitic rocks of these northern and eastern highlands (Bailey and Irwin, 1959). The lack of K-feldspar in the valley (east of the San Andreas fault) Franciscan Formation either indicates a different source area or that most of this formation predates the unroofing of the batholiths (Bailey and others, 1964). There is evidence to indicate that the Diablo Range was a periodically emergent land mass during later parts of the Late Cretaceous and that this area contributed sediments to the Late Cretaceous sea. The arkosic nature of the Tertiary sediments seems to indicate the principal source area was probably the elevated granitic batholiths of the Sierra Nevada and Tehachapi Mountains. Coarse arkosic sediments in the upper Miocene of the western San Joaquin basin, however, may indicate a granitic source area then existed west of the town of Fellows. Other localized areas in the Coast Ranges probably contributed debris into the Tertiary seas.

The Mesozoic basin of deposition covered a greater area than just the Great Valley trough, as Jurassic and Cretaceous rocks are either exposed in or underlie large portions of the region between the valley and the Pacific Ocean. In contrast, the Tertiary basins were much more restricted and distinct; they had relatively narrow and limited connections to the open western sea.

Pre-Uppermost Jurassic Rocks

Except along the west side, Paleozoic and other pre-uppermost Jurassic (pre-Tithonian) rocks are exposed on the highlands along the edges of the Great Valley. These rocks appear to have been uplifted and regionally metamorphosed near the close of the Jurassic with accompanying intrusion of granitic batholiths. Such rocks have been described from outcrops north of the Great Valley in the Redding and Taylorsville area, as well as all along the Sierra Nevada. Exotic blocks of marble and other metamorphic rocks of undetermined age in the San Emigdio Mountains, and in the Temblor Range west of Fellows, may indicate such rocks were formerly also exposed south and southwest of the valley.

Uppermost Jurassic Rocks

Recent geologic studies of the Upper Jurassic and Cretaceous rocks of the Great Valley and environs has led to the conclusion that two entirely different suites of rocks were deposited at the same time in closely adjoining areas (Irwin, 1957). These two units are the Franciscan assemblage and the thick sequence of equivalent clastic rocks that are best exposed along the western edge of the Great Valley. Both the Franciscan and the Great Valley sequence have been proven through fossil evidence to range from Late Jurassic to Late Cretaceous. Consequently, it now appears that any discussion of the stratigraphy of the Great Valley must include the Franciscan not as "basement," but as a eugeosynclinal facies of the miogeosynclinal Great Valley sequence.

Franciscan Formation

The assemblage of rocks generally referred to as Franciscan is widely scattered throughout the west side of the Great Valley from Paskenta south to Parkfield. Isolated intrusions of ultrabasic rocks carrying Franciscan inclusions are present as far south as Cedar Canyon at the S¼ cor. T. 27 S., R. 18 E. This is the southernmost occurrence of Franciscan east of the San Andreas fault, and it is interesting that this locale is nearly as far south as the southward extent of the Great Valley sequence on the west side of the San Joaquin Valley. The two sequences seem to go hand in hand.

The Franciscan comprises a thick sequence of graywacke, dark shale, volcanic rocks of submarine origin (pillow lavas), chert, limestone, and some metamorphic rocks containing minerals of the glaucophane or blueschist facies. Serpentinites are commonly associated with the Franciscan rocks but are excluded from the formation because they appear to be intrusions. The above may appear from the description to be a heterogeneous assemblage, but it is so typical and distinct that most of the Franciscan outcrops are readily recognizable as such.

The base of the Franciscan has never been seen, but it has been inferred that the formation lies on an ultramafic (peridotite) basement. The top of the formation is also subject to question and has not been adequately defined. The contact between the Franciscan and the Great Valley sequence, where exposed, is always a fault so that the relationship between these major units is also difficult to deduce.

The thickness of the Franciscan cannot be calculated by any conventional stratigraphic means owing to its great deformation as well as to the lack of a known base or top. Adding thicknesses of sections that are thought to have been deposited at different times leads one to conclude that a minimum thickness of about 50,000 feet was deposited (Bailey and others, 1964).

The fossils that have been found in the Franciscan give a range in age of from Late Jurassic to Late Cretaceous. Megafossils are very rare, but Foraminifera in limestone and Radiolaria in chert are locally abundant. It is unfortunate that the limestones with their diagnostic microfossils are so small a part of the Franciscan that a great deal of the formation cannot be dated by this means.

The source of most of the Franciscan along the west side of the Great Valley appears not to have been the same (Klamath Mountains and Sierra Nevada) as that of the Great Valley sequence because of the lack of K-feldspar and lithologic dissimilarity of the rocks. It appears likely that, except for older pre-Knoxville Franciscan rocks, the source area was to the west or even from cannibalism of older Franciscan exposures. This latter source area during the Late Upper Cretaceous may have been the emergent central part of the Diablo Range, as shown by a stratigraphic hiatus in the Great Valley sequence in this area.

Knoxville Formation

The oldest known unit that can be considered to be a part of the Great Valley sedimentary sequence is the Knoxville Formation of the Late Jurassic age. The Knoxville, as a formational unit, is based mainly on faunal rather than lithic criteria and most commonly refers to the beds containing the Late Jurassic *Buchia piochii* (White, 1885, p. 19).

The Knoxville crops out along the west side of the Sacramento Valley from just north of Mount Diablo northward to beyond Paskenta to the Elder Creek fault zone. Its eastern limit is buried in the Valley beneath younger rocks. On the west side of the San Joaquin Valley several areas contain limited outcrops of rocks that have been assigned to the Knoxville because of their fossil content. Such areas are found in the Tesla, Pacheco Pass, Priest Valley, and Panoche quadrangles, in the Orchard Peak area, and southward along the crest of the Temblor Range between Bitterwater and Salt Creeks. In these latter areas, however, the Jurassic fossils are either mixed with Cretaceous assemblages or the rocks have been so inadequately studied that stratigraphic conclusions are not certain.

Lithologically, the Knoxville includes all varieties of clastic rocks ranging from shale to conglomerate, but dark-gray to black hackly fracturing shale or mudstone predominates. Massive lenticular conglomerates up to several thousand feet thick are erratically distributed in the mudstone. The sandstones are dark gray and of the graywacke type. The lower part of the section in some places contains volcanic flows, tuff beds, and chert.

The thickest sections of the Knoxville are in the Sacramento Valley, where south of Paskenta it is about 20,000 feet thick. In other places the preserved Knoxville section is less, but as the basal contacts are usually faults it is difficult to determine whether there was actually reduced sedimentation in a southward direction.

The basal contact of the Knoxville is invariably faulted against Franciscan or associated rocks. In most areas the upper contact with overlying Cretaceous rocks is gradational with similar lithologies above and below. At the north end of the Sacramento Valley, however, buried Knoxville rocks are presumed to be overlapped by Lower Cretaceous strata that in outcrop rest on basement.

The depositional environment of the Upper Jurassic rocks was marine but of fairly shallow water, and the limited faunas suggest a turbid, brackish or very cold water ecologic condition. The source of the sediments was apparently from the Klamath Mountains to the north and the Sierra Nevada to the east.

The Knoxville fauna includes common *Buchias* (= *Aucella*), scattered belemnites and ammonites, and rare Foraminifera. The index fossil is *Buchia piochii.*

Cretaceous Rocks

Miogeosynclinal Cretaceous rocks are present throughout the Great Valley as far south as western Kern County. The Early Cretaceous sediments have commonly been assigned to the Shasta Series and Late Cretaceous rocks to the Chico Group. As a rule, lithologic similarities throughout the section have made division into formations difficult so that the separation of the Cretaceous rocks into the Shasta Series and Chico Group has been based mainly on faunal rather than lithologic criteria. Except for areas of limited extent, the most commonly used subdivisions in the subsurface are also based on faunal content.

Lower Cretoceous (Shasta) Rocks

Lower Cretaceous rocks are widely exposed along the western margin of the Great Valley, but they do not extend to the eastern side. The distribution of these rocks in the Sacramento Valley is fairly well documented but in the San Joaquin Valley they have not been as thoroughly studied. The apparent absence, near the base, of faunal zones found elsewhere in this interval, has led some geologists to place an unconformity at the lower boundary of the series, but the generally unfossiliferous character of the lower hundreds of feet of strata could account for this discrep-

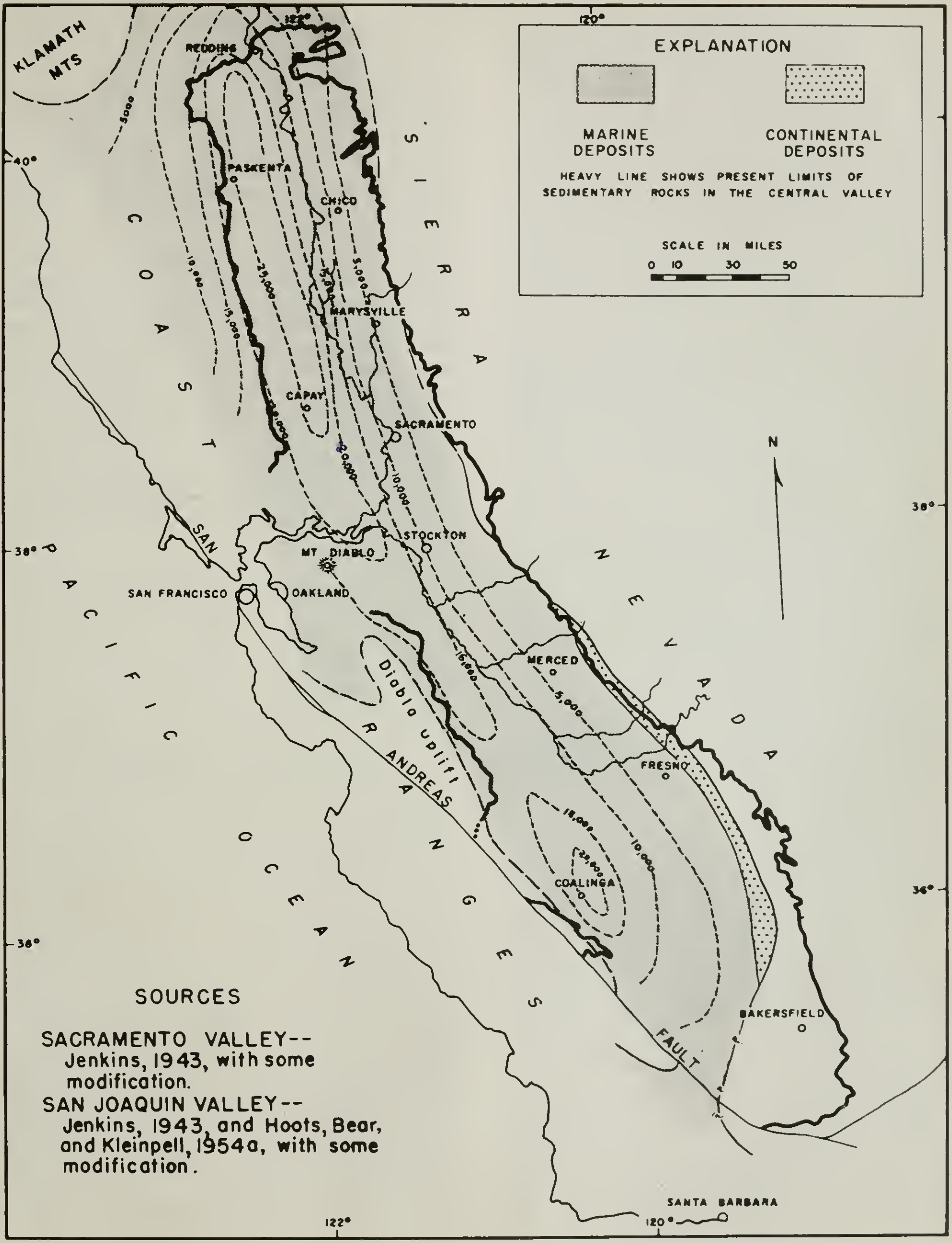

Figure 2. Distribution and thickness of Cretaceous sediments in the Great Valley at the beginning of Tertiary time. After Repenning (1960, fig. 4).

ancy equally well. The consensus of geologists now is that the Lower Cretaceous rocks are conformable at their base with the Knoxville and also at their upper contact with the Chico, except locally at the margins of the depositional basin where Upper Cretaceous rocks overlap the older units.

The Lower Cretaceous Shasta Series consists of over 20,000 feet of mudstone, siltstone, conglomerate, graywacke, and minor limestone. The mudstones cover large areas and are the dominant rock type. The graywacke sandstones occur in limited amounts, whereas the conglomerates attain great thicknesses but are very lenticular. In parts of the section the mudstones and sandstones are rhythmically interbedded, and the sandstones exhibit graded bedding indicative of deposition by turbidity currents.

The Lower Cretaceous sediments locally contain a moderately abundant and diversified megafossil fauna. Although ammonites are generally uncommon, with the help of pelecypods every stage of the Lower Cretaceous has been identified. Foraminifera occur throughout the section but are most numerous in the upper portion where some attempts to use them for zoning have been made.

The distribution of the megafossils, with many more in the northern area, indicates that the depositional environment for the Lower Cretaceous rocks was shallower in the north portion of the Great Valley than in other areas of outcrop. Farther south the predominant fine clastic lithology and the abundance of turbidities points to deposition below wave base for most of the section. One exception to this is the unusually great areal extent of the *Buchia crassicollis* fauna, which is ubiquitous in coarse sandstones or massive conglomerates near the base of the Lower Cretaceous. In the Sacramento Valley the coarser clastics to the north have been cited as an indication that the sediments were derived from a source area to the north or the northeast.

Upper Cretaceous (Chico) Rocks

Upper Cretaceous rocks are much more widespread than the previously described older Mesozoic units. They crop out throughout the west side of the Sacramento Valley and extend eastward beneath younger rocks in the valley to exposures in the eastern foothills where they are much thinner. The type Chico area on the east side of the Sacramento Valley represents only a small part of the Upper Cretaceous exposed on the west side. In the San Joaquin Valley, the Upper Cretaceous rocks crop out through the length of the Diablo Range and extend southward into the northern Temblor Range.

The Upper Cretaceous rocks have been studied in many areas in recent years, and many formations, members, and faunal zones have been described and named. In the Sacramento Valley, Kirby (1943) divided the upper part of the Upper Cretaceous strata exposed on the west side from Putah Creek in Yolo County to Logan Creek in Glenn County into six formations. At the northwest end of the Sacramento Valley, Murphy and Rodda (1960) described the Bald Hills Formation. In the northern San Joaquin Valley, from Mount Diablo southward to Coalinga, the Upper Cretaceous rocks have been subdivided into the Panoche and Moreno Formations. Further subdivision is made in the Coalinga area where two prominent sandstone members separated by a shale in the Panoche have been named in descending order the Brown Mountain Sandstone, Ragged Valley Shale, and Joaquin Ridge Sandstone.

Goudkoff (1945) subdivided the Upper Cretaceous rocks into several microfaunal zones lettered from A to H. These zones have been widely accepted as working units by most geologists dealing with the Cretaceous of the Great Valley, and they provide the basis for most subsurface correlations. Other Upper Cretaceous units, however, have been informally named by geologists working with well bore information in particular areas, and several of these units that are now widely known and used should be formally described and named. These units have such names as Dobbins Shale, Sacramento Shale, Lathrop Sand, Winters Sand, Tracy Sand, Starkey Sand, Delta Shale, Garzas Sand, Kione Sand and others.

The most distinct lithologic break present in rocks exposed along the west side of the Sacramento Valley separates the lower and upper portions of the Upper Cretaceous strata rather than the Lower and Upper Cretaceous beds. The sediments of the lower Upper Cretaceous are lithologically more like the Lower Cretaceous than the overlying Upper Cretaceous beds.. Beds that represent the lower part of the Upper Cretaceous can be readily separated and mapped as a unit throughout Colusa, Glenn, Tehama, and Shasta Counties, but south of Colusa County there is no apparent distinction between beds assigned to the lower part of the Upper Cretaceous and those belonging to the Lower Cretaceous. In southern Colusa County, the lower Upper Cretaceous is thickest (about 6,500 feet) and it thins northward. Northeast of Ono in Shasta County it is completely overlapped by the upper Upper Cretaceous strata. As is the case in the Lower Cretaceous, sandstones and conglomerates are important components in the north and shale is predominant to the south. However, in Colusa County, a persistent conglomerate, the "Salt Creek" Conglomerate (Dennings, 1954), marks the base of the lower Upper Cretaceous. Similar though discontinuous conglomerates are found more or less at the same stratigraphic level at the north end of the valley. These conglomerates carry reworked Lower Cretaceous clasts, which is interpreted by some geologists as indicating a period of uplift and erosion in local marginal areas at the end of the Lower Cretaceous.

An upper, major, part of the Upper Cretaceous on the west side of the Sacramento Valley has been well described by Kirby, whose formation—the Venado, Yolo, Sites, Funks, Guinda and Forbes—were deposited during this period. Alternations of sandstone with siltstone and shale comprise these formations, with the finer clastics being slightly predominant. Conglomerates are much less abundant than in the underlying older Cretaceous sequence, and most of those present are in the lowermost unit, the Venado Formation. Eastward across the Sacramento Valley equivalents of the Venado, Yolo, and Sites Formations are overlapped by the younger formations. No rocks older than Venado have been penetrated by wells in the alluviated portion of the Sacramento Valley, and no beds younger than Forbes crop out, except at the extreme southern end. The thickest section of strata assigned to the upper part of the Upper Cretaceous is along Putah Creek, on the Solano-Yolo County line, where 15,000 feet are present. Most of the gas produced in the fields recently discovered in the central and west side of the Sacramento Valley comes from lenticular sands equivalent in part to the Forbes Formation.

In the San Joaquin Valley, the Panoche Formation of the type locality (Panoche Hills-Fresno County) has been subdivided into six formations by Payne (1962). His subdivisions in ascending order are the Redil, Benito, Ciervo, Marlife, Television, and Uhalde Formations. They are composed of shale, sandstone, and conglomerate, with shale predominating, and they attain an aggregate thickness of over 22,000 feet. The overlying Moreno Formation consists of about 3,000 feet of interbedded organic shale and fine-grained sandstone, with a sand-shale ratio about 0.12. The contact between the Cretaceous and Tertiary rocks is gradational and has been placed within the Moreno.

The southernmost occurrence of Upper Cretaceous rocks in the Great Valley is at the headwaters of Salt Creek in the SE¼ of T. 29 S., R. 20 E., in western Kern County, where there are exposed interbedded shale and sandstone strata assigned by Dibblee (1962a) to the Panoche. At this point the Panoche is overlapped from the south by Tertiary beds, and its southward subsurface continuation is not known.

Source areas for the Upper Cretaceous rocks in the northern Sacramento Valley have not been positively identified, but the Klamath Mountains and Sierra Nevada are the most likely sources. Undoubtedly the Sierra Nevada also contributed substantially to the sediments deposited during Late Cretaceous time in the southern Sacramento Valley and the northern San Joaquin Valley, but studies of sand distribution in the subsurface of these areas indicate that a western source also existed during certain periods (Callaway, 1964; Hoffman, 1964). The strongest evidence for a western source is the fact that thick sand bodies appear to change facies to shale in an eastward direction. Parallel studies of the clasts and detritus in the west side outcrops have not been definitive enough to establish either a western or eastern source.

Tertiary Rocks

Development of the general form of the Tertiary basins began with tectonic movements near the close of the Late Cretaceous Period. These movements elevated many Coast Range areas, including the Diablo Range adjacent to the northern San Joaquin Valley and the larger regional uplift along the entire west side of the Sacramento Valley. The ancestral Tertiary San Joaquin and Sacramento Basins were thereby brought into being as restricted troughs of deposition lying between the uplifted western Coast Ranges and the eastern Sierra Nevada landmass. In these troughs marine and continental deposition took place throughout the Tertiary Period.

Tertiary rocks, ranging in age from Paleocene to Pliocene and of both marine and continental origin, were continuously deposited at one place or another in the Great Valley. The greatest accumulation of these strata is in the southern San Joaquin Valley, where they are more than 35,000 feet thick. In the Sacramento Valley at least 12,000 feet of Tertiary rocks occur in the southern part, or Delta area. These points of greatest accumulation, and their relationships, indicate that the Tertiary marine rocks were laid down in two separate basins. These basins, the San Joaquin and the Sacramento, were separated by a faulted trans-valley Cretaceous high called the Stockton Arch (Hoots and others, 1954). Northward toward this Stockton Arch the lower Tertiary marine sediments of the San Joaquin Basin appear to thin and in the vicinity of Modesto they are truncated by overlying continental sediments. Because of this truncation one cannot determine whether lower Tertiary sediments were deposited and later eroded from the Stockton Arch or were never deposited there. On the north side of the arch a thick section of marine Tertiary sediments abuts the large fault which marks the north edge of the arch (Am. Assoc. Pet. Geologists, 1958, no. 10), indicating its crest during the lower Tertiary deposition was not in its present position near Stockton but farther south in the vicinity of Modesto. In the Sacramento Basin the Tertiary marine section also thins northward and is overlapped by Pliocene continental sediments north of Chico.

The depositional history in the Great Valley during the Tertiary was very complex. Rapid lateral changes in thickness and lithology are common, and as a result a large number of units have been named, both formally and informally.

Paleocene Rocks

Rocks of Paleocene age are present in both the northern San Joaquin Valley and in the southern Sacramento Valley. In both areas deposition appears to have been continuous from Cretaceous into Paleocene time, and time boundaries do not necessarily coincide with lithologic boundaries.

Formations in the San Joaquin Valley which have been assigned to the Paleocene include the upper part

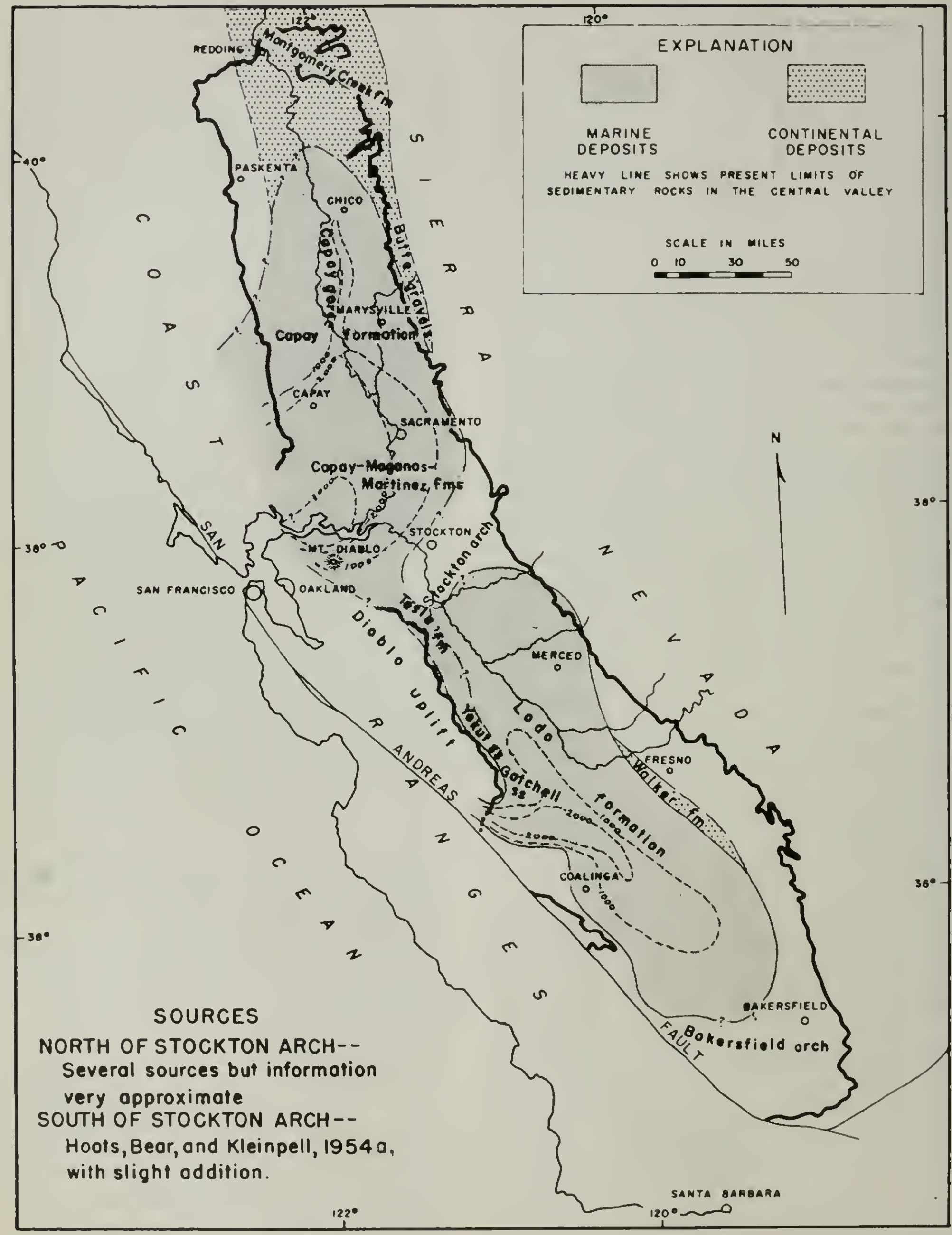

Figure 3. Distribution and thickness of Paleocene and lower Eocene sediments in the Great Valley at the beginning of late Eocene time. After Repenning (1960, fig. 5).

of the Moreno, the Laguna Seca, the lower portion of the Lodo, the Dos Palos, and the Weyant sand of the Helm oil field. They are best developed along the west side of the Valley north of Coalinga. However, in the southern San Joaquin Valley, Paleocene rocks seem to be absent and probably they do not extend south of a line drawn between Coalinga and Hanford. Toward the Stockton Arch in the vicinity of Modesto, Paleocene rocks are truncated by the overlying Miocene-Pliocene continental beds (Hoffmann, 1964). Eastward from the central part of the valley the Paleocene units are truncated by the significant unconformity at the base of upper Eocene.

In the southern Sacramento Valley the Paleocene is represented by the Martinez Formation and the lower portion of the Meganos Formation. The type Martinez contains rocks younger than those considered to be of Paleocene age, but in outcrop in other areas and in the subsurface it has been restricted to the Paleocene. The Martinez pinches out in exposures south of Mount Diablo, but is present in the subsurface to the east and north. At the type section it consists of 2,000 feet of silty claystone with thin interbeds of sandstone and conglomerate. The younger Paleocene rocks generally are assigned to the lower part of the Meganos Formation, which is dominantly sand with shale interbeds. Meganos sediments fill a meandering channel or gorge several hundred feet deep, which has been found by drilling and other methods to extend from the vicinity of the Thornton gas field (Silcox, 1962) westward through the Brentwood oil field.

Recognition of Paleocene strata in many places depends solely on faunal content. In some areas of outcrop megafossils have been used, but in the subsurface Foraminifera are most useful. Laiming (1943) subdivided the Eocene (including the Paleocene) into faunal zones lettered A through E, with the Paleocene section forming his D and E zones.

Eocene Rocks

Eocene rocks of both marine and continental facies are widespread throughout the Great Valley. The thickest deposition took place along the western margin of the basin with greatest accumulation in the Delta area of the Sacramento Valley and at Devils Den in the San Joaquin Valley. Sand distribution patterns suggest that source areas for the Eocene sediments were highlands lying on all sides of the basin.

Lower Eocene Rocks. Lower Eocene rocks in the Sacramento Valley are assigned to the Capay Formation and the upper part of the Meganos Formation; in the San Joaquin Valley they are assigned to the upper part of the Lodo Formation and to the Yokut Sandstone. South of Mount Diablo, Huey (1948) has described the Tesla Formation and assigned it to the lower Eocene. As is the case with the Paleocene, no lower Eocene rocks are present in the southern San Joaquin Valley.

In the Sacramento Valley lower Eocene rocks are exposed along the west side as far north as Chico. In the central Sacramento Valley the lower Eocene is buried, but is known to be largely confined to a deep narrow subsurface gorge which has been named the "Capay Gorge" (Repenning, 1960) or "Princeton Gorge" (Am. Assoc. Pet. Geologists, 1960, no. 13; Safonov, 1962). Although most of the lower Eocene rocks of the Sacramento Valley are referred to the Capay Formation, some in the Mount Diablo area and in the nearby subsurface are assigned to the upper part of the Meganos. The Capay Formation, and the portion of the Meganos assigned to the lower Eocene, is composed of dark shale, which appears to have been deposited in a basin with stagnant bottom conditions. In general, the Capay thickens westward, but throughout most of the southern Sacramento Valley it has a rather uniform thickness of 300 to 400 feet. At the type locality, however, it is about 2,500 feet thick, and it fills the "Capay Gorge" to depths of 2,000 feet.

Lower Eocene strata are discontinuous across the Stockton Arch, but south of it lies the Lodo Formation that is similar lithologically to the Capay but with a much larger content of sand and fewer features suggesting stagnant marine conditions. These differences suggest that the Stockton Arch acted as a barrier between two basins of deposition during the early Eocene.

In the San Joaquin Valley the lower Eocene was deposited as far south as the Bakersfield Arch, but is not found south of it (Hoots and others, 1954). Deposition began with the Lodo Formation, which has been subdivided into the lower Cerros Shale, the intermediate Cantua Sandstone, and the upper Arroyo Hondo Shale. The Lodo has a maximum thickness of 5,000 feet in the west side outcrops but in many areas is less than 1,000 feet thick. In going eastward the Lodo Formation pinches out by thinning from the bottom and truncation at the top. The Yokut Sandstone overlies the Lodo Formation along the western side of the San Joaquin Valley between Coalinga and the Panoche Hills. In outcrop it is usually about 200 feet thick, but it is thicker to the east and south where in the subsurface it is known as the Gatchell Sand.

The Tesla Formation where exposed along the western edge of the northern San Joaquin Valley attains a thickness of 2,000 feet. It is predominantly a sandstone unit and contains megafossils indicating it is equivalent in age to the Lodo and Yokut. Just south of Mount Diablo it is overlapped by Miocene units.

Minor amounts of continental sediments may have been deposited at this time in the eastern San Joaquin Valley forming the lower part of the Walker Formation, and in the northern Sacramento Valley forming the Montgomery Creek Formation.

The early Eocene closed with a marked regression of the sea that resulted from uplifts along the margins of the Great Valley and from elevation and folding

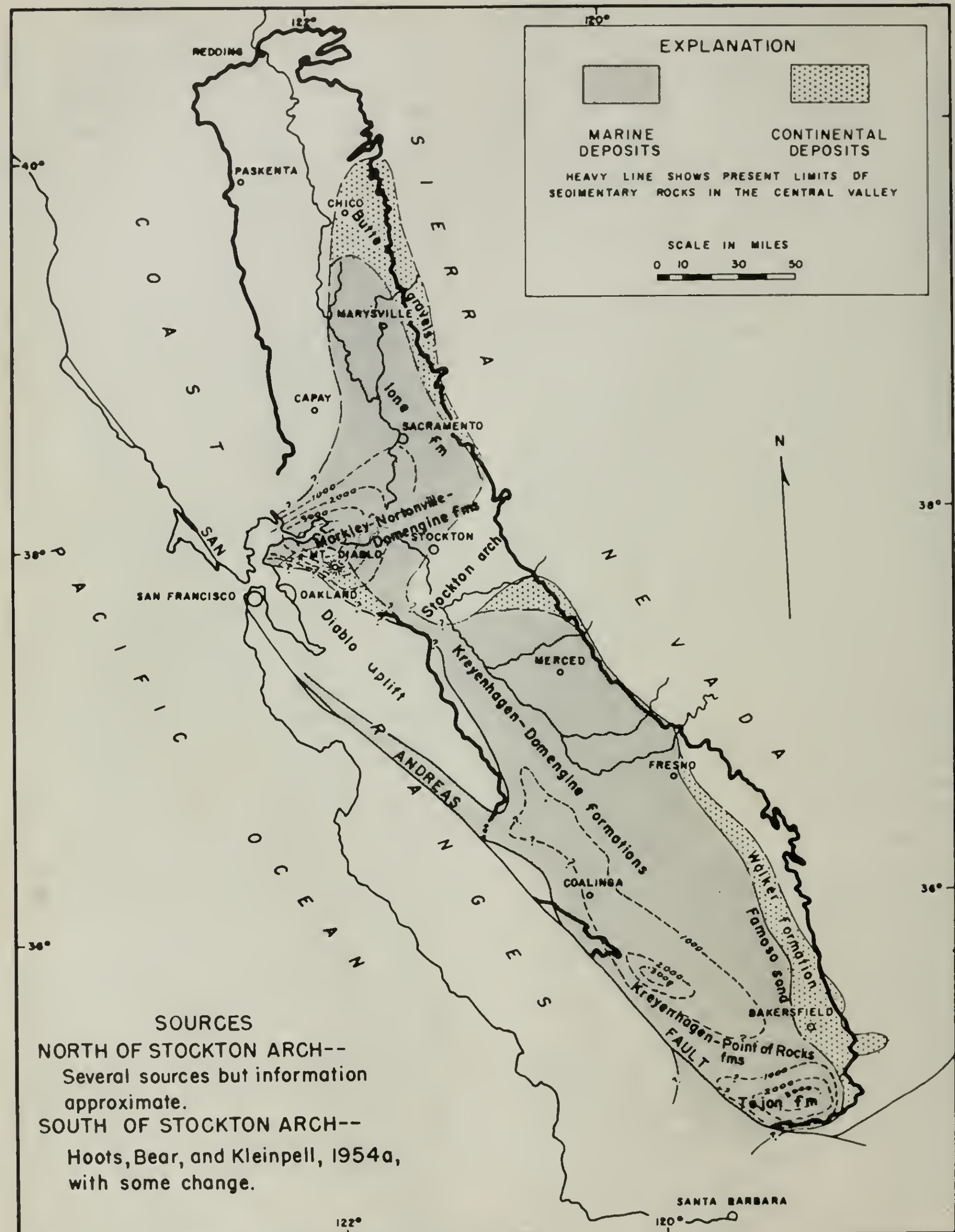

Figure 4. Distribution and thickness of upper Eocene sediments in the Great Valley at the beginning of Oligocene time. After Repenning (1960, fig. 6).

of some previously submerged basin areas in the valley.

Upper Eocene Rocks. Regional subsidence at the beginning of late Eocene time brought about an extensive marine transgression in the San Joaquin Valley and to a lesser extent in the Sacramento Valley, forming a significant unconformity between the lower and upper Eocene. In the San Joaquin Valley, this unconformity is at the base of the Domengine Sandstone, or beneath younger units that overlap the Domengine at the margin of the basin. In the Sacramento Valley, the unconformity is also present at the base of Domengine in the Delta area and is at the base of the Ione Formation to the north and east.

In the San Joaquin Valley the upper Eocene rocks comprise a fairly complete cycle of basin deposition, and the different cycles and lithologic facies in different areas have received numerous names. The earliest transgression of the late Eocene sea deposited in the northern San Joaquin Valley a gritty or conglomeratic sandstone called the Domengine Formation, and at about the same time in the area south of Bakersfield the Uvas Conglomerate Member of the Tejon Formation was deposited. Well bore data suggest that the Domengine and the older portion of the Tejon were separated in the vicinity of Bakersfield by a barrier—the Bakersfield Arch (Hoots and others, 1954). Subsequent Eocene deposition covered the Bakersfield Arch, but differences between the Tejon fauna and the Kreyenhagen fauna in rocks farther north indicate that the depositional environment north and south of the Arch was not the same. The Tejon Formation at the south end of the valley consists of 2,500 to 4,000 feet of sandstone, siltstone, and clay shale believed to have been derived from the nearby San Emigdio and Tehachapi Mountains still farther south. At the same time farther north and west in the San Joaquin Valley the Domengine, Canoas, Point of Rocks and Kreyenhagen Formations were deposited. The Domengine is quite variable in thickness, ranging from a few feet of "grit zone" to 1,000 feet of strata in the Mount Diablo area. An equivalent of the Domengine found in the Kettleman Hills area is the thick (1,000± feet) Avenal Sandstone. The Canoas consists predominantly of clay shale and in certain areas, such as Devils Den, it contains sand lenses of significant thickness. Overlying the Canoas is the Point of Rocks Sand, which has a maximum of several thousand feet. The Kreyenhagen Formation consists of a thick and widespread sequence of shale which crops out along the western side of the San Joaquin Valley from south of Pacheco Pass to the vicinity of Devils Den. It extends in the subsurface southward and eastward towards the central part of the basin. The Kreyenhagen, Point of Rocks, and Canoas, are in reality depositional facies of one another laid down in different environments during the upper Eocene. Farther east these marine units change facies to a near-shore deposit known as the Famosa Sand, which, in turn, grades still farther eastward into nonmarine clays and sands that have been included in the Walker Formation. The Walker, however, encompasses more than just Eocene sediments, as the term has been used to include nonmarine sediments of Eocene to early Miocene age along the east side of the southern San Joaquin Basin (Rudel, 1965). The Kreyenhagen becomes sandier to the north and is correlative with the Nortonville and Markley Formations of the Mount Diablo area.

In the Sacramento Valley the oldest upper Eocene rocks are represented by the Ione Formation, which is present throughout the central part of the valley. In most places the Ione is an unusual nearly massive quartzose sand with a high percentage of interstitial clay, but a shale which overlies the sand in the center of the basin is generally also assigned to the Ione. The formation throughout most of the area is about 200 feet thick, although near Mount Diablo an Ione equivalent, which lies in the Domengine, is about 500 feet thick. The Ione grades northeastward into the Butte Gravels, which overlie the granitic basement along the eastern edge of the valley. Throughout the central and northern part of the Sacramento Valley the Ione represents the last marine invasion, and it is unconformably overlain by Oligocene or Miocene volcanic rocks or nonmarine Pliocene sediments. In the southern part of the Sacramento Valley, however, younger Eocene rocks are marine and include, in ascending order, the Domengine, Nortonville, and Markley Formation. The Domengine Formation in outcrop along the north side of Mount Diablo is about 1,000 feet thick and consists of a lower shale and coal unit, 500 feet of sandstone called "Ione," and 800 feet of upper shaly brown sandstone. In the subsurface of the Delta area, in the southern Sacramento Valley, the lower unit varies in thickness and character but the typical white of the "Ione" sand and brown (greenish in subsurface) of the upper sandstone are prominent. Towards the eastern margin of the basin the Domengine thins and the units lose their individual character. The younger Markley Formation on the north flank of Mount Diablo is composed of a lower 2,000-foot sandstone member, a 700-foot shale unit, and an upper 500-foot sandstone. The intermediate shale unit has been correlated with the Kreyenhagen Shale of the San Joaquin Valley. The basal unit of the Markley has been called the Nortonville Formation, and in the subsurface of the southern Sacramento Valley this is a relatively widespread unit of marine shale locally containing thin sandy beds. A well-documented buried channel—the Markley Gorge—filled with upper Eocene and Oligocene sediments extends in the subsurface from southeast of Marysville beneath Sacramento and continues to the south towards the Rio Vista Gas Field. (Almgren and Schlax, 1957; Safonov, 1962). To the north up the regional gradient of the Sacramento Valley, the channel cuts down into the Upper Cretaceous Starkey Sand but in

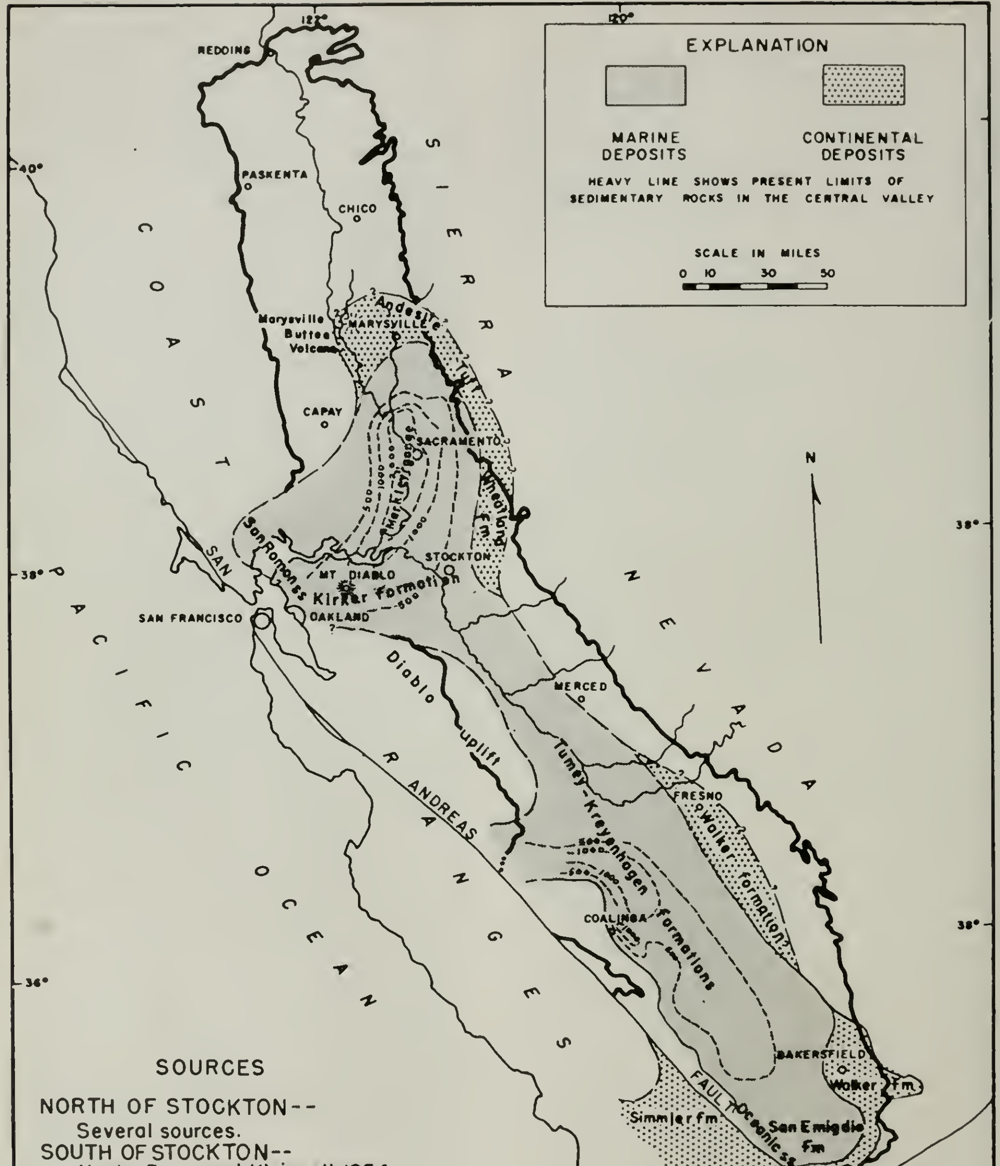

Figure 5. Distribution and thickness of Oligocene sediments in the Great Valley at the beginning of Miocene time. After Repenning (1960, fig. 7).

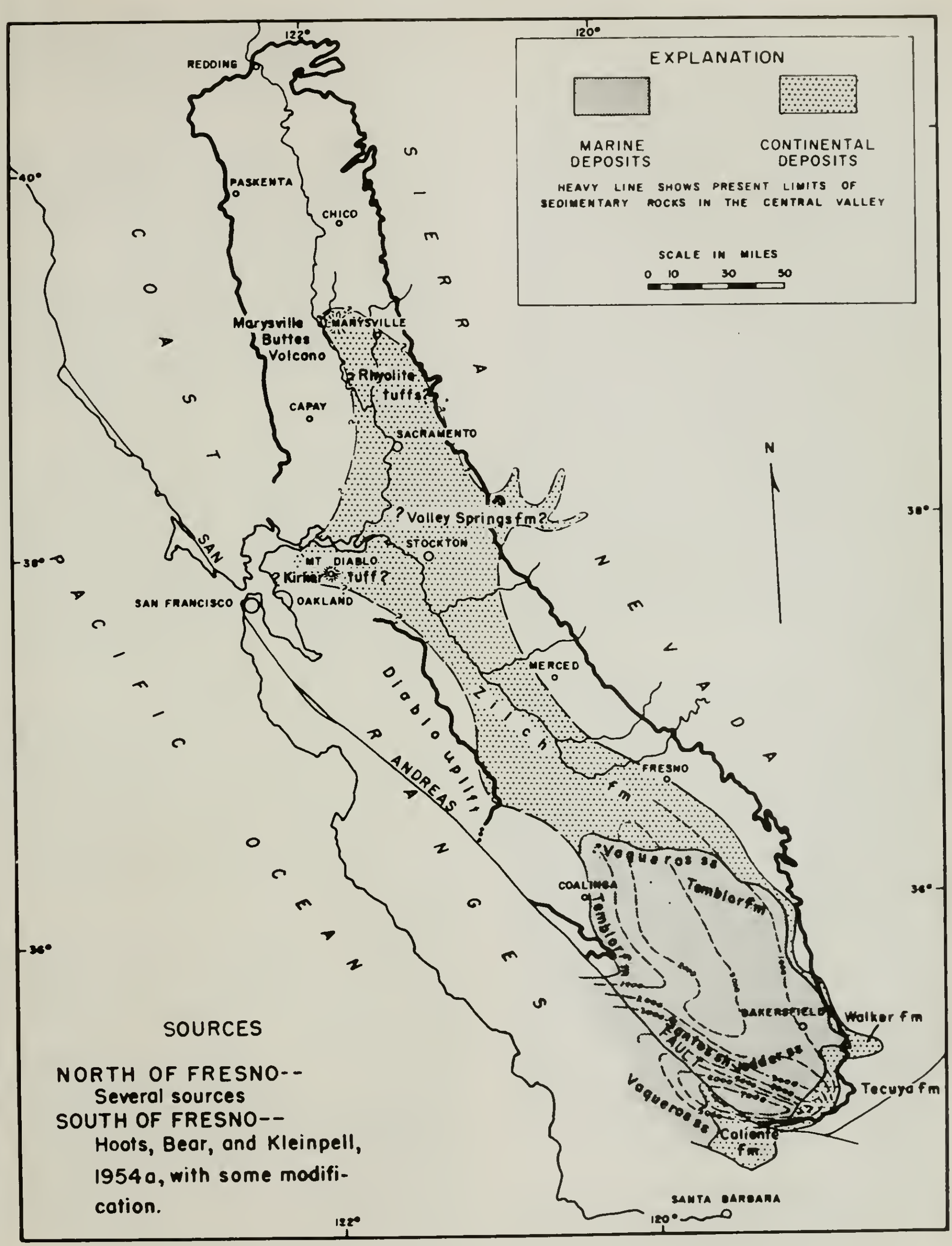

Figure 6. Distribution and thickness of lower Miocene sediments in the Great Valley at the beginning of middle Miocene time. After Repenning (1960, fig. 8).

the vicinity of Rio Vista it only breaches the Capay Shale.

Oligocene Rocks

Regional uplift at the close of Eocene time affected the basin areas of the Great Valley, with the result that Oligocene marine deposits are thinner and more restricted in extent than the Eocene marine rocks.

Oligocene rocks in the San Joaquin Valley includes such marine units as the Tumey Shale (including in certain areas the upper part of the Kreyenhagen Shale) the Oceanic Sand, the San Emigdio Formation and a portion of the Pleito Formation. Continental deposits are represented by the Tecuya and the Walker Formations. The Tumey Shale is present along the western and central parts of the San Joaquin Valley from the Panoche Hills southward to the Bakersfield Arch, and along the west side it includes a basal sandstone which crops out north of Coalinga. Farther south, in the subsurface between Devils Den and McKittrick, a basal sand that has been termed the Oceanic Sand is present. South of the Bakersfield Arch the predominantly marine sandstone and siltstone of the San Emigdio Formation and the lower part of the Pleito Formation were deposited near the present base of the San Emigdio Mountains. At the southeastern extremity of the Valley a series of continental deposits was laid down in late Oligocene and early Miocene time—these rocks have been named the Tecuya Formation. Similar continental rocks, known as the Walker Formation, were deposited farther north along the east side of the San Joaquin Valley.

In the Sacramento Valley, Oligocene rocks are represented by the Kirker Formation along the western margin, and possibly by the Wheatland Formation along the southeastern margin. The San Ramon Sandstone of the Berkeley Hills is of the same age. The Kirker Formation, which was described in the area north of Mount Diablo, consists of 400 feet of sandstone and tuff resting unconformably on underlying rocks. Very little is known of the subsurface distribution as the available information is inadequate to separate it from younger continental sediments lying on it. The Markley Gorge in the subsurface of the Sacramento Valley has been reported to contain marine Oligocene sediments as well as upper Eocene strata.

In nearly all parts of the Great Valley an erosional unconformity separates Oligocene or older units from the overlying Miocene rocks. In the southern San Joaquin Valley, especially in the basinal portions, the discordance is well developed, with marked angularity and truncation of beds north of the Panoche Hills, and on the Stockton Arch pre-Miocene rocks are truncated across the whole width of the valley.

Miocene Rocks

The Miocene rocks of the Great Valley have very complex facies variations, and the stratigraphic nomenclature, both formal and informal, reflects the many lithologic dissimilarities of the different depositional environments. In general, the basin contains nonmarine clays, sands, and conglomerates along its margins, marine near-shore sandstones in the intermediate areas, and marine, deep-water, shales and sandstones in the center.

The seas were confined to the southern San Joaquin Basin during the early Miocene but gradually, probably with some recessions, spread northward so that by late Miocene time marine sediments were being deposited along most of the western side of the Great Valley at least as far north as Vacaville.

The Miocene rocks were derived from the granitic highlands on the east and south and from the Franciscan terranes exposed on the west along the rising Diablo uplift between Coalinga and Mount Diablo. Along the southwest margin of the basin, granitic source areas also appear at times to have been present, perhaps as a result of uplifts in the area west of the San Andreas fault.

Lower Miocene Rocks. Marine sediments of early Miocene age are restricted to the southern San Joaquin Valley where they have been segregated into numerous units. On the west side of the basin these units have been named, in ascending order, Salt Creek Shale, Phacoides Sand, Lower Santos Shale, Agua Sand, Upper Santos Shale, Carneros Sand, and Media Shale. The east side equivalents are the Vedder Formation, Pyramid Hill Sand, Jewett Silt, Freeman Silt, and the lower portion of the Olcese Sand. In the Coalinga-Kettleman Hills area the lower Miocene marine rocks have been subdivided more loosely into the "Vaqueros" and lower "Temblor."

Nonmarine lower Miocene rocks are represented along the south and southeast margin of the San Joaquin basin by the upper part of the Tecuya and Walker Formations, and north of Coalinga continental deposits that have been named the Zilch Formation, or simply "continental Miocene," probably include some lower Miocene rocks. In the southern Sacramento Valley such units as the Valley Springs Formation and the Kirker Tuff may include deposits of early Miocene age.

Uplift of the Tehachapi-San Emigdio area in early Miocene was accompanied by volcanism that laid down basalt and dacite flows at the south end of the valley. Ash beds and bentonites in the Freeman Silt and at the top of the Vedder also reflect volcanism in the lower Miocene.

Unless one calls upon large lateral displacement along the San Andreas fault, it is difficult to determine through what inlet the seas entered the San Joaquin Basin during lower Miocene time. No marine lower Miocene rocks occur anywhere immediately west of the San Andreas fault opposite the San Joaquin marine basin. This relationship of a thick marine section of rocks east of the San Andreas fault adjacent to a nonmarine section west of the fault continues to

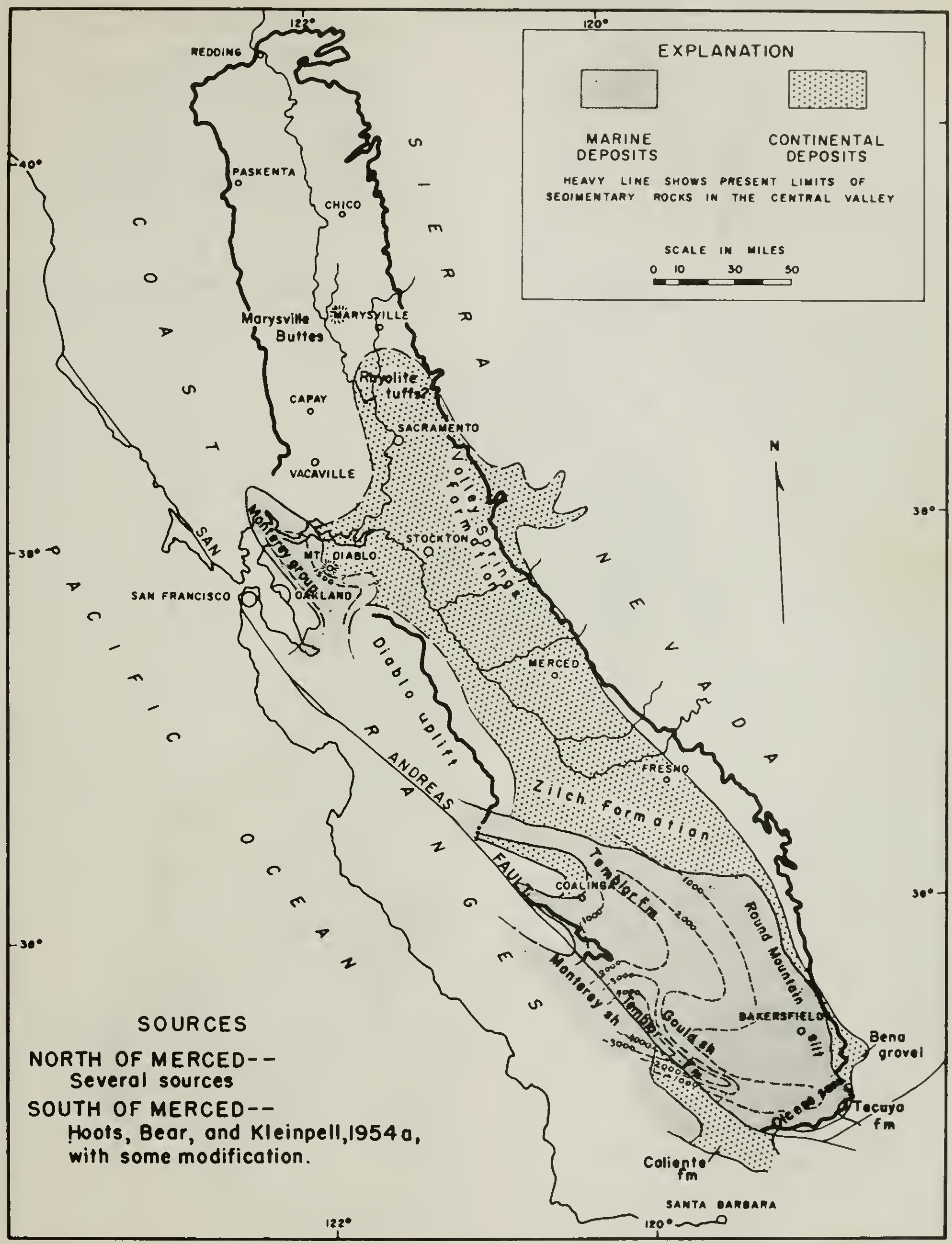

Figure 7. Distribution and thickness of middle Miocene sediments in the Great Valley at the beginning of late Miocene time. After Repenning (1960, fig. 9).

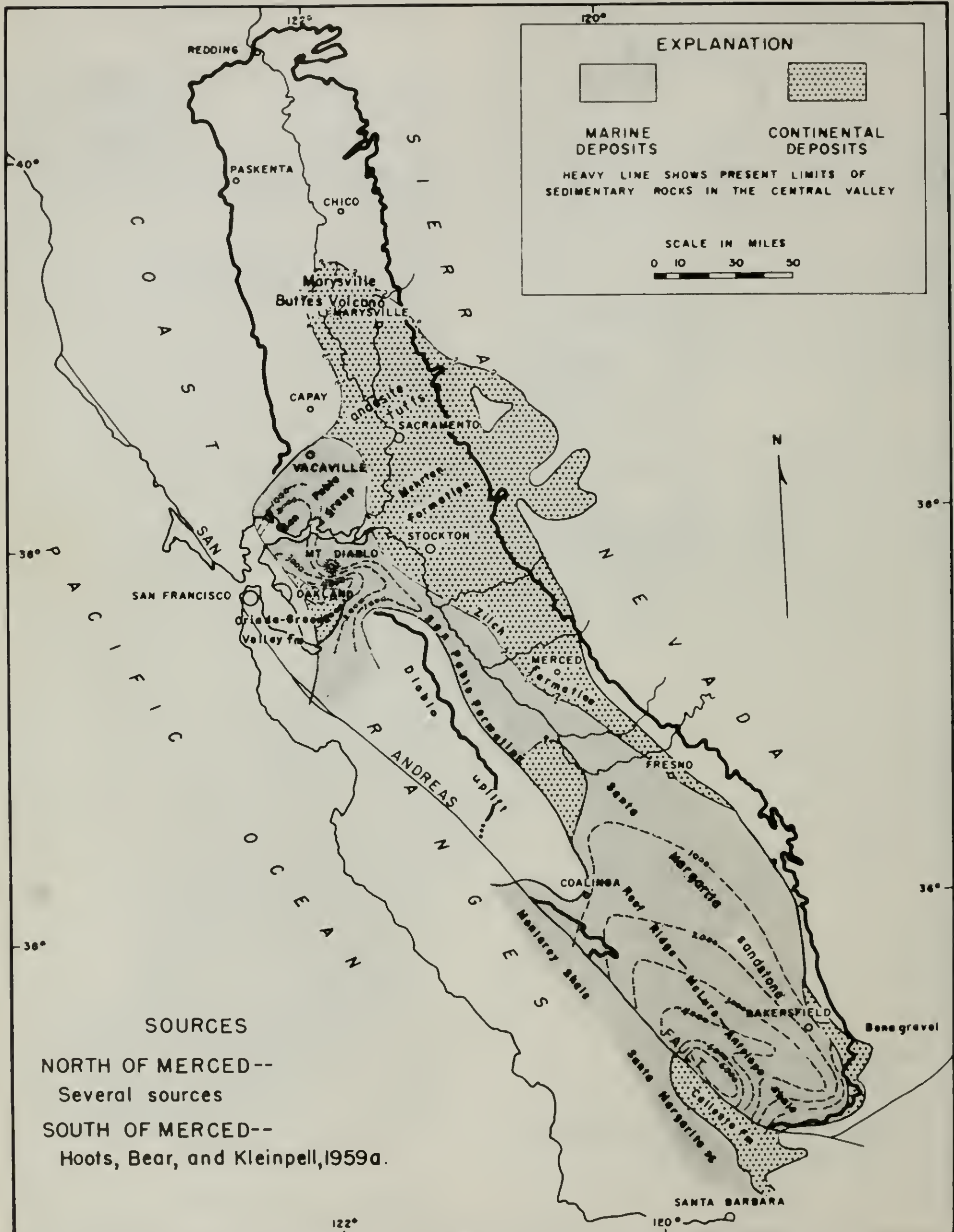

Figure 8. Distribution and thickness of upper Miocene sediments in the Great Valley at the beginning of Pliocene time. After Repenning (1960, fig. 10).

show up on paleogeographic maps drawn to represent various intervals throughout the remainder of the Miocene.

The thickest sequence of lower Miocene rocks in the Great Valley lies in the southwest portion of the basin where several thousand feet of marine sediments were deposited. Pulsating movements of the sea in the area of the San Joaquin Basin during lower Miocene time are suggested by basal conglomerates (or "grits") at the base of the Salt Creek Shale (base of Miocene), at the base of the Phacoides Sand, and at the base of several units of the Vedder Sand.

Middle Miocene Rocks. Deposition of marine rocks in the Great Valley in the middle Miocene, as in lower Miocene time, was limited to the southern half of the San Joaquin Basin. On the west side of the Valley, these rocks have been assigned in ascending order to the Button Bed Sand, Gould Shale, and Devilwater Silt. On the east side, equivalent marine rocks are encompassed in the Olcese Sand and Round Mountain Silt. In the Coalinga-Kettleman Hills area the middle Miocene is represented by the upper part of the Temblor Formation. To subdivide the marine middle Miocene rocks into more discreet and local units, especially in the subsurface, many informal names are commonly used by petroleum geologists. In this category fall such names as Kettleman sand, Belridge sand, Nozu sand, Reserve sand, Upper and Lower Variegated, Big Blue, and lower Maricopa shale.

A long, narrow trough which was the site of deposition of the marine Temblor Formation occupied the area of the present Vallecitos syncline northwest of Coalinga (Flynn, 1963). This trough may have provided the outlet from the San Joaquin Basin to the western sea.

Nonmarine sediments of considerable thickness were also deposited in the Great Valley during middle Miocene time. Areas of extensive nonmarine deposition occur throughout the basin north of Coalinga and along its eastern and southeastern margins. These central valley terrestrial beds have been called the Zilch Formation or "continental Miocene". At the southern extremity of the valley terrestrial deposits of middle Miocene age have been assigned to the upper portion of the Tecuya Formation, and north of the White Wolf fault and south of the Kern River similar rocks comprise the Bena Gravels.

Middle Miocene was a time of local uplifts along the margins of the San Joaquin Basin. Evidence for this is found in the coarse Franciscan detritus found in the Big Blue and Upper and Lower Variegated Members of the Temblor Formation in the Coalinga area, and in the presence of nonmarine or very coarse deposits in the middle Olcese Sand and Round Mountain Siltstone (Bena fanglomerate lenses).

As the middle Miocene seas were restricted to the southern end of the Great Valley only nonmarine deposits, assigned to the Valley Springs Formation, are present in the Sacramento Valley. West of Mount Diablo there are marine sands and shales of the Monterey group but they are not Great Valley deposits.

The thickness of middle Miocene rocks varies to a great degree, depending on their position in the basin. The greatest accumulation appears to be in the northern Temblor Range, where the marine sediments are more than 4,000 feet thick (Seiden, 1964).

Upper Miocene Rocks. Deposition of marine rocks was more widespread during late Miocene time than earlier in the Miocene, though the distribution and persistency of the sea still favored the southern San Joaquin Valley, where more than 6,000 feet of strata were deposited.

On the west side of the basin, the marine units of the upper Miocene are primarily shale and have been called the Reef Ridge, McLure, and Antelope Shales. Locally on the west side very contrasting facies of shale, diatomite, chert, and even conglomerate were deposited adjacent to, and interspersed with, each other. Toward the east a great portion of the marine upper Miocene is taken up by a subsurface wedge of sand, which has been termed the Stevens Sand. Sands are also present in local channels in the subsurface near the west side of the basin, and have received such local names as Leuthholtz, "555", and Asphalto Sands. A similar environment appears to be present along the eastern limit of the Stevens Sand deposition, which was perhaps at the hinge line of the basin, where sands at the Rosedale and Bellevue oil fields have long, narrow trends. East of the deep-water Stevens Sand province, marine rocks are represented by the widespread Santa Margarita sand of shallow marine origin. Other local marine upper Miocene units in the subsurface on the east side of the San Joaquin Basin have been named Fruitvale Shale and Wicker Sand.

Towards the eastern margin of the San Joaquin Basin, the Santa Margarita sand grades into the upper portion of the nonmarine Bena Gravels. Northward it appears to interfinger with the nonmarine Zilch Formation. Farther north, on the west side of the San Joaquin Valley and in the southwestern Sacramento Valley, the marine San Pablo Group appears to be the equivalent of the Santa Margarita. Whether or not continuous upper Miocene marine sediments exist in the subsurface from Mount Diablo to Fresno is not yet determined.

Nonmarine rocks of probable late Miocene age are extensive on the east side of the northern San Joaquin Valley and in the Sacramento Valley as far north as Marysville. In this area they have been assigned to the Mehrten and Zilch Formations, but commonly they are simply referred to as "continental Miocene" by petroleum geologists. Other thick nonmarine deposits of coarse detritus are exposed in the Caliente Creek drainage of the southeastern San Joaquin Valley and have been described and named the Bena Gravels.

A substantial part of the eastern and southern San Joaquin Valley received an accumulation of nonmarine clay and sand during the late Miocene; these rocks comprise the lower part of the Chanac Formation. This formation is one manifestation of the orogeny that elevated the east side of the San Joaquin Valley near the end of Miocene time. By means of the uplifts that came into being during this time, the present general structural configuration of the Great Valley Basin was formed.

Pliocene Rocks

The tectonic movements which began in the upper Miocene continued into the Pliocene and resulted in considerable erosion, particularly along the edges of the San Joaquin Valley. As a result, Pliocene deposits of continental origin are found in all parts of the Valley. Regional uplifting in most of the Valley continued throughout Pliocene time, and marine waters were able to invade only the southern and western portions of the San Joaquin Basin.

Marine rocks of the lower and middle Pliocene have been assigned to the Etchegoin Formation, although in the vicinity of Coalinga the lower portion of the undifferentiated Etchegoin is called the Jacalitos Formation. The most extensive marine member of the Etchegoin is the Macoma Claystone, a subsurface unit. The Macoma Claystone extends well east of the main mass of the Etchegoin, and it separates the nonmarine Chanac Formation from the overlying terrestrial Kern River Formation (Am. Assoc. Pet. Geologists, 1957, No. 8).

The upper portion of the marine Pliocene strata has been named the San Joaquin Formation, which is best developed in the deepest portion of the San Joaquin embayment. The San Joaquin Formation represents the last stand of marine waters in the Great Valley.

Marine Pliocene rocks attain a gross thickness of somewhat over 5,000 feet and are composed of claystone, sandstone, and conglomerates.

The extensive continental deposits of the Pliocene on the east side of the San Joaquin Valley have been assigned to the Chanac and Kern River Formations and those in the western San Joaquin Valley are called the Tulare Formation. In the northern San Joaquin Valley the Pliocene rocks include parts of the Mehrten and Laguna Formations. Farther north, in the Sacramento Valley, the nonmarine Pliocene rocks have been assigned to the Tehama Formation. In the western part of the Sacramento Valley, north of Mount Diablo, continental beds equivalent to the Laguna Formation have been called the Wolfskill Formation. The Wolfskill overlies a lower Pliocene tuff called the Pinole or Lawlor Tuff. Further north, a similar tuff called the Nomlaki Tuff occurs near the base of the Tehama Formation.

The nonmarine Pliocene rocks vary considerably in lithology, depending on the local source area. As an example, beds equivalent to the Tehama have been called the Tuscan Formation where they are largely derived from a volcanic terrain. In general the lithology of these continental deposits consist of claystones, sandstones, and conglomerates, with the coarser units becoming more common as source areas are approached. The greatest thickness of nonmarine Pliocene occurs in the Tehama where a thickness of about 2,000 feet is present.

Pleistocene and Recent Rocks

Rocks of Pleistocene and Recent age occur throughout the Great Valley. They are all continental in origin and generally grade downward into similar Pliocene units. They are discussed in greater detail in this bulletin in the following article by J. F. Poland and R. E. Evenson.

At the northern extremity of the valley a coarse fluvial unit of predominant red color, called the Red Bluff Formation, attains a thickness of about 100 feet. In the southern part of the valley the nonmarine Pleistocene sediments have been assigned to either the Tulare Formation on the west side or to the Kern River Formation on the east. Both the Tulare and Kern River Formations have lithologies indicating local sources. It is common for the Tulare to be composed of shale-pebble conglomerates derived from the uplifted Temblor Range, and the equivalent Kern River Formation is generally formed of granitic sands and conglomerates derived from erosion of the Sierra Nevada. The Tulare and Kern River Formations attain thicknesses of several thousand feet, with the maximum being about 5,000 feet on the downthrown side of the White Wolf fault south of the Bakersfield Arch.

Recent alluvium and lake deposits cover most of the central lower parts of the present Great Valley.

IGNEOUS ACTIVITY

The areas of igneous activity in the Great Valley of California are, curiously enough, at its two extremities. In the northern Sacramento Valley, volcanic rocks are present at the surface and in the subsurface from south of the Marysville Buttes north to the latitude of Chico. At the south end of the San Joaquin Valley, volcanic flows are found in surface and subsurface of the Tejon embayment, and in the outcrop north of the White Wolf fault in the vicinity of Bena.

The Marysville Buttes, which form an isolated topographic prominence about 2,000 feet high northeast of the town of Marysville, are the most prominent igneous feature in the Great Valley. The Buttes are circular in shape, about 10 miles in diameter, and their topography reflects their geology. They consist of a central core of andesite porphyry and tuff surrounded by a ring of sediments, and these sediments are embraced in turn by a ring of andesite tuff and breccia which extends to the Valley alluvium. Intrusions of rhyolite porphyry are scattered through the sediments and in the central core. The porphyries were the first volcanic rocks emplaced and appear to have been injected at a slow rate; the final igneous activity, however, was an explosive phase forming a

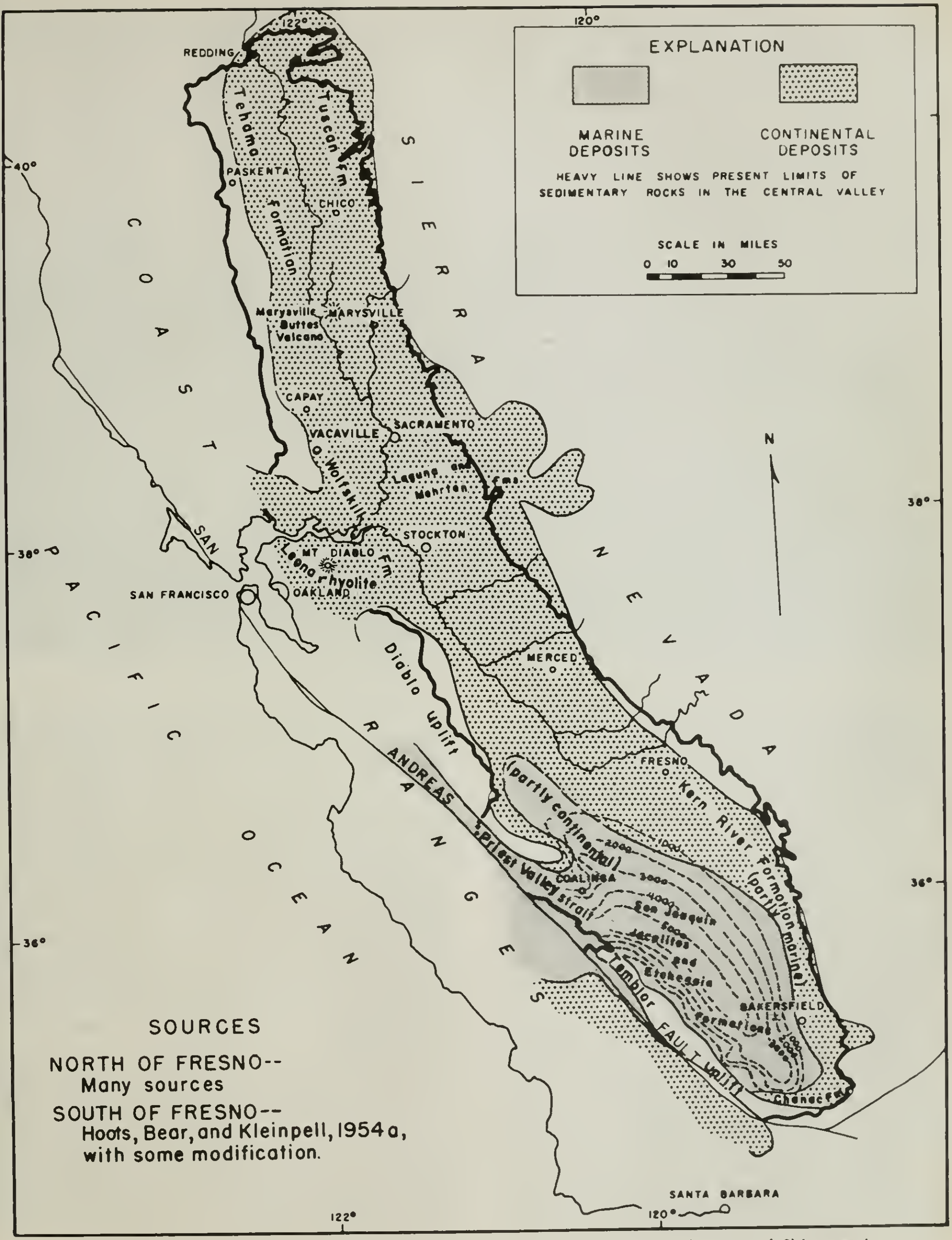

Figure 9. Distribution and thickness of Pliocene sediments in the Great Valley at the beginning of Pleistocene time. After Repenning (1960, fig. 11).

volcano one mile in diameter which ejected fragments of andesite varying in size from boulders to fine-grained tuff. Subsurface information shows that the volcanic rocks have been intruded into Upper Cretaceous and Eocene sediments as well as into the lower part of the Tehama Formation, thus fixing the time of the intrusion.

North of the Marysville Buttes, volcanic flows of basalt are common, and they generally occur near or at the base of the Tehama Formation.

The volcanic rocks at the south end of the San Joaquin Valley consist of basalt and dacite flows. These rocks are enclosed within lower Miocene sediments and most appear to have been submarine flows.

STRUCTURE

Structurally, the Great Valley of California is a large, elongate, northwest trending, asymmetric trough. This trough has a long stable eastern shelf, which is supported by the buried west-dipping Sierran slope, and it has a short western flank, which is formed by the steep upturned edges of the basin sediments.

Four major periods of tectonism are recorded in the sedimentary section of the Great Valley. These are the post-Moreno, the pre-Domengine, the pre-Pliocene, and the mid-Pleistocene. These periods of maximum structural activity are responsible for the major changes in the configuration of the basin throughout geologic time. The most severe period of deformation was in the mid-Pleistocene, and it brought to a climax the structural evolution of the basin.

The Great Valley geosyncline with its pronounced regional southward tilt is significantly interrupted by two cross-valley faults. These major structures, the Stockton fault and the White Wolf fault, are associated with the cross-valley structural highs known as the Stockton Arch and the Bakersfield Arch.

The Stockton Arch, located in the central portion of the basin, extends from the Sierran slope across to the Diablo uplift of the western flank. The high appears to have been formed by Eocene time, though uplift may have continued into the Miocene. Most of the present elevation of the arch appears to be due to upward movements on the south side of the Stockton fault, though stratigraphic evidence suggests that, when the arch first began, its axis lay further south in the vicinity of Modesto.

The Bakersfield Arch, in the southern end of the basin, also extends from the Sierran slope westward, but appears to terminate near the axis of the geosyncline instead of continuing on to the western flank. This arch apparently formed the southern edge of the valley depositional basin until middle Eocene time. The barrier was then overwhelmed and the Eocene seas spilled into the sub-basin that is sometimes called the Tejon embayment south of the White Wolf fault.

The Tejon embayment south of the Bakersfield Arch, and in particular south of the White Wolf fault, has been a somewhat distinct structural unit through geologic time and has been thought by some geologists to be more closely related to a group of intermontane basins formed during the lower Tertiary to the west in the adjacent Coast Ranges. Evidence for this is found in the similarity of sections in the Oligocene and Miocene, for example, in the red bed sequences in the Tecuya Formation of the valley and the Sespe Formation of the Coast Ranges. The Coast Range basins, west of the San Andreas fault, are thought to have been offset northward along the fault so far that they are no longer adjacent to the valley basin. More detailed structural and stratigraphic studies are needed, however, before such a hypothesis can be regarded as proven.

Other subsidiary basins along the Great Valley trough also complicate the concept of a simple southerly tilted basin. In the Sacramento part of the trough, for example, such basins are in the vicinity of Colusa and between Rio Vista and the Kirby Hills.

The mid-Pleistocene orogeny formed many flexures throughout the Great Valley, and it also rejuvenated many of the folds that had formed during previous orogenic periods. Much of the disturbance took place along the short mobile western flank, where numerous folds and faults are now particularly evident. Many of these flexures are asymmetric and associated with compressional faults of the reverse type. The magnitude of the folds decreased eastward but was still strong enough to cause the formation of lines of folding out to, and even beyond, the basin axis. The eastern shelf is relatively free of folds, and faulting in this region is of the normal tensional type.

The western mobile flank flexures are too numerous to enumerate, but because of their economic importance those of the Central Valley will be summarized. Many of these folds are evident at the surface, but because of the extensive alluvium cover, many other flexures are known only from seismic data and well bore information. In the Sacramento Valley significant anticlinal trends are found at Corning, Willows-Beehive Bend, Sites, Rumsey Hills, Wilbur Springs, Dunnigan Hills, Lodi-Thornton, Rio Vista, and McDonald-Roberts Island. In the San Joaquin Valley, most of the large anticlines are in the southern portion; among these are the Coalinga Nose-Kettleman Hills-Lost Hills Trend, North and South Belridge, Salt Creek-Cymric-McKittrick Front Trend, Elk Hills, Buena Vista Hills, Wheeler Ridge, Coles Levee, Ten Sections, and Greeley-Rio Bravo.

Faults are numerous in the Great Valley. In the Sacramento Valley the most prominent faults are those (1) associated with the Willows-Beehive Bend trend, (2) reverse faults at the north flank of Dunnigan Hills, (3) faults north of Mount Diablo near Willow Pass, and (4) the Midland fault which traverses the Rio Vista gas field. This latter fault was active during Eocene time as demonstrated by the different thickness of equivalent rock units on each side of it. In the San

Photo 1. Natural gas well being drilled at Marysville Buttes. *Photo by Edmund W. Kiessling.*

Joaquin Valley, faults with considerable displacement are common. The Stockton and White Wolf faults have already been mentioned. In the reverse or thrust category are such faults as (1) the McKittrick thrust in western Kern County, (2) the Pleito thrust in the Tejon embayment, and (3) the Edison fault in the outcrop southeast of Bakersfield. Large normal faults which bear mentioning are the Kern Gorge fault and its associated echelon members the Round Mountain and Mount Poso faults; also deserving mention are the group of faults in the Edison and Mountain View oil fields, some of which appear to cut only middle Miocene and older sediments while others are present only in the Pliocene and upper Miocene.

Tectonic activity, though reaching its climax in the mid-Pleistocene, is still continuing in the Great Valley as borne out by seismic disturbances, the most recent of which was the destructive earthquake of 1952 that originated along the White Wolf fault.

ECONOMIC GEOLOGY

The mineral economic resources of the Great Valley are summarized in this bulletin in an article prepared by Earl W. Hart and will be only commented upon here. Briefly the highlands on each side of the basin have yielded millions of dollars from the metallic minerals recovered; prime examples, of course, are the gold of the Sierra Nevada and the mercury associated with the Franciscan in the Coast Ranges. In the Great Valley itself, although these minerals are also found, the mineral commodities of greatest value are oil and gas, water, and gravel deposits.

The sedimentary section of the Great Valley has been found to be an enormous storehouse for oil and gas. The Sacramento Valley has been found lacking in any important oil resources, but gas in economic quantities has been produced from at least 25 fields. Much of this gas has been reservoired in rocks of Eocene and Late Cretaceous age. In the San Joaquin Valley, both oil and gas are prevalent, though the oil resources are concentrated in the central and southern part. Oil has been found, in significant amounts, as far north as the latitude of Fresno; north of there the hydrocarbon accumulations are gas. The billions of barrels of oil found in the San Joaquin Valley have been reservoired in sediments ranging in age from Late Cretaceous to Pleistocene; however, the majority have been produced from Miocene and Pilocene rocks. Of the dry gas produced in the San Joaquin Valley most in the southern end comes from Pliocene rocks and in the northern portion most is from Upper Cretaceous rocks. Several theories have been advanced to explain why oil is found chiefly in the San Joaquin Valley and dry gas occurs largely in the Sacramento Valley. It is likely that the distribution is related to the source material in the sediments; certainly, the organic content of the Eocene and Cretaceous shales of the Sacramento is very different from the Miocene and Pliocene shales of the San Joaquin.

The water resources of the Great Valley are becoming more and more important as the population increases at an accelerated rate. The available waters of the valley come from two main sources: (1) the numerous streams flowing westward from the Sierra Nevada, and (2) the ground-water reservoirs. Most of the ground-water resources exist in the younger portion of the sedimentary column—the Pliocene, Pleistocene, and Recent alluvium. The following article in this bulletin by Poland and Evenson presents a more thorough treatment of this subject.

Again, chiefly as a result of the increase in population, the sand and gravel deposits suitable for road building and construction are becoming more and more important. The broad expanses of stream gravels along the major streams flowing from both sides of the valley offer an almost unlimited source. Their economic utilization usually is dependent only on the distance to the market.

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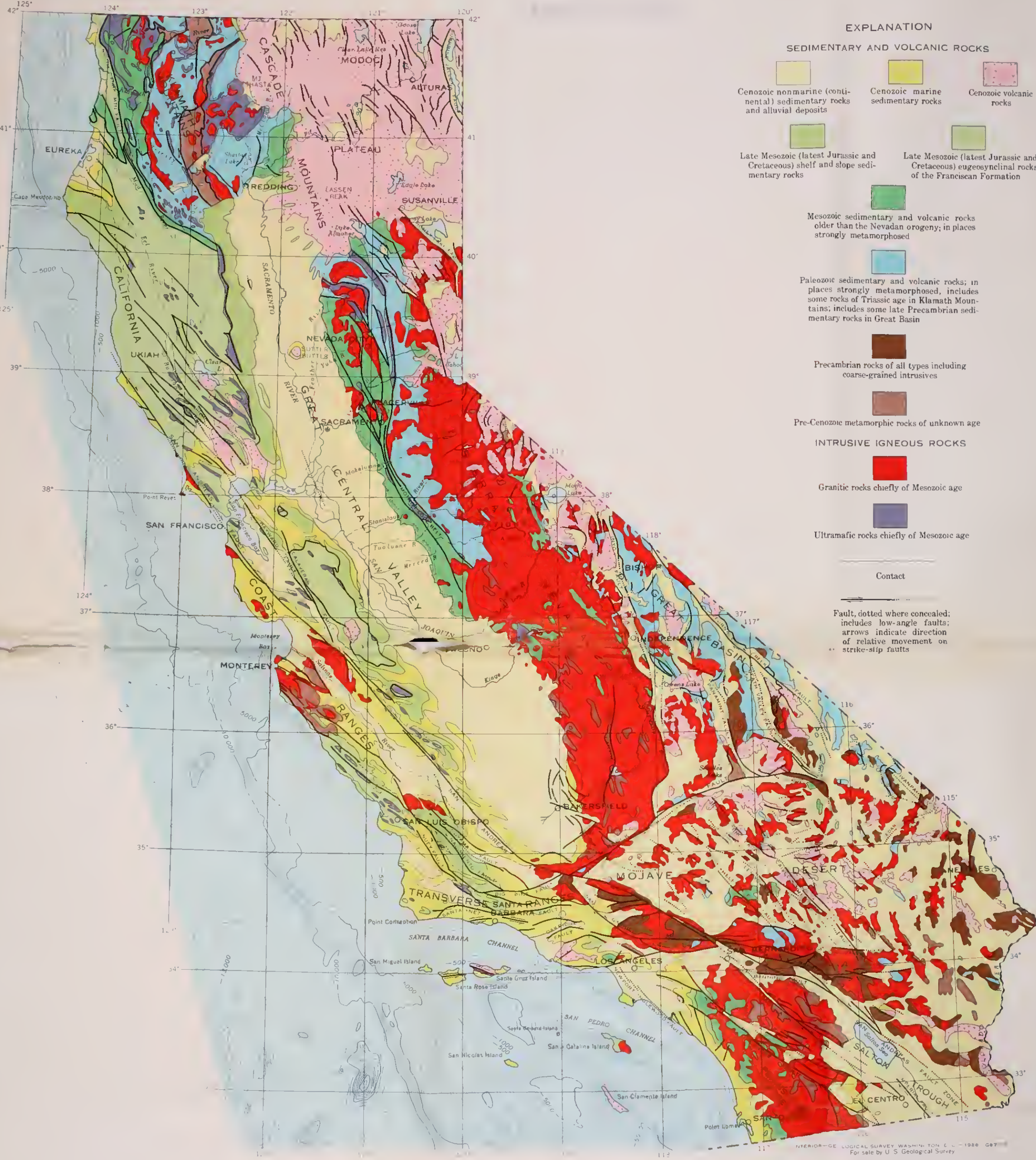
DEPARTMENT OF INTERIOR
UNITED STATES GEOLOGICAL SURVEY

MISCELLANEOUS GEOLOGICAL INVESTIGATIONS
MAP I-512



EXPLANATION

SEDIMENTARY AND VOLCANIC ROCKS

Cenozoic nonmarine (continental) sedimentary rocks and alluvial deposits

Cenozoic marine sedimentary rocks

Cenozoic volcanic rocks

Late Mesozoic (latest Jurassic and Cretaceous) shelf and slope sedimentary rocks

Late Mesozoic (latest Jurassic and Cretaceous) eugeosynclinal rocks of the Franciscan Formation

Mesozoic sedimentary and volcanic rocks older than the Nevadan orogeny; in places strongly metamorphosed

Paleozoic sedimentary and volcanic rocks; in places strongly metamorphosed, includes some rocks of Triassic age in Klamath Mountains; includes some late Precambrian sedimentary rocks in Great Basin

Precambrian rocks of all types including coarse-grained intrusives

Pre-Cenozoic metamorphic rocks of unknown age

INTRUSIVE IGNEOUS ROCKS

Granitic rocks chiefly of Mesozoic age

Ultramafic rocks chiefly of Mesozoic age

Contact

Fault, dotted where concealed; includes low-angle faults; arrows indicate direction of relative movement on strike-slip faults

INTERIOR—GEOLOGICAL SURVEY, WASHINGTON, D.C.—1966
For sale by U.S. Geological Survey

GEOLOGIC MAP OF CALIFORNIA

COMPILED BY U.S. GEOLOGICAL SURVEY
AND CALIFORNIA DIVISION OF MINES AND GEOLOGY

SCALE 1:2 500 000

0 50 100 MILES

SUBMARINE CONTOUR INTERVALS 500 AND 1000 FEET DATUM IS SEA LEVEL

1966