TERTIARY PHOSPHATIC FACIES OF THE COAST RANGES

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The mid-Tertiary marginal seas which crossed central and southern California contained luxuriant growths of phytoplankton. Massive evidence from modern seas shows that a complex circulation of currents lay behind these plant concentrations. The phytoplankton were nourished by sustained turbulent upwelling of cold phosphorus-rich water from deep-sea reservoirs, the blooms multiplying in swift and close relation to the phosphorus supply (Redfield and others, 1963). The upwelling and the productivity were focused in large stable eddies which accompanied prevailing southerly coastal currents (Currie, 1953; Emery, 1960). These slowly rotating swirls, extending for as much as 200 miles, further concentrated the phytoplankton in vividly colored patches of surface water and channeled their remains into thick accumulations on the shelving sea floor.

Photo 1A. Phosphatic shale consisting of light laminae, ½ cm thick, of carbonate fluorapatite in dark organic silt shale. Monterey Formation. Naples.

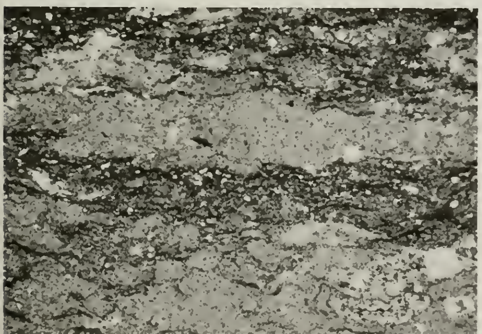

Photo 1B. Photomicrograph showing billowy phosphate laminae and organic interlayers. Field of view is 1 cm.

In a temperate, slowly oxidizing environment, phosphorus was regenerated from this organic debris and formed colloidal aggregates that were eventually incorporated in two principal rock types, depending on the depth of the shelf and the mechanical energy of the bottom water. One type, phosphatic shale (photo 1A, B), consisting of billowy blebs, lenses, and laminae of carbonate fluorapatite, a centimeter or less thick, typically, in organic argillaceous to sandy silt shale, originated in the outer deeper portions of the shelf, where relatively quiescent bottom water permitted mass flocculation of the apatite colloids.* A second type formed in the shallower, more agitated water of the inner shelf, where intensified particle contact, cluster formation, and agglomeration pelletized the apatite colloids in sand-sized grains, and with increased energy shoreward created oölitic structures. Mechanical concentration of pellets and oölites by tidal currents and other near-bottom turbulence resulted in the formation of pelletal phosphorite or pelletite (photo 2A, B). The transition from phosphatic shale to pelletal phosphate occurred where the shoreward movement of apatite clusters was balanced by the tractive forces that carried sand relatively seaward. By analogy with the existing shelf, a transition zone at 100 to 130 m may be conjectured.

These phosphatic rock types, varying laterally and vertically with respect to each other and to their position within the enveloping formation or formations, comprise the phosphatic facies whose distribution and stratigraphic relations in the central and southern Coast ranges are summarized in the following pages and shown in figures 1 and 2. Localities are numbered in the text and in these figures.

Two features of the California setting make these facies worth study: The phosphate occurrences were sediments of marginal seas of a greater range of depths and phosphate sediment types than their more abundant counterparts from epeiric environments whose deposits have received the most attention, and the California terrestrial occurrences are adjacent to marine basins that contain existing phosphate sediments.

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* The modes of formation of the phosphatic rock types are treated in a California Division of Mines Bulletin in preparation.

Photo 2A. Washed concentrate of pelletal phosphate. Long diameters are ½ to 1 mm. Monterey Formation. Carmel Valley.

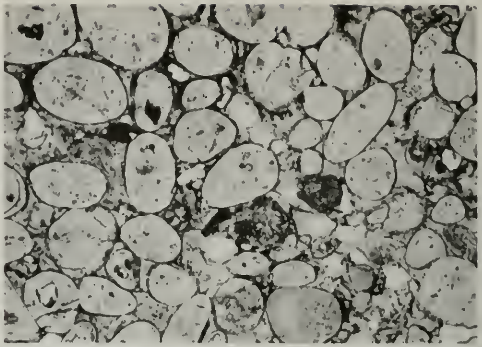

Photo 2B. Photomicrograph of pelletal phosphate. Most such pelletites have been mechanically concentrated. Note broken pellet, upper center, elongation of some pellets by accretion, and partial solution of phosphate at boundaries of some adjoining pellets.

GENERAL FEATURES OF DISTRIBUTION

The phosphatic facies are thickest and richest in southern and central California. From peak concentrations in the Ventura and Los Angeles basins, the phosphate-bearing rocks diminish in thickness and in phosphorus content northward through the Coast Ranges, with the major facies, which is of middle Miocene age, pinching out somewhere in the vicinity of the 38th parallel north of San Francisco Bay (fig. 1). Only a few scattered occurrences of phosphate rock are known north of this latitude within the Coast Ranges, in spite of northern occurrences of rock types and microfossil assemblages with which the 400-mile-wide Miocene facies is associated in the central and southern areas.

Although Paleozoic and Mesozoic rocks comprise approximately as much of the present California land surface as the Tertiary rocks outlined in figure 1, nearly all the phosphate-bearing strata shown are in Miocene or younger rocks. A few known occurrences of phosphate pellets and nodules of Late Jurassic to Early Cretaceous age are widely separated in the northern and central Coast Ranges. A nodular facies of Late Cretaceous age may underlie the western Sacramento Valley. Late Eocene pelletal mudstone crops out in the Panoche Hills along the western edge of the San Joaquin Valley. An Eocene and Oligocene phosphatic shale-pellet facies appears in the Santa Cruz Mountains, and a ferruginous phosphatic unit of comparable age is known in the northern Santa Lucia Range. However, none of these thinly scattered pre-Miocene occurrences is known to extend more than a few tens of miles.

In contrast, the Miocene series, and especially the middle Miocene, hosts abundant and extensive deposits. Phosphatic shales and pelletal sandstones and mudstones are seen in Zemorrian and lower Saucesian strata in the Temblor Range along the southwestern border of the San Joaquin Basin, and in uppermost Zemorrian and Saucesian strata in scattered localities from the Santa Cruz Basin to the eastern Ventura Basin. Instances of phosphate deposition become more numerous in rocks of Relizian age, the phosphate-bearing rocks become more extensive, more clearly correlative with each other, and in general continue into younger strata. The mounting incidence of phosphate accumulation culminates in a widespread facies of Luisian age in which phosphate, in one discrete form or another, was deposited within shales and contiguous sandstones almost continuously from the vicinity of the site of San Francisco Bay to the northern Santa Ana Mountains, and from Point Conception to the Sierra Nevada foothills east of Bakersfield. In southern California, and locally in central California, deposition continued into early Mohnian time.

Though lacking the continuity of the middle Miocene phosphatic facies, early or early middle Pliocene deposits—in the northern Coast Ranges of northwestern Sonoma County, on Gabilan Mesa, in the east-central Diablo Range, and in the northern Purissima Hills—are thought to be correlative.

This nonuniform distribution of phosphates in time reflects, in part, a greater abundance of data for the younger rocks, as a result of the focusing of oil exploration in the middle and upper Tertiary. Nonetheless, the paucity of phosphate concentrations in pre-Tertiary strata in California is thought to be real, and a result of differences in sedimentary and tectonic environments of deposition—in the turbulent deposition of the eugeosynclinal Franciscan sediments, for instance—as compared with the more stable shelf setting of the mid-Tertiary marginal seas.

PRE-TERTIARY PHOSPHATIC ROCKS

The few known instances of phosphate deposition in the lower two-thirds of the stratigraphic record in

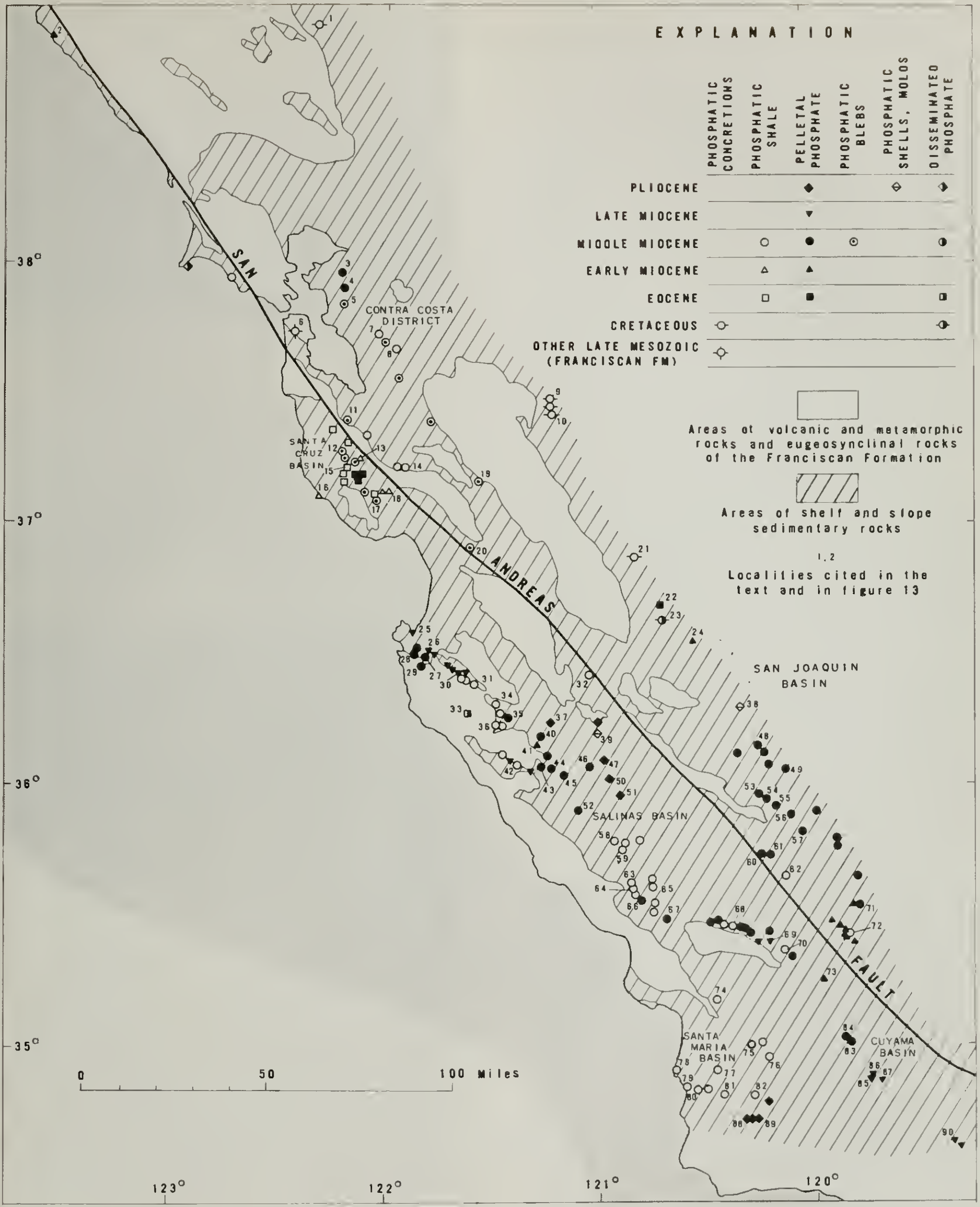

Figure 1. Map of phosphate-bearing localities in the central and southern Coast Ranges of California.

the Coast Ranges are geographically and stratigraphically isolated.

The only phosphates reported in the 15,000-square-mile area of Franciscan outcrop are nodular concretions, containing about 10 percent P_2O_5, taken from a shear zone within greywackes and shales near Laguna Honda in San Francisco (J. Schlocker, oral communication, 1965). These concretions contain what appear to be *Marthasterites tritrachiatus*, a calcareous nannofossil that is abundant in the California Eocene but rare in Cretaceous or in older rocks (W. R. Evitt, oral communication, 1965), so that even this rare instance of phosphate deposition in the Franciscan may be based on a displaced specimen.

Near the apparent boundary between the Lower and Upper Cretaceous in uppermost sandy mudstone beds of the Brophy Canyon Formation near Cache Creek, Yolo County (1), coarse phosphate pellets are found within concretions, and smaller (2 to 3 cm) pods of pelletal phosphate appear in the subjacent Buck Island Member of the Davis Canyon Formation (R. W. Ojakangas, oral communication, 1964).

At several localities along the western margin of the Sacramento Valley, phosphate concretions to lengths of 5 cm are distributed in the organic mudstone of the Upper Cretaceous Moreno Formation (10, C. E. Bishop, oral communication, 1965; 9, 21, C. A. McLeroy, oral communication, 1965). In Escarpado Canyon, Fresno County, this unit includes mudstone in which phosphate is so finely disseminated that its presence is known only by chemical test (Gulbrandsen and others, 1963), and locally it also contains apatized wood with small nodules of leucophosphite. Although these small nodules resemble pelletal apatite, the leucophosphite is a secondary mineral concentrated near fractures and toward the outer surfaces of the phosphatized specimens—a rare form of marine phosphate which, in deposits all over the world, tends to assume the composition and structure of carbonate fluorapatite.

EOCENE AND OLIGOCENE * PHOSPHATIC FACIES

The oldest phosphatic facies of significant areal extent recognized in California consists of Eocene and Oligocene(?) phosphatic shales in the Big Basin area of the central Santa Cruz Mountains (15, Brabb, 1960). These are olive-black carbonaceous phosphatic shales, interlayered to thicknesses of 50 m in massive arkosic late Eocene sandstones of the upper Butano Sandstone and lower San Lorenzo Formation over an area of at least 200 square miles. The phosphate beds are cut to the east by the San Andreas fault. They are distinguished from their thicker, more extensive mid-Miocene counterparts by the presence of thin, sharply outlined, pizza-shaped † laminae and local, very thin, weakly phosphatic sandstones which are cross bedded and convoluted. Brabb has assigned a late Narizian age to the shales on the basis of faunal reports by the staff of the Union Oil Co.

South of the Ben Lomond-Gabilan pluton, in the northeastern Santa Lucia Range, a ferruginous phosphatic mudstone appears in Oligocene (Refugian) remnants which parallel Church Creek (33, W. R. Dickinson, oral communication, 1963). Continuity of the San Lorenzo Formation of Narizian and Refugian age with the Church Creek Formation has been suggested by Dickinson (1956), who notes similarities of stratigraphic succession, lithology, and fauna. A correlation of the phosphatic horizons, and continuity of the Narizian and Refugian basin from the Santa Cruz Mountains across the Ben Lomond pluton into the Santa Lucia Range, may eventually be established if the phosphatic facies of the San Lorenzo can be traced southward into the Refugian San Juan Bautista Formation at the northern edge of the Gabilan Range.

The top of the phosphatic shales in the San Lorenzo Formation in the Big Basin area is marked by half a meter of glauconite in which phosphate is finely disseminated. In massive mudstone of the upper San Lorenzo Formation an apparent break in deposition is characterized by a glauconite and phosphate pellet and pebble bed to 3 m in thickness. The latter unit can be recognized as a marker bed over a distance of 12 miles. These strata have been identified with the bottom of the Refugian and Zemorrian Stages, respectively, by Brabb (1960).

North of the mouth of Skooner Gulch near Point Arena (2), about 150 miles north of the San Lorenzo glauconite, there is a somewhat similar unit. It consists of 3 m of glauconitic sandy siltstone with 1 or 2 percent of phosphate pebbles 2 to 3 cm long, marking the base of the Gallaway Beds of C. E. Weaver (1943). Below the phosphate pebble bed, the glauconitic beds coarsen to gritty sandstones of Weaver's Skooner Gulch Formation; 25 m above the pebble zone, thin (0.8 m) lenses of similarly sized phosphate pebbles appear where the glauconitic sandy siltstones are succeeded by finer clastics. Foraminifera identified by Kleinpell (1938, table 16) from approximately the same stratigraphic level as the phosphate pebble zone indicate an early Zemorrian age.

East of the San Andreas fault, in the Panoche Hills at the western edge of the San Joaquin Valley, phosphate pellets are scattered in a half-meter thick mudstone unit that intervenes between basal sandstone and glauconite pebble beds and shale units of the Kreyenhagen Formation of Eocene and Oligocene(?) age (22, Payne, 1951).

The thin occurrences of pelletal phosphate near Point Arena and in the Panoche Hills illustrate, on a small scale, a phenomenon that is more apparent in the younger, more extensive phosphatic rocks—a concentration of phosphate pellets at transitions from fine to coarse clastic deposition or the reverse. As a result of major transitions in sedimentation, pellet beds will

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* The boundaries of the European-based epochs of the Tertiary are assigned here according to the recent usage of Mitchell and Repenning (1963, table 1), which places the California equivalent of the Aquitanian Stage (Zemorrian Stage) within the Miocene.

† A thickening of the rims of the laminae is thought to be a diagenetic modification.

Photo 3. Distorted phosphatic shale of the Lambert Formation at the core of a small anticline at Año Nuevo Point. Field of view is 1.8 m.

commonly coincide with the base or top of a formation, but phosphate pellets may also appear where irregularities in basin topography or shifts of climate have brought about minor variations in sediment types within major lithologic units. Consequently, phosphate pellet beds are less reliable as marker horizons than the phosphate-laminated shales, which tend to be more uniform and more persistent because they form in a deeper and more stable shelf environment.

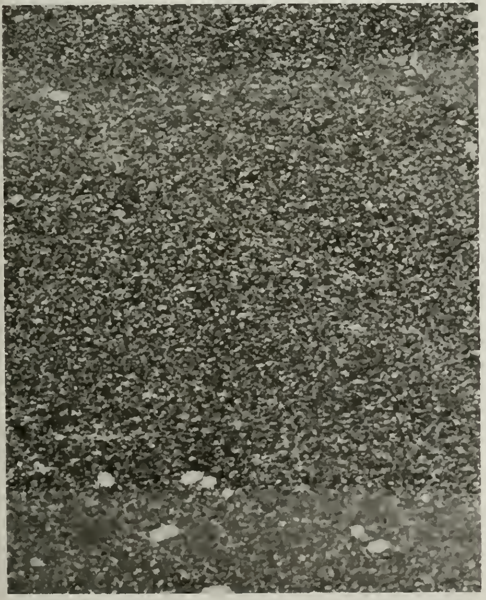

Photo 4. Graded phosphatic laminae. Light collophane particles coarsen and grade downward into dark organic silt interlayers. About 1½ cm thickness shown. Lambert Formation. Zayante Canyon.

LOWER MIOCENE PHOSPHATIC FACIES

Conspicuous phosphatic strata were laid down in the early Miocene at an uppermost Zemorrian or lower Saucesian horizon at two widely separated localities in the central and southern Coast Ranges on opposite sides of the San Andreas fault.

In the central Santa Cruz Mountains (18, J. C. Clark, oral communication, 1964), the Lambert Formation (Dibblee, 1965) includes up to 75 m of dark-gray phosphatic shales closely resembling the Eocene and Oligocene phosphatic shales in the Big Basin area. A coastal exposure near Año Nuevo Point (16, J. C. Clark, oral communication, 1964) (photo 3), and several exposures 20 miles inland near the San Andreas fault (13), indicate that the Lambert phosphatic facies once occupied much of the same area as the older phosphatic shales, though it is separated from them near the fault by as much as 1,500 m of mudstone and sandstone. Like the Butano and San Lorenzo Formations, these strata show bedding features uncommon to the younger phosphatic shales—thin graded sandstone interbeds and sharply graded phosphatic laminae (photo 4), implying a deeper and quieter bottom environment than that of the locally current-bedded Eocene shales. Small phosphatic blebs,* which are interspersed in all the phosphatic shales in California, continue for several meters above and below the phosphatic laminae in the eastern exposures of the shale. Foraminifera from the phosphatic facies are predominantly of the lower Saucesian *Siphogenerina transversa* zone.

South of the Ben Lomond-Gabilan pluton, in the western Santa Lucia Range near King City, small phosphate pellets comprise up to 10 percent of a mudstone member of the Vaqueros sandstone. In Reliz Canyon (41), the mudstone is judged to be of probable middle or late Zemorrian age, on the basis of a lower Saucesian fauna identified by R. M. Thorup (1942) in the superjacent Sandholdt Formation. A southward extension of the Lambert phosphatic facies along a former narrow seaway across the Gabilan uplift is more conjectural than for the Eocene-Oligocene phosphatic facies, because the rocks of the Vaqueros group (of Allen, 1946) in isolated exposures south of San Juan Bautista are interbedded and overlain by continental breccias and conglomerates composed largely of limestone and granite derived from the emerging Gabilan Range. On the other hand, some intermittent shallow inundation during Zemorrian, and possibly into Saucesian, time is indicated by sandy marine beds within and below the Vaqueros continental debris, and in overlying volcanic agglomerates.

Scattered instances of earliest Miocene phosphate deposition, south of the phosphatic shale of the Santa Cruz Mountains and Vaqueros beds and west of the San Andreas fault, are not known to fit regional facies

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* Small (to 5 cm) lenticular segregations of phosphorus about which laminae or other bedding features form a swirl pattern. The blebs formed—presumably from phosphate in interstitial water, which by analogy with modern sediments was an adequate source—after the sediments were deposited, but before they were compacted (see photo 7A, B).

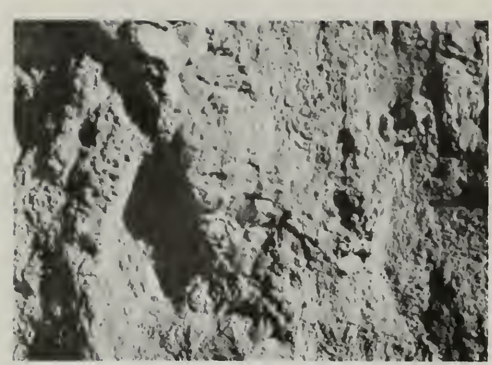

Photo 5. Steeply dipping pellet-bearing Upper Santos Shale in Chico Martinez Creek canyon. Sandstone interbed in upper left has slumped into poorly consolidated pelletal shale. Field view, 2.2 m.

patterns. Collophane pellets in siliceous clay shale in the upper part of the Zemorrian Soda Lake Formation in the Carrizo-Cuyama basin (73, R. K. Cross, 1962), and thin pellet-bearing upper Zemorrian beds in the lower Rincon Formation in the western Transverse Ranges, may be synchronous, in part, with the phosphate deposition to the north. However, the distribution of the Soda Lake pellets is not known, and the usually sparse, irregularly distributed pellets in the lower Rincon and subjacent Vaqueros Formation of the Ventura basin do not comprise a traceable zone of well-defined vertical range.

East of the San Andreas fault, and 175 miles south of the Santa Cruz Basin, a well-known Miocene section exposed along Chico Martinez and Zemorra Creeks (72), on the southwestern margin of the San Joaquin Basin, contains a pelletal phosphate facies correlative with the Lambert phosphatic shales of the Santa Cruz Mountains. Phosphate pellets appear at intervals throughout a sandy lower and lower middle Miocene section in the western San Joaquin Basin. Discrete concentrations (17 to 20 percent pellets over one 10-m section) at the base of the brownish-gray finely fractured upper Santos Shale (photo 5) and within a lower part of the Santos Shale are a recognizable facies over 8 miles of outcrops between Salt Creek and Media Agua Creek. They also extend subsurface for at least 10 miles to the Belridge oil field. The pellet beds are characterized by abundant glauconite, by oölites of alternating glauconite and collophane shells around glauconite and/or collophane cores (photo 6), and, locally, by crusts of gypsum. The pellet beds of the upper Santos Shale lie directly above the top of Kleinpell's Zemorrian Stage at his type locality.

Data from wells in several localities in the western San Joaquin Basin record collophane or pyritized collophane pellets at scattered intervals within the lower Miocene of the Temblor Formation, but few of the occurrences have been correlated with the phosphate beds in Santos Shale outcrops, or with each other (71, Wharton, 1943; Woodring and others, 1940; 57, Curtin, 1955; 24, Garrison, 1955).

THE MIDDLE MIOCENE PHOSPHATIC FACIES

A north to south traverse of the phosphate-bearing strata in the California middle Miocene bypasses the northern third of the State to the 38th parallel. Although the Eel River Basin, in Humboldt County, and the Gualala Block, near Point Arena, both contain diatomaceous mudstone and shale-bearing Luisian and Mohnian Foraminifera, which is an auspicious rock-time association to the south, phosphate has not been recognized in these northern units. Chemical tests made on samples from Miocene sections along the Eel River, along Salmon Creek to the west of Fortuna, and along the Point Arena coast have been generally negative.

Contra Costa Basin

The northernmost exposures of the middle Miocene phosphatic facies in the Contra Costa and Santa Cruz Basins are only meagerly phosphatic. However, minor phosphate components can be traced throughout the lateral extent of the middle Miocene Monterey Group of the Contra Costa Basin. Small pellets are disseminated in the lower part of the upper Luisian Oursan Sandstone of Pinole Ridge (3) and other localities to the south; pellet beds lie in silty shale near the top of the lower Luisian Claremont Shale along Oursan Ridge near Bear Creek (4); pellets and pebbles increasing in coarseness and concentration are found toward the top of an 8-m-thick zone in the Claremont Shale [1] south of Dublin (8); 20 m of phosphatic shale with discontinuous nodular laminae occur within an isolated fault-bound siliceous shale sequence of the Monterey Formation of early Luisian age east of Los Gatos (14); and weakly phosphatic shale has been found in the

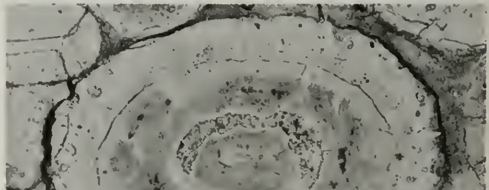

Photo 6. Core and shell of glauconite (dark) alternating with shells of collophane (light). Pellet is ½ mm long. Santos Shale. Chico Martinez Creek.

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[1] These phosphate pebble beds, which bear little resemblance to the typical Claremont Shale, are shown in the most recent literature of the area as Cretaceous.

Photo 7A. Phosphate blebs, indicated by arrows, in Claremont Shale at Mission Pass. Field of view is .5 m.

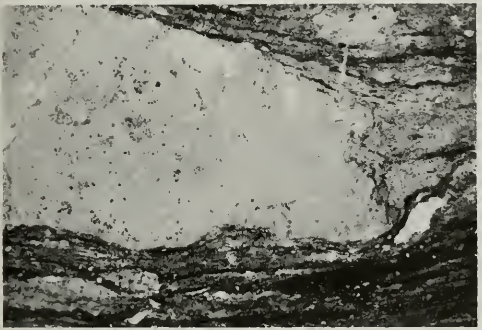

Photo 7B. Photomicrograph of phosphate bleb. Displaced laminae and platy flecks of organic material form flow patterns around these blebs.

Monterey Formation of Allen (1946) near the faulted western basin margin north of San Juan Bautista (20).

These occurrences share a relatively narrow time range within the Luisian Stage, but they are discontinuous and do not of themselves form a traceable phosphatic horizon. Continuity is supplied, however, by small white phosphate blebs, from 1 to 2 cm long, sparsely distributed within the finely laminated siliceous Claremont Shale (photo 7A, B). The blebs are identical with those which extend above and below the lower Saucesian phosphatic shale facies in the Santa Cruz Mountains. In the Claremont Shale, phosphate blebs are dispersed over a strike length of 60 miles, from the western Berkeley Hills southeast to the northwestern flanks of the Diablo Range east of Morgan Hill (19) (see fig. 1).

In Crow Canyon at the southern end of Las Trampas Ridge (7), a phosphate pellet and pebble zone 2 m thick in olive-gray sandstone, has been assigned to the Sobrante Formation by Aarons (1958), which is subjacent to the Claremont Shale. The phosphate outcrops are part of a complex fold pattern in which sandstone and shale are encountered successively down section. Both the shales, which are of similar lithology to some that have been assigned to the Claremont in this area, and these pelletal sandstones may be interbedded within the Claremont Shale and part of the Luisian facies as are the pebble beds south of Dublin.

To the west of the Stanford University campus, sparse collophane pellets occur in an unnamed dark-gray silty sandstone of probable Luisian age penetrated by boreholes drilled for the Stanford linear accelerator (11).

Santa Cruz Basin

In the neighboring Santa Cruz Basin, west of the San Andreas fault, the Woodhams Shale Member of the Monterey Formation (Cummings and others, 1962) over a strike length of at least 15 miles is characterized by light-pinkish-gray phosphatic blebs, to 5 cm in length. The blebs are most abundant in northern exposures near Peters Creek (12) and are sparser to the south. Although they differ in color and size, their distribution is similar to that of the blebs in the Claremont Shale. Phosphate blebs in the Monterey Formation north of Felton (17) are of early Luisian age (J. C. Clark, oral communication, 1963), and correlation with the Claremont Shale east of the San Andreas fault is probable.

Salinas Basin

The phosphate beds increase markedly in concentration and in chronologic range south of the Ben Lomond-Gabilan-Monterey massif, which separated deeper portions of the Santa Cruz and Salinas basins during the middle and early late Miocene. A near-continuous phosphatic shale and pellet facies cuts through the Sandholdt, Monterey, and Santa Margarita Formations, where these units and their southern correlatives comprise the Relizian, Luisian, and lower Mohnian Stages, from Carmel Valley to the Cuyama and Santa Maria basins and beyond into the Transverse and Peninsular Ranges provinces. In general, the phosphatic sequences in the foraminiferal clay shale of the Sandholdt Formation are characterized by dispersions of phosphatic blebs and by phosphatic laminae; the phosphate beds in the opaline and diatomaceous shales of the Monterey Formation in the Salinas Basin consist mostly of discrete layers of pellets and phosphatized organic remains.

In the northwestern Salinas Basin where the phosphatic strata abut the Monterey granodiorite pluton, they grade northward from phosphatic shales of the Sandholdt Formation occupying deeper portions of the basin in the Paloma Valley lowland to a consistent pellet facies within the transgressive Monterey Formation overlying the Monterey massif in the vicinity of Carmel Valley. These beds include phosphatized fish and invertebrate remains and collophane pellets which appear near the top of the basal sandstone of the Monterey in exposures in Potrero (28) and Robinson (27, O. E. Bowen, oral communication, 1963) canyons and in the vicinity of San Jose Creek (29). In younger, thick, otherwise barren sequences of opaline shales interlayers of flood pellets 5 to 50 cm thick appear in many exposures over a distance of more than 20 miles from Canyon del Rey north of Monterey (25, R. R. Compton, oral communication, 1963) through Carmel and Tularcitos valleys (26, 30) and along Tularcitos Ridge as far south as Cachagua Conejo Creek (31, Weidman, 1964). Although most pelletal phosphate in California is little altered by weathering, some sandy porous ridge-top exposures in the Tularcitos area have been leached of most of their phosphate, leaving only cavities, or kernels of phosphate within cavities, remaining in the siltstone matrix.

The phosphatic basal sandstone in Robinson Canyon contains Luisian Foraminifera. The pellet beds within the superjacent Monterey shales extend into the lower Mohnian Stage north of Monterey (Brabb and others, 1962), and near Juan de Matte Canyon in Carmel Valley they lie 20 m above the granodiorite base (O. E. Bowen, oral communication, 1963). East of Chupines Creek in Tularcitos Valley they are upper Luisian or lower Mohnian.

The calcareous phosphatic shales and mudstones of the Sandholdt Formation, containing phosphates in the form of grayish-pink blebs and a few thin phosphatic laminae, outcrop 16 miles southeast of Tularcitos Ridge in Paloma Valley (34). Here the Sandholdt wedges between Monterey and the conformably underlying Vaqueros Formation, and the foraminiferal ages for the phosphatic beds in different exposures range from lower Luisian to upper Luisian. Phosphate elements become more prominent within the Sandholdt as the unit thickens toward the Arroyo Seco. A transitional contact with underlying Vaqueros Formation is marked by abundant phosphate blebs and locally by 10 to 15 cm of pebble phosphorite, and the phosphate grades upward from thin lenses in sandy siltstones to near-continuous laminae and abundant blebs in silty shale. About 30 m of this phosphatic shale, containing Luisian Foraminifera, are well exposed west of Rocky Creek (36).

A few pelletite interlayers and the familiar phosphate blebs mark the apparent top of the facies in the Paloma Creek-Arroyo Seco basin. In an exposure south of Sand Creek (35), for instance, a single interlayer of coarse pellets, phosphate pebble fragments, and very fine grained sand occur in porcelaneous shale in which phosphate blebs to 4 cm in length are dispersed over a 30-m thickness. On either side of Reliz Canyon (40), a few hard dolomitized beds 5 to 60 cm thick of pellets and phosphatized organic debris are interlayered in porcelaneous shale and bituminous limestone. These occur near the base of the Mohnian Stage, as established by R. M. Kleinpell (1938) in his detailed section in this area. Similar pellet beds at the same approximate horizon in Vaqueros Creek were mentioned by R. D. Reed in 1927, and this is believed to be the first published reference to phosphate of the California middle Miocene facies.

The lateral facies change from phosphatic shale to pelletal phosphorite observed toward the northwestern margin of the basin is also seen in central portions of the basin, where the phosphatic facies pinches and swells above undulations in the former basin topography. Thus, the Sandholdt Formation and its phosphatic shale interbeds thin toward the San Antonio River, and the entire unit condenses from nearly 100 m at its faulted margin west of Arroyo Seco to a sandy phosphate pellet zone, 25 m thick, near Mission Creek (43) in the northern part of the Hunter Liggett military reservation (Stanford Univ. Summer Field Classes, 1952, 1953).

Similar, less-conspicuous changes in form are observed in phosphatic interlayers within younger siliceous shales deposited on this irregular mid-Miocene basin floor. Along the North Fork of the San Antonio River (42), phosphatic blebs, comparable to those in the subjacent Sandholdt in size (to 4 cm) and abundance (500 or more per cu m [*]), are seen in thinly laminated opaline shales of the Monterey Formation. South of Cosio Knob, east of Quemado Canyon (44, 45, R. W. Weidman, 1958), and along the eastern border of the Santa Lucia Range in the vicinity of Espinosa Canyon (46, D. L. Durham, 1964), light-brown well-polished collophane oölites comprising up to 25 percent of thin sandy silt interlayers within the siliceous beds. Farther east, at the head of Topo Valley (32) where a depression of the Gabilan shelf adjoins the San Andreas fault, Luisian calcareous and siliceous shales and earthy mudstones of the Monterey Group of I. Wilson contain finely disseminated phosphate which does not appear to have been pelletized.

Except for a few thin beds of small pill-shaped pellets in diatomaceous (Monterey) shale in Lockwood Valley (52, D. L. Durham, oral communication, 1965), the phosphate exposures along the southern course of the San Antonio River, in Bee Rock Canyon (58) and in the vicinity of Nacimiento Dam (59), consist mostly of weakly phosphatic shales whose pale laminae and blebs are commonly almost imperceptible against a background of silt interlayers of the same color.

The middle Miocene phosphatic facies extends southward as a richly foraminiferal phosphatic silt rock and shale sequence that is well exposed in the Adelaida area west of Paso Robles (63, 64). An abundant microfauna in Peachy Canyon (65) includes usually diagnostic forms of both lower Relizian and upper Relizian Stages. An apparently older isolated occurrence of flood pellets (0.6 m thick) is exposed on Willow Road southeast of Adelaida (66) in uncertain stratigraphic relationship to phosphatic shales which crop out within a mile. Its generally Saucesian fauna is the age equivalent of an extensive pellet facies of the western Ventura basin, but broken collophane grains and similar sorting of pellets, associated clasts, and Foraminifera suggest that the fauna is displaced. None-

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[*] A plane surface does not give the impression of such an abundance of phosphate blebs; a cu m of rock containing 500 blebs will show on a plane surface an average of only 9 per sq m.

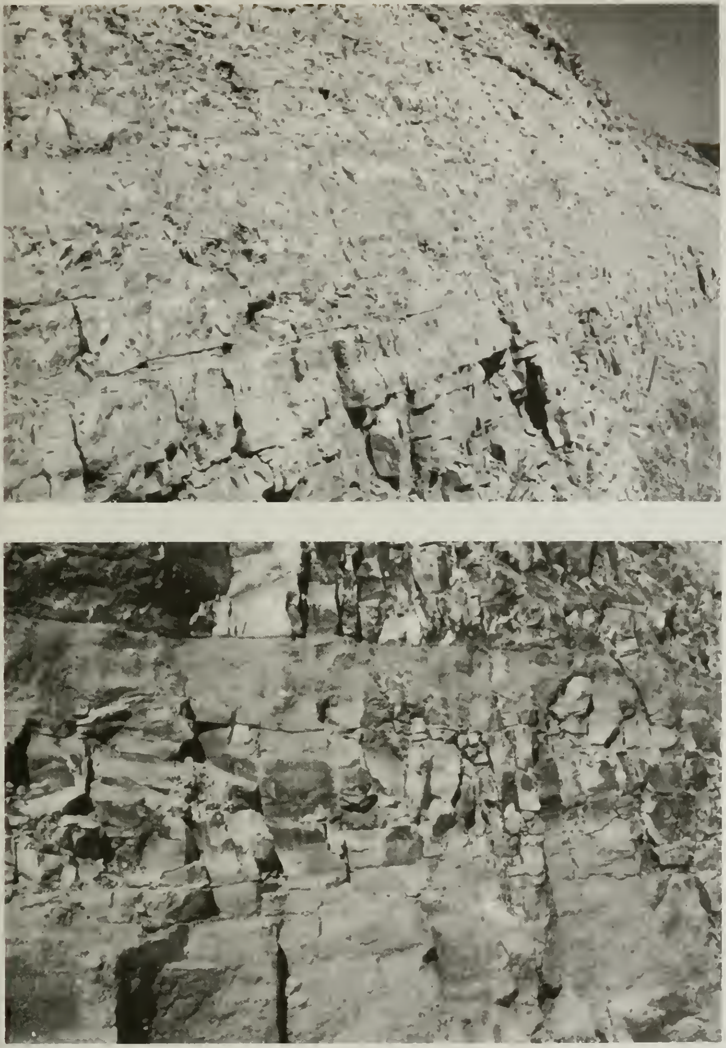


Photo 8. (A, top) Pelletal phosphate interbedded with porcelaneous shale of the Monterey Formation in roadcut near Indian Creek., (B, bottom) Pelletal phosphate beds 10 and 25 cm thick separated by fractured porcelanite.

theless, the lower range of the middle Miocene facies, which does not appear until the middle Relizian in most localities where its age is definitely known, may be less distinct, and in this area the facies may merge with older phosphatic rocks.

The middle Miocene phosphatic strata diverge around granodiorite and Mesozoic rocks of the La Panza Range eastward into the Carrizo-Cuyama Basin and southeast through the Arroyo Grande-Huasna trough into the Santa Maria Basin. Near the point of divergence north of Atascadero (67), a few thin beds of small black collophane pellets are interspersed within large thicknesses of porcelanite. This is the westernmost of a series of exposures of pelletal phosphate, within porcelaneous and diatomaceous shale, which can be traced for 65 miles along the eastern flank of La Panza Range into the Cuyama Basin. In exposures in Quailwater and Indian Creeks (68), these beds are part of an uninterrupted succession of phosphatic clay shale, pelletal phosphorite interlayered with phosphatic shale, and flood concentrations of pellets to 60-cm thickness in porcelaneous shale. Overlying these are ash beds and sandstones of the Santa Margarita Formation. In Hay Canyon (70), pellets also appear in sandy siltstones within the Monterey-Santa Margarita transition.

The porcelanite tends to mark the highest appearance of shale in the Indian-Quailwater Creek section. Its ratio to interlayered pellets is locally as low as 2.5 to 1. The beds average 20 to 25 percent pellets over thicknesses of 4 m or less, but over larger thicknesses the porcelanite-pellet ratio expands to 10 to 1 or more (photo 7A, B).

At the type locality, 3 miles west of Quailwater Creek, the top of the Luisian Stage has been designated by Kleinpell as the horizon between diatomaceous and cherty organic shale and overlying pellet-bearing sandstone and siltstone. In the Quailwater Creek exposures, the lower soft organic phosphatic shale portion of the facies may extend through the Luisian Stage. Upper Relizian or lower Luisian assemblages were obtained in this locality both near and 20 m below the lowest porcelanite bed which marks the top of the Sandholdt Shale (Saltos Shale Member of Monterey Formation of Hill and others, 1958). The phosphatic sandy siltstones in Hay Canyon are of latest Luisian or early Mohnian age.

These exposures illustrate the typical shoreward facies progression of phosphate deposition in the marginal seas of the California middle Tertiary. The sequence is the vertical equivalent of the lateral transition from phosphatic shale, to phosphate pellets, to sandstones observed toward Carmel Valley. The order contrasts with a transition in the eastern Santa Monica Mountains of the Los Angeles Basin where mid-Miocene submergence resulted in a reverse vertical sequence—an erosional unconformity overlain by successive deposits of sandy conglomerate, phosphate pellets and pebbles, and bituminous phosphatic shale with interbedded limestone.

Within the lower Santa Margarita Formation northeast of the La Panza Range is found a sequence of interlayered porcelaneous shale, siltstone, and pelletite nearly identical to the older Monterey occurrences, in lithology, except for an admixture of sand. These younger beds, which are 10 m thick in exposures on the west side of Windmill Creek (69), may be condensed equivalents of much larger thicknesses of late Miocene diatomaceous siltstone and shale which have been measured by Richard (1933) within his Santa Margarita Formation to the north and west. If so, these pelletal shales may constitute a separate younger facies despite their appearance as transitional beds of the older Monterey Formation. A pattern of occurrence of pelletal phosphate, both at the base of the Santa Margarita Formation and in a shale unit within the sandstones, is also observed in the Cuyama Basin 50 miles southeast.

In the southern Santa Lucia Range southwest of the La Panza Range, the middle Miocene facies continues into the Santa Maria Basin via the Arroyo Grande-Huasna Valley.

Santa Maria Basin

The consistent succession from organic clay shale to siliceous shale that distinguishes the Sandholdt from the Monterey Formation in the Salinas Basin is not everywhere in evidence in middle Miocene shale farther south, and most workers in the Santa Maria Basin combine the two lithologies as the Monterey Formation. In the northern Huasna Valley east of Arroyo Grande (74), for instance, phosphatic blebs and laminae appear in siliceous silt shales which lie between Santa Margarita sandstone and a subjacent unit of porcelaneous mudstone. This phosphate-bearing shale is Luisian on the basis of microfossil dating by Kleinpell, and partly Mohnian on the basis of a megafossil assemblage studied by C. A. Hall.

South of Huasna, on the northern side of Cuyama Valley (75), the following 30-m succession is exposed —arkosic silty sandstone with sparse phosphate pellets, a few glauconite-bearing phosphate pellet interlayers in silty shale, organic silt shale with thin poorly defined phosphatic laminae, and thinly laminated cherty shale containing a few phosphate blebs. Locally, the thicker pellet interlayers within the silty shale are sites of large carbonate concretions which have formed around and through the phosphatic interlayers without having replaced them (photo 9). Here, the relative stratigraphic position of phosphatic pellets and laminae reverses that north to the La Panza Range. A few species of poorly preserved Foraminifera recovered from these rocks are probably Relizian.

Phosphatic shales continue south of Cuyama Valley through scattered exposures in the western San Rafael Mountains (76); they disappear beneath the basin cover south of Santa Maria and crop out farther west near Casmalia and in sea cliffs north and south of Point Sal (80, 78, 79). Woodring and Bramlette (1950) assign a late Relizian and Luisian age to this phosphate horizon in the western Santa Maria Basin. Numerous oil well logs (77, 81) indicate that these phosphate-bearing shales occur through a 210-m total thickness in the East Cat Canyon field (82, R. K. Cross, 1943) and extend throughout the subsurface Monterey Formation in the Santa Maria Basin.

In the adjoining Transverse Range province, the middle Miocene phosphatic shales crop out east of Point Conception along the southern flank of the Santa Ynez Mountains and extend another 160 miles eastward, almost without interruption, to the Peninsular Ranges east of Los Angeles (photo 10A, B).

Cuyama Basin

In the southeastern prong of the Salinas Basin, the pelletal facies within the Monterey, which can be traced along the northeastern La Panza Range for 25

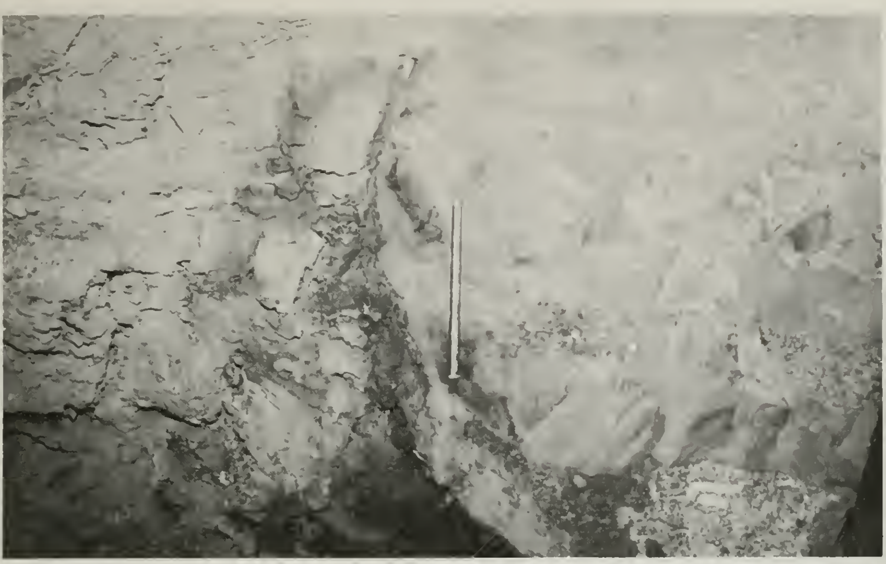


Photo 9. Thin beds of pelletal phosphate distended by a carbonate concretion. Monterey Formation. Cuyama Valley.

miles, is concealed beneath the northern edge of the alluvial Carrizo Plain, and is inconspicuous through the Caliente Range to Cuyama Valley. Only a few thin layers of pellets in sandy gypsiferous diatomaceous shale have been observed near the top of the Monterey Formation in Morales Canyon (83) and to the west (84, Gower and Madsen, 1964). However, south of Cuyama Valley between the Monterey Formation (here called the Branch Canyon Formation by Hill and others, 1958) and the Santa Margarita Formation, a transitional zone includes at least 10 m of thinly interlayered pelletite, pelletal sandy siltstone, and porcelaneous shale. This interval is prominently exposed east of Branch Canyon (85). The lower beds of the Branch Canyon Formation contain Relizian Foraminifera, according to Hill and others who project a Luisian age for the rest of the unit, but megafossils suggest a Mohnian-equivalent age for the pellet beds within the transition zone, according to J. G. Vedder.

The phosphate-pellet zone in a fine-grained sequence of the Santa Margarita Formation of the northeast La Panza Range is matched by similarly placed pellet beds within the Santa Margarita of the Cuyama Basin. Abundant late Miocene oyster shells enveloped in collophane pellets underlie 30 m of pelletites and pelletal

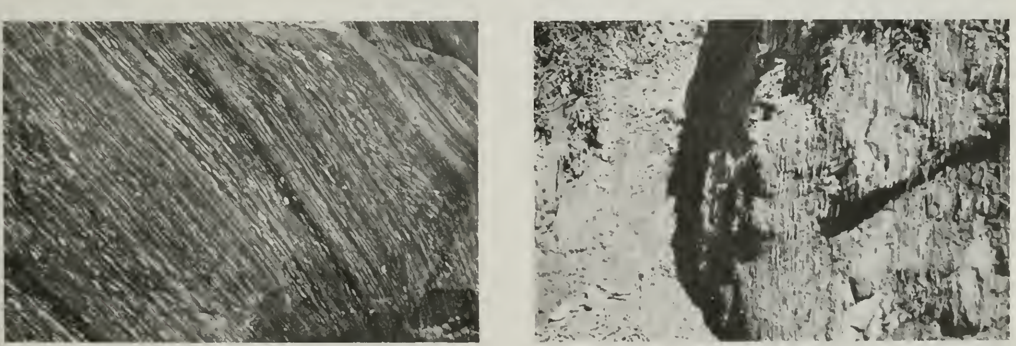


Photo 10. Middle Miocene phosphatic shale facies exposed (A, left) in sea cliffs east of Naples in the Ventura Basin, (field of view, .7 m) and (B, right) in the Los Angeles Basin, at Malaga Cove (field of view, 1.8 m).

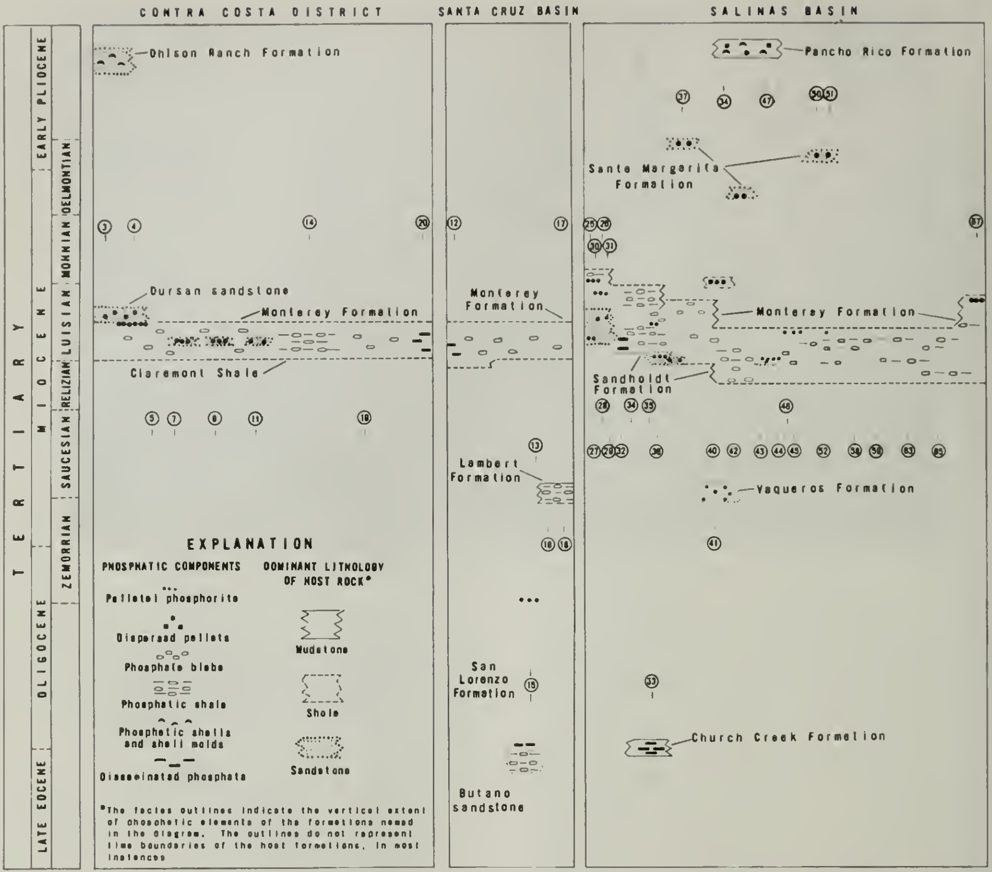


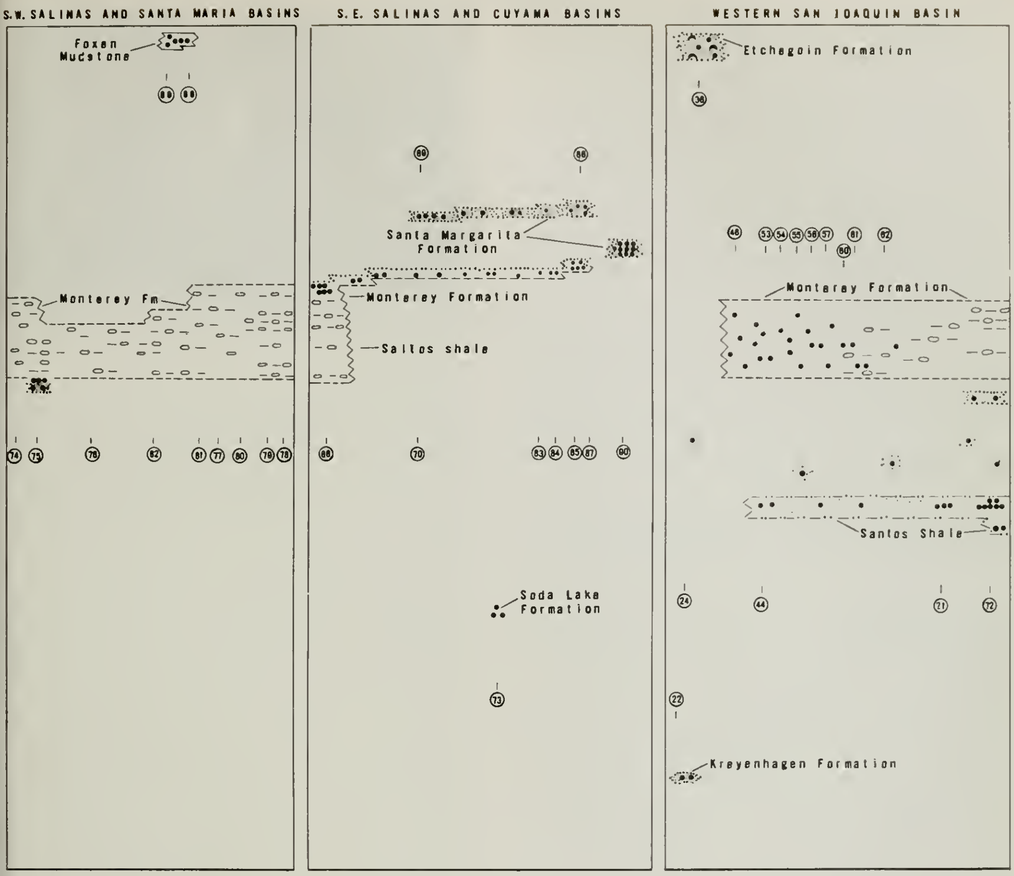
Figure 2. Correlation diagram of Tertiary

sandstones and siltstones in exposures in the southeast Cuyama oil field (86). A 24-m thickness is reported for this zone east of Newsome Canyon (87, Gower and Madsen, 1964).

A large erosion remnant exposed 25 miles southeast of Branch Canyon near Sespe Creek includes thick sandstones of the Santa Margarita Formation in which a zone of pellet-bearing fine clastics locally exceeds 80-m thickness. It crops out for 6 miles to a fault boundary. Pellets comprise more than 70 percent of beds that are as much as 0.75 m thick, and over one 32-m measured section (90) the average pellet concentration is 16.5 percent. Massive gypsum beds occur a few tens of meters higher in the sandstone. These pellet deposits, which were discovered by the Stanford University Summer Field Class of 1963 led by W. R. Dickinson, may become the first commercial source of phosphate developed in California.

Despite a resemblance in lithology to the younger Santa Margarita pellet zone in Cuyama Valley, and apparently similar stratigraphic positions within their respective sandstone units, the Sespe Creek pelletites are believed, on the basis of a similar succession of megafossils at the two localities (J. G. Vedder, oral communication, 1964), to correlate with the older pellet zone at the base of the Santa Margarita Formation to the north.

Any formerly existing lateral merging of the lower Cuyama-Sespe Creek pellet facies with the phosphatic shale facies lying relatively seaward in coastal exposures of the Ventura Basin has been removed by erosion, but continuity of these two prominent phosphatic horizons may be reasonably inferred on the basis of the well-established lateral and vertical relations of the facies elsewhere. The time for mechanical accumulation of the thick pellet zone near Sespe Creek



phosphatic facies in the Coast Ranges.

would be expected to extend somewhat beyond the cessation of deposition of phosphate farther south in the early Mohnian.

Western San Joaquin Basin

The pelletal phosphorites of the Cuyama Basin grade northeast into gypsiferous continental deposits, negating any correlation of phosphatic facies across the San Andreas fault into the southwest San Joaquin Basin. The point to the north where the phosphatic facies abuts the fault, and could continue eastward, is concealed beneath the Carrizo Plain.

The phosphatic shales which characterize the Monterey Formation of the coastal basins are known only in the southern San Joaquin Valley; to the north, the middle Miocene facies is represented by a pellet-bearing brown shale which has long served oil geologists as a marker horizon.

Phosphatic blebs and laminae are dispersed within 75 m (M. N. Bramlette, 1946) of an upper Luisian soft foraminiferal clay shale (Devilwater Silt Member) in the Monterey Formation along Chico Martinez Creek (72). On the eastern side of the San Joaquin Basin, phosphatic streaks are reported in well cuttings from the Fruitvale Shale at substantially the same horizon.

The phosphatic character of these units changes northward to a mixed pellet and shale zone near Still Canyon, and to a dispersed pellet zone in the vicinity of Polonio Pass. Calcareous shales in Still Canyon (62) containing upper Relizian to Luisian Foraminifera include at intervals several meters of phosphate blebs and laminae, nodules, a few thin compact beds of poorly sorted pellets, and lenses of hard yellow weakly phosphatic limestone. Ten miles northwest the phosphate zone is well exposed over more than 100-m thickness, and consists only of pellets dispersed in glauconitic clayey mudstone and a thin phosphate pebble bed (60 and 61, Gower and Madsen, 1964).

On the north slope of Reef Ridge, this unit is from 10 to 60 m thick. It includes phosphate pebble conglomerates to the south near Sulphur Springs Canyon (56), but only sparse pellets northward in Canoas and Baby King Creeks (53, 54) and in Garza Creek (55, Woodring and others, 1940). Numerous well logs show that this "brown shale" thickens eastward to nearly 300 m in the Middle Dome of the Kettleman Hills (49), extends at least 60 miles southward to the Belridge field (71), and reduces to 15 m in the Guijarral Hills east of Coalinga (48). Seven or more discrete layers of these pellets, typically pyritized and referred to locally as "sporbo," an acrostic term, from *s*mooth, *po*lished, *r*ound, *b*lack, *o*bjects (photo 11), are stratigraphically persistent in the Kettleman Hills area (Goudkoff, 1934). The subsurface brown "sporbo shale" is equated with the Luisian *Valvulineria californica* zone by most oil geologists.

The pellet facies wedges out against the southern edge of the Diablo Range, and any northern extension into the Contra Costa Basin is interrupted by erosion.

Summary

Contemporaneous or correlative deposition of phosphate on a regional scale spanning several marine basins began in Relizian time, and in most areas in late Relizian time, and extended into the Luisian. Deposition continued into the early Mohnian south of Monterey and probably took place somewhat later in the inland Cuyama Basin and its southeast extension, but the horizon of most widespread and continuous deposition is of Luisian age. All of 40 sections that summarize the distribution of phosphate in the several basins and extend through the middle Miocene show phosphate-bearing rock within the Luisian Stage (Dickert, 1965). Within the perimeter of the area in which this facies is distributed, each stratigraphic sequence which could be dated as Luisian—through direct microfossil evidence, inference from faunas in contiguous strata, or through extensions of dated beds—includes phosphatic components, or, as in a few instances, the sequence consists of coarse sandstones or graywackes that doubtless inhibited the deposition of phosphate. The weight of this evidence then is that in the middle Miocene, and in particular in early Luisian time, a near-continuous phosphatic facies existed over an area of some 20,000 square miles in central and southern California.

PLIOCENE PHOSPHATIC ROCKS

At the approximate time that sandy diatomaceous sediments with pelletal phosphate were beginning to form on granodiorite in the vicinity of Monterey, a thick accumulation of Monterey-type pellet-bearing sediments was being covered by sand 120 miles to the southeast near the present site of Santa Margarita. This shale-sandstone transition can be traced northwestward back over the traverse of the Salinas Basin previously described; and, as the contact becomes progressively younger, the pelletal phosphate shrinks in thickness and in concentration, although some pellets and phosphatized organic debris appear in basal Santa Margarita beds that may be Delmontian or younger in the northern Salinas Basin (50, 51; 37, R. M. Weidman, 1958).

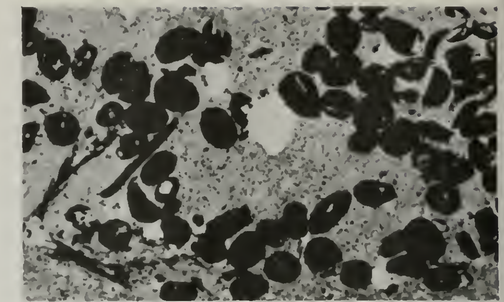


Photo 11. Pyritized pellets. A bone fragment in lower left is partially replaced by pyrite. Field of view 3 mm. Monterey Formation. Kettleman Hills.

In Sonoma County, basal sandstones of the late early or early middle Pliocene Ohlson Ranch Formation locally exhibit coarse, dark pelletal phosphate and phosphatized shell fragments (Higgins, 1960). Over the northern half of the Gabilan Mesa of the Salinas Basin, the Pancho Rico Formation of similar age includes a thin extensive blanket of pellets and phosphatized organic debris (47, T. W. Dibblee, oral communication, 1965; 39, D. L. Durham, oral communication, 1965).

The Pliocene Sisquoc Formation of the Santa Maria Basin is marked locally at its base by a few phosphate nodules and pellets, and a few interlayers of collophane pellets and phosphatic fossil molds occur at intervals throughout the overlying diatomite (Woodring and Bramlette, 1950). Similar stringers of phosphate nodules and pebbles were observed within the superjacent Foxen Mudstone, which thins eastward from about 250 m in the western Purisima Hills to less than 15 m where it disappears in the central Purisima Hills. This condensation (88, 89) is represented chiefly by pelletites and pellet-bearing sandy siltstone, with the pellets extending up into the lower part of the overlying Careaga Sandstone and down into the uppermost Sisquoc diatomite. Pellets comprise 20 percent of a 16-m section, which includes near its base layers 20 cm to 1.5 m thick containing 60 percent or more well-sorted pellets.

In the San Joaquin Basin south of Anticline Ridge (38), basal beds of the Pliocene Etchegoin Formation of sandy siltstones contain lustrous dark phosphate pellets and phosphatic organic debris in concentrations to 20 percent. Phosphatic pellets and nodules at the base of this unit are recorded in two subsurface sections in the southeastern sector.

The Ohlson Ranch, Pancho Rico, and Foxen Formations have been correlated with the Etchegoin of the San Joaquin Basin on both microfossil and megafossil evidence by several workers. Further reconnaissance of Pliocene units in California may reveal the existence of a lower Pliocene phosphatic facies almost as extensive as that of the middle Miocene. However, in the absence of thick deposits of phosphatic shale, such a facies will probably lack the continuity found in the older beds and will consist largely of disconnected aggregates of granular phosphate.

SOME IMPLICATIONS OF THE PHOSPHATIC FACIES

With their lateral continuity and vertical limitations established in part, the phosphatic facies may be used to shed light on some cloudy areas in the stratigraphy of the Coast Ranges. Two illustrations follow.

The Monterey Formation in the Light of its Phosphatic Facies

Most of the extensive middle Miocene phosphate beds are usually assigned to the Monterey Formation, a unit much better known for its siliceous rocks. Moreover, the siliceous and phosphatic facies tend to be exclusive of each other. Littoral pelletite beds commonly interlayer with thick siliceous sequences, but the more synchronous phosphatic shales consistently formed earlier than the siliceous strata.

The transition from a predominantly calcareous phosphatic facies to a siliceous facies is thought to relate to lowered water temperatures in early Mohnian time. The latitudinal and bathymetric distribution of marine phosphate implies the existence of a depth-temperature fence, colder but analogous to that restricting the distribution of authigenic calcium carbonate, known authigenic carbonate-fluorapatite as rare in cold abyssal waters * at low and intermediate latitudes as in shallower waters at high latitudes. The supply of carbonate ion which diminishes with the increased capacity of colder water to retain carbon dioxide is a possible limiting factor.

On the other hand, colder temperatures tend to enhance the production of diatoms and the persistence of their remains, the probable sedimentary source of silica in the Monterey Formation (Bramlette, 1946). Experiments cited by Conger (1942) show that the attendant increase in dissolved oxygen and carbon dioxide markedly favor diatom growth; the cold-water inhibition of phosphate deposition increases the supply of this nutrient for diatom production; and the lowered temperatures tend to diminish solution of their remains. The extraordinary concentration of diatoms in the Monterey sediments presumably required a significant ultimate source of silica such as water-deposited vitric pyroclastics, and the emergence of protected basin-receptacles to concentrate the diatomaceous deposits, as suggested by Bramlette. However, lowered temperature is the common environmental modification which both inhibited the retention of phosphate in sediments and favored the production and retention of diatoms. The reappearance of an extensive phosphatic facies in the late early Pliocene appears to coincide with the warmer temperatures inferred by Ingle (1963) for that period.

Only diatomaceous sediments, with interlayered phosphate pellets and basal phosphatic sands, were deposited on the submarine prominence at the Monterey type locality. However, both the siliceous and subjacent calcareous phosphatic shale facies appear in deeper portions of the Salinas Basin. Here, the calcareous unit is distinguished by most workers as the Sandholdt Formation, or the Sandholdt or Saltos Shale Member of the Monterey Formation. Elsewhere, as in parts of the Ventura and Los Angeles basins, both facies are combined in the Monterey Formation.

In those basins where continuity with the type locality is broken by the San Andreas fault or by a submarine barrier, the presence or absence of the middle Miocene phosphatic facies has been helpful in discriminating between units which have been referred to the Monterey chiefly on the basis of apparently abnormally siliceous strata. For example, in the Santa Cruz Basin, though separated by a sandstone unit and by an unconformity, both the Woodhams Shale Member, containing phosphate inclusions, and a younger diatomaceous mudstone have been assigned to the Monterey Formation for many years. The latter unit is non-phosphatic even at its lower sandstone contact, in contrast to the Monterey Formation at the type locality 25 miles to the south, and these strata have recently been designated a separate formation by J. C. Clark (1966). The older phosphatic Woodhams Shale Member is the age equivalent of basal phosphatic sandstones at the Monterey type locality, and is also equivalent in age and lithology to the Claremont Shale, which contains similar phosphate inclusions, east of the San Andreas fault.

The latter correlation inevitably suggests another stratigraphic puzzler.

Phosphate Beds across the San Andreas Fault

Much of the data cited to support small cumulative offset on the San Andreas fault expectably centers on the matching of rock units directly across the fault zone. The existing evidence of the phosphatic facies may be summarized as follows. While distinctive time-restricted phosphate-bearing units may be traced with confidence from northwest to southeast over very large distances on either side of the fault, these beds have not been traceable directly across the fault zone, so far.

One notable exception is the probable continuity of the Woodhams Shale Member in the Santa Cruz Basin with the Claremont Shale of the Contra Costa district. However, since their cumulative exposures are about 100 miles long and the units are separated by the 25 mile-wide San Francisco Bay block, their original relationship is obscure.

Tertiary strata of the central Santa Cruz Basin and time-related rocks adjacent to the east of the San

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* The very few known abyssal occurrences show evidence either of transport or of a previously shallower environment.

Andreas fault comprise one of several comparative sections analyzed by B. Oakeshott (this bulletin) as evidence of small cumulative displacement along the fault, and the distinctively laminated phosphatic shales of Narizian and of late Zemorrian or early Saucesian age should furnish a check on this continuity. Both of these facies outcrop within a mile of the western border of the San Andreas fault trace through the Santa Cruz Mountains, but have not been observed directly to the east in the rocks thought to be of similar age.

Some of the more distant possible continuities are amenable to similar tests. The conspicuous phosphatic laminates which characterize the lower part of the San Lorenzo Formation of the Santa Cruz Mountains should be sought in the San Emigdio Formation, the eastern counterpart to the San Lorenzo in the southern San Joaquin Basin Suggested by T. W. Dibblee (this bulletin).

Studies of interceptions of the phospatic facies by the San Andreas fault will be most useful if linear elements, such as phosphatic shale-pelletite transition or a depositional boundary, can be identified. For example, along the faulted eastern margin of the San Joaquin Basin, Luisian pellet-bearing Monterey "sporbo" shale gives way to a sandstone barrier to the blebby Claremont Shale of the Contra Costa district at some point north of the presently known northernmost pelletal shale exposure in Polonio Pass. In the Salinas Basin just west of the fault, Luisian phosphate-bearing shales are similarly barred from the phosphatic Monterey shale of the Santa Cruz Basin, with the northernmost exposure encountered so far 65 miles north of Polonio Pass. Continuity of a boundary of non-deposition north of these localities has not yet been investigated but close study of points of interception by the San Andreas fault of such explicit lithologic features as the phosphatic facies may be fruitful.

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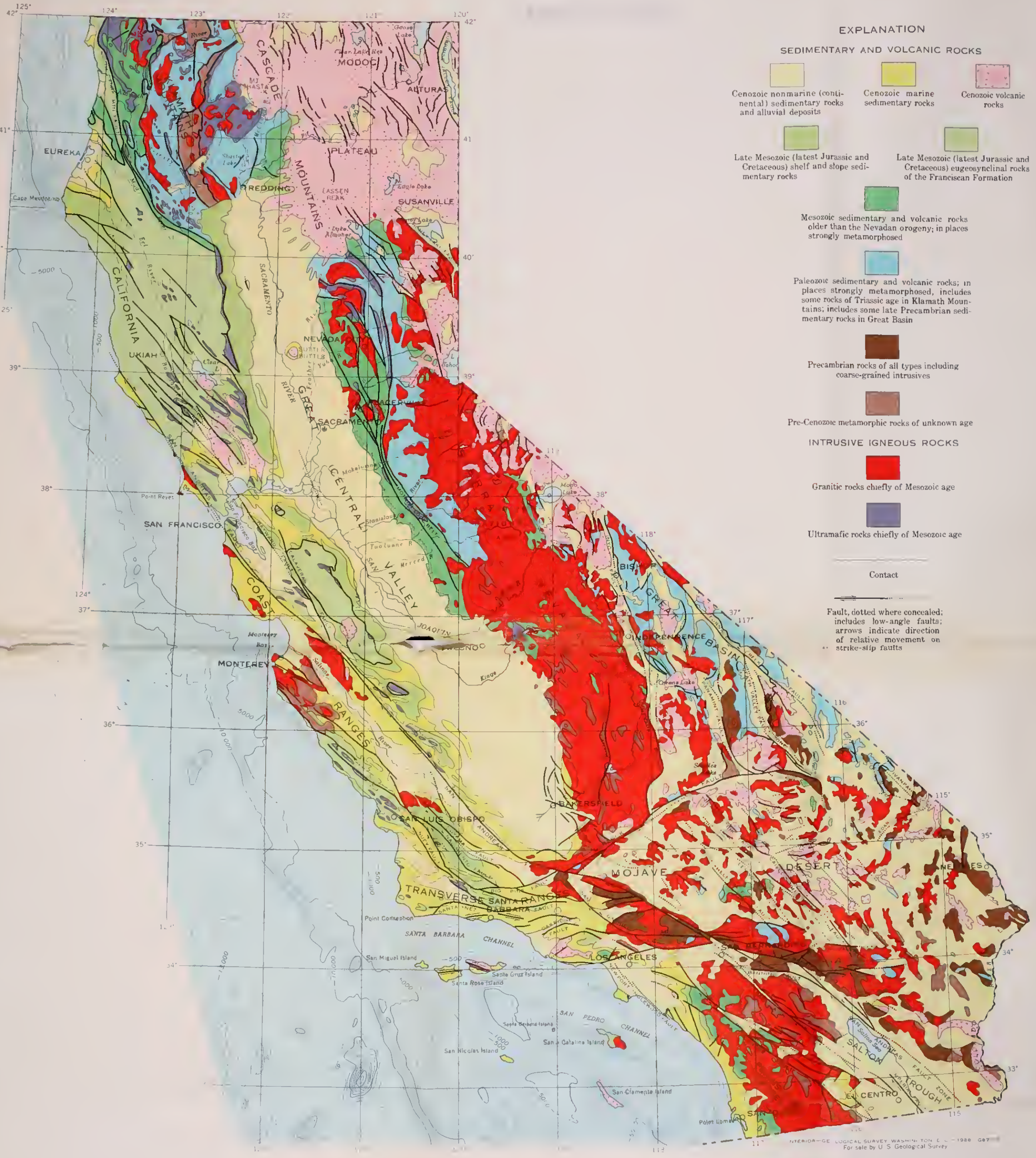
DEPARTMENT OF INTERIOR
UNITED STATES GEOLOGICAL SURVEY

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 G67
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