

Southern California Structure, Sea-Floor Spreading, and History of the Pacific Basin

Abstract: Coastal southern California is east of the Darwin Rise and west of the East Pacific Rise. Accordingly, southern California structural history has implications regarding Pacific Ocean Basin history, particularly the age and nature of the Darwin and East Pacific Rises and the Murray fracture zone, using the sea-floor-spreading model. The Darwin Rise is related to the Franciscan and has a minimum age range of Jurassic to early Late Cretaceous. The Murray fracture zone can be dated through paleogeographic reconstruction of the Late Cretaceous-Early Tertiary coastal sequence; it formed later than Maestrichtian, but no later than middle Eocene time. During the Miocene, the East Pacific Rise moved eastward under the Coast Ranges at a rate of 5.6 cm/yr, producing volcanism and rift topography as it passed, and reaching the site of the Gulf of California in latest Miocene time.

Introduction

The sea-floor-spreading model (Dietz, 1962; Hess, 1962) provides a new frame of reference for interpretation of the tectonic evolution of southern California. If this interpretation is valid, the structures of southern California, formed as side effects of sea-floor spreading, may serve to date the Darwin and East Pacific Rises and the Murray fracture zone with greater precision in California than on the ocean floor itself.

Briefly stated, the sea-floor-spreading hypothesis requires an upwelling of subcrustal material along an oceanic rise, which is an area of high topography, high heat flow, slow upper-mantle seismic velocity, and shallow-focus earthquake activity. This material spreads laterally away from the rise, carrying the sea-floor passively along with it. Spreading rates are determined by correlating the strong linear magnetic anomalies of the flanks of the rise with the geochronology of known magnetic polarity reversals (Vine, 1966; Cox and others, 1964; Doell and Dalrymple, 1966). The subcrustal material descends below an oceanic trench; the interface between descending mantle currents and a stationary crust on the far side of the trench is marked by shallow-, intermediate-, and deep-focus earthquakes, defining a presumed fault zone (Benioff megathrust), parallel to the trench axis, dipping

away from the rise and underneath the continent.

Menard (1964) suggested the presence of a Mesozoic trans-Pacific Darwin Rise which subsided in Early Tertiary time. The East Pacific Rise developed at least by Late Tertiary time nearly at right angles to the Mesozoic rise, and is active today. It intersects the western edge of North America at the mouth of the Gulf of California and reappears off the northern California coast, north of the Mendocino fracture zone, as the Gorda Rise. The position of the rise in North America is unclear. It may end in the Gulf of California, it may continue through the Great Basin of the western United States (Menard, 1964) and be offset in some way by an easterly extension of the Mendocino fracture zone, or it may be offset directly from the Gulf of California to the Gorda Rise by the San Andreas Fault, in which case the San Andreas is a transform fault (Wilson, 1965).

In any of these interpretations of the continental position of the East Pacific Rise, the Coast Ranges of California west of the San Andreas Fault are west of the East Pacific Rise and east of the Darwin Rise. If the Darwin Rise is assumed to have affected the North American coast, now over 6000 km away, onshore structures in the Coast Ranges related to the northeast-spreading Darwin Rise should have been affected in an opposite sense to structures related to the west-spreading East

Pacific Rise. Because the Coast Ranges have been the site of near-continuous marine deposition since Jurassic time, the ages of structures in this region may help determine the ages of both the Darwin and East Pacific Rises.

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Darwin Rise and the Franciscan

The evidence for the Darwin Rise includes ridge and trough topography and transverse fracture zones analogous to those associated with modern rises (Menard, 1964). In contrast to modern rises, seismicity and heat flow are normal, and velocity of seismic waves in the upper mantle is faster than is the world average, indicating that the rise is now inactive. Evidence for its Mesozoic age includes Middle Cretaceous reef organisms on guyots in the Mid-Pacific Mountains (Hamilton, 1956). While the Darwin Rise was active, the sea floor presumably spread northeastward toward the North American coast, forming a trench at the interface between the Pacific Basin and the continent.

The Franciscan Formation of coastal California consists principally of graywacke, dark shale, chert (locally ferruginous), tholeiitic volcanic rocks, and serpentine. On the basis of this lithologic association, particularly the large amount of bedded chert, Bailey and others (1964) concluded that the Franciscan was deposited in average Pacific Basin water depths (4 km). The Franciscan is an orogenic deposit; much of it is chaotic terrane similar to the *argille scagliose* of Italy. The graywackes are of pinch-and-swell type, in contrast to the regular bed thicknesses of graywackes of the same age in the Great Valley to the east (Hsü, 1966). Fossils from the Franciscan are of Tithonian (latest Jurassic) to Turonian (early Late Cretaceous) age; a Campanian (late Late Cretaceous) locality may also be Franciscan (Bailey and others, 1964).

Much of the Franciscan has been metamorphosed to the blueschist facies. A comparison between observed blueschist-facies mineral assemblages and experimental phase equilibrium data has led Ernst (1965) to conclude that the Franciscan rocks were deposited in a trench,

with a thickness in the axis of the trench of nearly 30 km. Apparent ages of metamorphism based on radiometric dating of muscovite from blueschists range from 128 to 149 m.y. (Lee and others, 1964), overlapping the age range based on fossils (Bailey and others, 1964). Rb-Sr ages of metagraywacke with Early Cretaceous fossils are 105 ± 16 m.y. (Blake and others, 1967), indicating approximate contemporaneity of deposition and metamorphism.

South of the main Franciscan area, the Catalina Schist of Catalina Island (E. H. Bailey, 1941, Ph.D. thesis, Stanford Univ.), the Pelona, Orocochia, and Rand Schists of the San Andreas and Garlock fault areas (Ehlig, 1968), and the "Franciscan" off the western coast of Baja California (Cohen and others, 1963) resemble the Coast Range Franciscan in their pre-metamorphic rock types. Correlation of these sequences, assumed herein, is controversial; others consider a Paleozoic or even Precambrian age more likely for the Pelona Schist. However, the major diversity in all these terranes is in metamorphic facies, not pre-metamorphic character. Metamorphic facies boundaries are irregular and sinuous in these rocks because the facies boundaries apparently were originally low-dipping surfaces which were strongly deformed in Cenozoic time. Nevertheless, the distribution of metamorphic rocks in these terranes shows a strong northwesterly alignment (Yeats, 1968) and ranges from zeolite facies on the southwest (Mendocino and Sonoma coast northwest of San Francisco, described by Bailey and others, 1964) to local epidote amphibolite facies on the northeast (Ehlig, 1968, and 1967, personal commun.). The alignment of facies is unaffected by the major strike-slip faults of the Coast and Transverse Ranges, including the San Andreas Fault. The alignment is parallel to the continental escarpment and to the Darwin Rise.

The Franciscan Formation of the northern Coast Ranges, the Catalina Schist of Catalina Island, and the Pelona Schist of the San Gabriel Mountains comprise terranes overlain tectonically by granite-bearing thrust plates (Vincent thrust in the San Gabriel Mountains), yet all three terranes are completely free of pre-Tertiary granites. In each area, metamorphism of the lower plate rocks appears to increase upward toward the thrust, with the thrust zone rocks themselves metamorphosed (Blake and others, 1967; E. H. Bailey, 1941, Ph.D. thesis, Stanford Univ.; Ehlig, 1968). These relationships, together with the anoma-

lous high-pressure, low-temperature mineral assemblages (Ernst, 1965), suggest that the thrust plates form the upper contact of a Benioff-type mega-thrust zone extending from the Franciscan trench underneath the granite-bearing continent. The base of the thrust would presumably be the deeply buried contact between the Franciscan and underlying basaltic or peridotitic crust (Bailey and others, 1964), a tectonic contact which was originally an unconformity.

If the Pelona, Catalina, and Franciscan terranes are correlative, they should be laterally continuous beneath the granite-bearing thrust plate, based on the lack of offset of metamorphic facies boundaries and the evidence of major thrusting in which the granitic rocks have overridden the Franciscan. The base of the granite-bearing thrust plate is the upper part of a fundamental interface between continent and ocean basin, along which the continent has moved westward relative to the ocean basin (*see* earlier suggestions by Gilluly, 1963, and Hamilton and Myers, 1966). The thrust is deep-seated enough to be accompanied by greenschist- or blueschist-facies metamorphism, and it contains deep crustal or mantle elements including eclogite and serpentine (included as part of Franciscan terrane by Bailey and others, 1964).

These relationships suggest northeastward sea-floor spreading away from the Darwin Rise during the time of Franciscan deposition (Tithonian-Turonian or possibly Campanian). The major thrust separating the Coast Range Franciscan from the overlying Klamath Mountains granite-bearing plate is clearly post-Early Cretaceous and is inferred to be post-early Late Cretaceous and pre-late Late Cretaceous (Irwin, 1964). Page (1966), on the other hand, believes the age of thrusting may be as young as Early Tertiary in the Central Coast Ranges. In the San Gabriel Mountains, thrusting pre-dated unmetamorphosed Paleocene marine beds. This time of termination of thrusting may be the same as the time the Darwin Rise became inactive.

The Franciscan trench could also be explained by drift of North America west from the crest of the Mid-Atlantic Ridge. This explanation does not account for the elimination of the trench and the termination of large-scale, low-angle thrusting by Early Tertiary time, because sea-floor spreading from the Mid-Atlantic Ridge has continued throughout the Tertiary and is active today.

Coastal Wedge of the Late Cretaceous and Early Tertiary

In southern California, west of the San Andreas Fault, there is no clear evidence of strong deformation subsequent to Franciscan thrusting and prior to Miocene block faulting. Upper Cretaceous to lower Miocene sedimentary rocks accumulated in a west-facing coastal wedge ranging from nonmarine deposits on the east to deep-water turbidites on the west (Yeats, 1968). The coastal-wedge nature of these older rocks is not readily apparent because of large-scale, right-lateral strike-slip along the San Andreas Fault and left-lateral, oblique-rifting (rift-slip) across the Transverse Ranges (Murray fracture zone). Palinspastic restoration of these lateral offsets indicates that the Coast Range sedimentary prism is a connecting link between the Great Valley wedge (Hackel, 1966) and a sequence on the western coast of Baja California recognized by Allison (1968). The coastal-wedge nature of the Great Valley and Baja California sequences is more easily recognized, because the beds were deposited at the western edge of large blocks which were not broken up by later faulting as were the Transverse Range blocks.

By removal of effects of lateral movement across the San Andreas Fault and the Transverse Ranges, the north-northwest-trending coastal wedge is apparent. The eastern edge of the Upper Cretaceous wedge is remarkably straight, particularly in the Peninsular Ranges (Gastil and Allison, 1966; Yeats, 1968) showing no effect of the Murray fracture zone. The Eocene and Oligocene sequences, on the other hand, form a southwest-opening embayment across the Transverse Ranges, as shown by paleocurrent and conglomerate source data (Yeats, 1968). The distinctive "Poway-type" conglomerate facies (DeLisle and others, 1965) is restricted to the southeastern side of this restored basin. This embayment is on trend with the Murray fracture zone; no other comparable embayment in the Eocene is known to exist in the Coast Ranges.

The middle Eocene (Domengine of the West Coast invertebrate time scale) contains the oldest evidence for the Murray fracture zone; all younger sequences show effects of it (Yeats, 1968). The Late Cretaceous (as young as Maestrichtian) and older sequences show no effects of the Murray fracture zone. The marine Paleocene, although widespread and apparently one of the most transgressive sequences of

California, has thus far provided too fragmentary a sedimentary record to show any evidence of the presence or absence of Murray fracture-zone effects.

The Late Cretaceous-Early Tertiary sequence shows no evidence of any contemporaneous sea-floor spreading, either from the east or from the west, in southern California.

East Pacific Rise

Rusnak and Fisher (1964) concluded that the Gulf of California rift was related to the East Pacific Rise, and the rift opened in Miocene. Strong evidence of the age of this event is present in the Coast Ranges in terms of the age of volcanism, the age of fault-bounded depositional troughs, and the age of rifting.

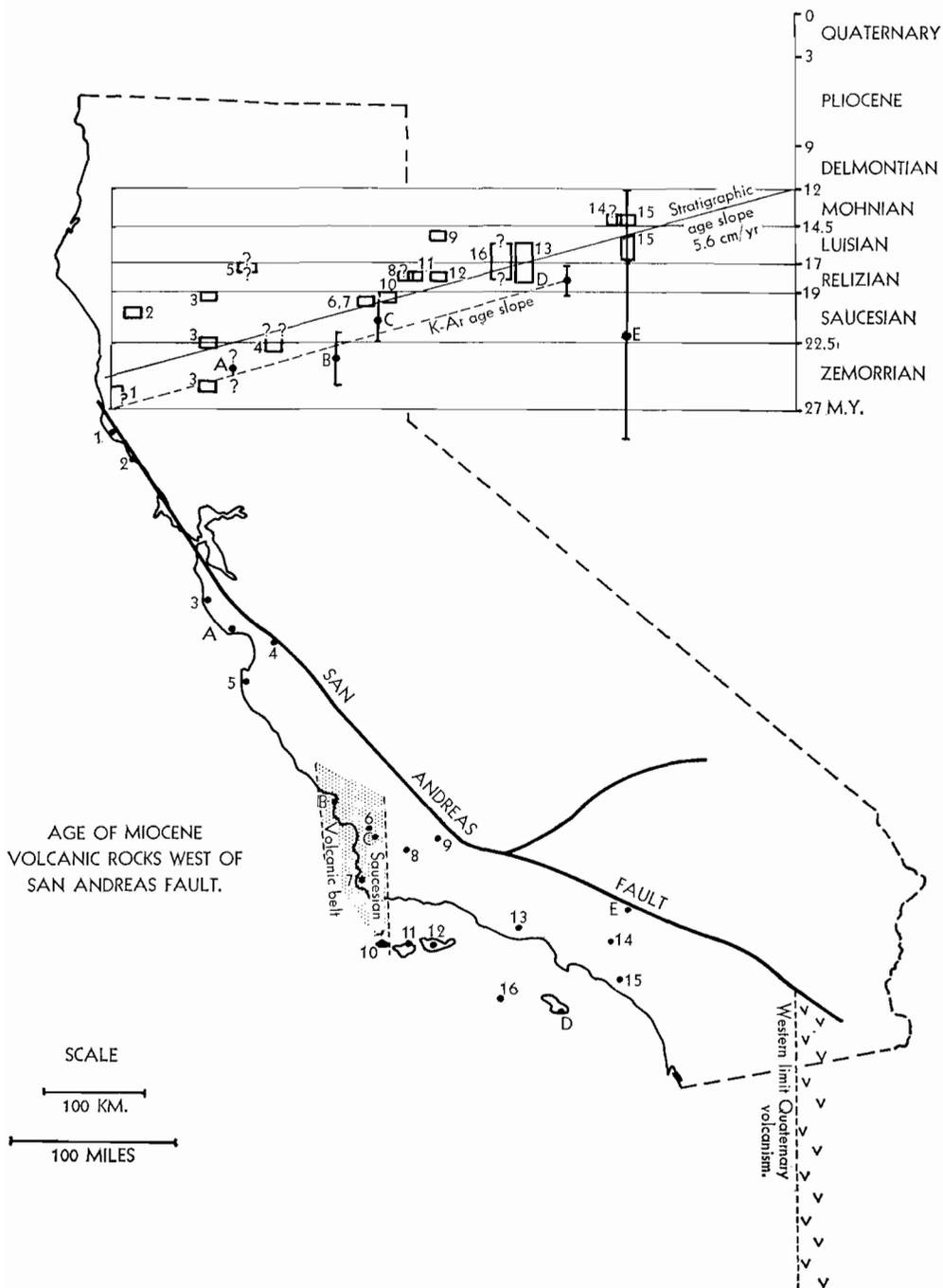
In the Coast Ranges west of the San Andreas Fault, Cenozoic volcanism is restricted to the Miocene time. Moreover, it proceeded from west to east like a wave, beginning in the Zemorrian (earliest Miocene microfaunal stage described by Kleinpell, 1938) in the coastal areas north of San Francisco and in the Santa Cruz basin, and continuing into the Mohnian (early late Miocene microfaunal stage described by Kleinpell, 1938) in the hills east of Los Angeles. This wave is clearly evident only west of the San Andreas Fault; it is not apparent east of the fault and in the Gulf of California. Figure 1 indicates those localities in which volcanic rocks are associated with marine sedimentary rocks in such a way that they can be dated with respect to the Kleinpell microfaunal stages. Based on estimated absolute age

limits of the Kleinpell stages (Evernden and others, 1964), the volcanic wave proceeded across the Coast Ranges west of the San Andreas Fault at a rate of 5.6 cm/yr. Scanty K-Ar age data on Miocene igneous rocks suggest a similar rate, but are consistently older, indicating that the time scale in Figure 1 may be too young. The rate is faster than the present spreading half-rate of 4.4 cm/yr on part of the East Pacific Rise (Vine, 1966), but no as fast as the rate of spreading in the western Caribbean, which is 6.5 cm/yr (Krause, 1967). The wave probably trended nearly north-south in the Saucesian, based on the trend of late Saucesian volcanic rocks at San Luis Obispo, Santa Maria, and San Miguel Island (6, 7, and 10 of Fig. 1). This trend is approximately parallel to the western limit of Quaternary volcanism in the Peninsular Ranges (Allen and others, 1965), and to the present orientation of the East Pacific Rise in the northern Gulf of California (Vine, 1966).

The volcanic wave also coincided with the beginning of formation of narrow fault troughs into which detritus was shed from adjacent high ridges. In the Salinas and Santa Maria basins, the earliest trough deposits were unfossiliferous nonmarine redbeds (Berry Conglomerate, Lospe Formation). Because of their resemblance to the vertebrate-dated Sespe Formation of the Transverse Ranges, these redbeds have been considered as Oligocene, but they are spatially related to and conformable with overlying Saucesian marine beds and are, therefore, probably Miocene. In the Santa Monica Mountains, a new trough began in

Figure 1. Age of Miocene volcanic rocks west of San Andreas Fault. Numbers indicate stratigraphic control; letters indicate K-Ar age measurements. Absolute ages of Miocene stages of Kleinpell (1938) estimated by Evernden and others (1964). Western limit of Quaternary volcanism based on Allen and others (1965). 1. Iverson Basalt, unconformably overlain by Zemorrian sandstone (C. M. Wentworth, unpub. map); 2. Basalt at Fort Ross, Saucesian (C. M. Wentworth, unpub. map); 3. Northern Santa Cruz Mountains (Cummings and others, 1962); 4. San Juan Bautista area (Bazeley, 1961); 5. Olivine basalt near Carmel, middle Miocene (Bowen, 1966); 6. Obispo Fm., Nipomo quadrangle (Hall and Corbató, 1967); 7. Tranquillon Volcanics (Dibblee, 1950); 8. Loma Pelona area, diabase intrudes Relizian beds (J. G. Vedder, 1967, personal commun.); 9. Triple basalt, Caliente Range (J. G. Vedder, 1967, personal commun.); 10. San Miguel Island, volcanics concordant on Saucesian, overlain by lower Relizian beds; 11. Santa Rosa Island, volcanics overlie and are interbedded with Relizian beds; 12. Santa Cruz Island, volcanics overlie Relizian beds, are overlain by lower Luisian beds; 13. Santa Monica Mountains, volcanics overlie Relizian, are interbedded with Luisian, and are overlain by Mohnian beds; 14. Puente Hills, diabase intrusive into lower Mohnian beds; 15. San Joaquin Hills (Yerkes and others, 1965); 16. Santa Barbara Island, interbed of middle Miocene shale in volcanics (Jennings, 1962).

A. 24.1 m.y., basalt flow in Vaqueros Sandstone (J. C. Clark, Ph.D. thesis, Stanford Univ.); B. 23.5 ± 1.8 m.y., plagioclase in andesite-dacite porphyry, Morro Rock volcanic neck (Hall and others, 1966); C. 20.9 ± 1.5 m.y., plagioclase in Obispo Fm. (same age as Loc. 6) (Hall and others, 1966); D. 18.2 ± 1 m.y., diorite intrusive into Catalina Schist (J. A. Forman, 1967, personal commun.); E. 22 m.y., average of two biotite ages of 17 ± 5 m.y. and 26 ± 3 m.y. from the same outcrop of quartz monzonite intrusive into thrust mylonites, Telegraph Peak (Hsü and others, 1963; P. L. Ehlig, 1967, personal commun.).



the Relizian (Topanga Formation), and the Los Angeles basin was initiated in the Luisian.

The wave of volcanism and the initiation of fault topography are attributed to the eastward migration of the crest of the East Pacific Rise beneath the Coast Ranges to its present site in the Gulf of California. The scatter of volcanic ages shown in Figure 1 may be used as a first approximation of the width of the rise crest during the time of its migration; it was slightly more than 300 km, about the same width as the heat-flow band at the crest of the present-day East Pacific Rise (Menard, 1964). Based on an eastward extrapolation of the rate established in Figure 1, the rise would have arrived at its present site in the Gulf in Delmonian time. The rise does not now underlie the Coast Ranges, because the Coast Ranges now have normal heat flow and upper mantle seismic velocity (Stuart and others, 1964).

An additional criterion for the passage of the East Pacific Rise to a position east of the Coast Ranges is the evidence for westward rifting of the granitic blocks and their pre-middle Miocene sedimentary veneer. The eastern edge of the Upper Cretaceous, the depositional axis of the Eocene and Oligocene basin, and the lower Miocene marine-nonmarine facies boundary show evidence of 190 ± 30 km of left lateral, rift-slip displacement across the Transverse Ranges (Yeats, 1968). This offset is comparable in magnitude to less well-defined, left-lateral offsets of the quartz-diorite line (Moore, 1959, revised for California by Yeats, 1968) and the eastern edge of the middle Mesozoic eugeosynclinal belt (Galice, Mariposa, Santa Monica, Bedford Canyon, and Santa Cruz Island sequences). From these offsets, it is concluded that (1) left-lateral rift-slip across the Transverse Ranges is entirely post-early Miocene, in contrast to the San Andreas Fault north of the Transverse Ranges, where considerable pre-Miocene right-lateral displacement has been demonstrated (Hill and Dibblee, 1953), and (2) left-lateral rift-slip is limited to the granitic blocks and their Upper Cretaceous-lower Miocene sedimentary veneer, because the metamorphic facies boundaries in the Franciscan show no evidence of offset (Yeats, 1968).

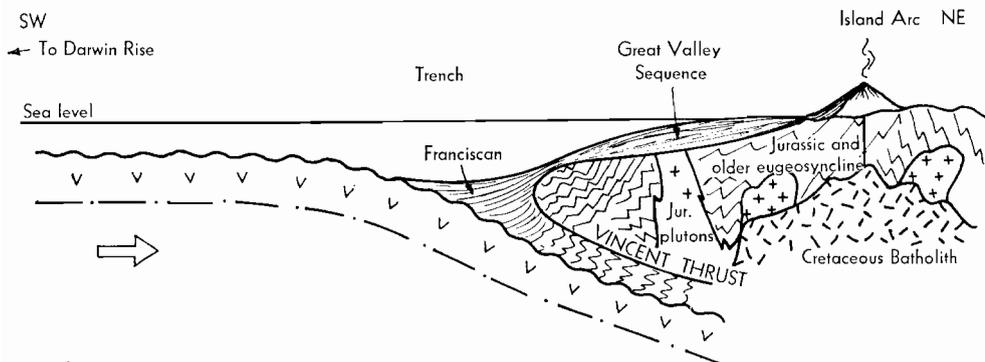
The limitation of offsets to the granitic blocks indicates that the Franciscan did not participate in the left-lateral rift-slip across the Transverse Ranges. The continuity of metamorphic facies across (or beneath) intervening granitic blocks suggests that the granitic blocks moved independently of one another as

rootless, iceberg-like rafts floating in a sea of Franciscan. The surface of detachment was the Mesozoic thrust plane; the time of detachment was after the deposition of pre-rift lower Miocene rocks. The postulated mechanism for detachment was westward sea-floor spreading from the crest of the East Pacific Rise in the northern Gulf of California.

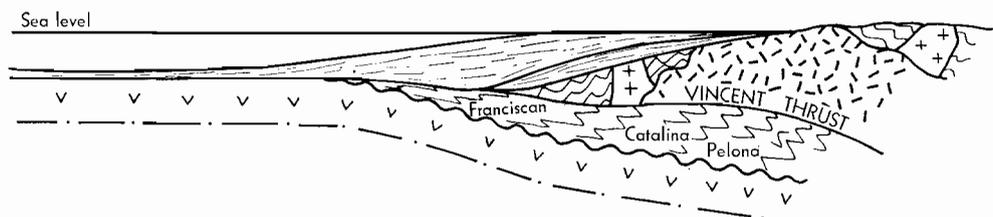
Westward spreading of oceanic crust beneath the Coast Ranges cannot be demonstrated directly, because the presumed basaltic basement under the Franciscan is not exposed at the surface. The effects of spreading are an attenuation of the two-layer continental crust (granite over Franciscan) west of the East Pacific Rise. The Franciscan, being highly mobile, yielded in a ductile fashion, welling up in the rifts in early stages, and later being attenuated to form the floors of Late Tertiary rift basins. The granitic thrust plate, being brittle, broke apart and formed rafts in the Franciscan, which were dragged along passively by the westward-spreading sea floor.

According to this interpretation, the Franciscan-floored Los Angeles and Santa Maria basins were covered by granitic upper-plate rocks prior to Miocene rifting (Fig. 2); therefore, the Franciscan was not in a position to shed detritus or receive sediments prior to the Miocene. The oldest sedimentary rocks resting on the Franciscan or containing Franciscan detritus in both these areas are Miocene. This is clearly recognized in the Los Angeles basin (Yerkes and others, 1965) but not in the region around Santa Maria where pre-Miocene rocks have been assumed to be in depositional contact with Franciscan. However, Cretaceous rocks supposedly resting on Franciscan northeast of Santa Maria have been reinterpreted as a thrust plate (Brown, 1967), and Franciscan rocks along the Santa Ynez fault in a predominantly Eocene section are probably in piercement structures (Bailey and others, 1964). Franciscan(?) detritus in Oligocene rocks of the western Santa Ynez Range may be derived from an area northeast of the San Andreas Fault, where rifting may have occurred much earlier than Miocene (Bailey and others, 1964).

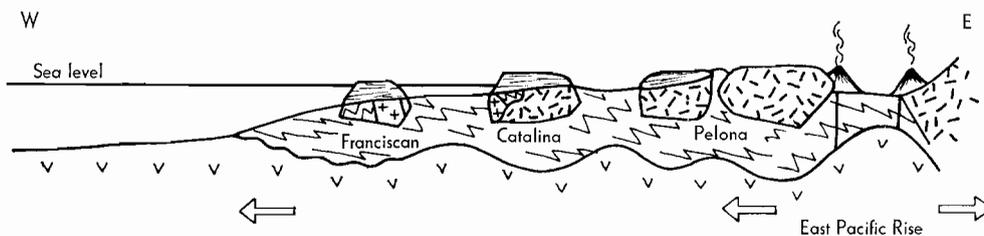
Also, according to this interpretation, the San Andreas Fault would be a shallow feature of the crust, penetrating only to the base of the granitic thrust plate. The San Andreas has been interpreted as a shallow feature by Hamilton and Myers (1966); subsequent evidence based on focal depths of earthquakes in and near the San Andreas Fault indicates a depth



1 Underthrusting of continent by sea-floor spreading from Darwin Rise. Franciscan deposited on oceanic crust in trench, dragged beneath the continent along Vincent thrust during deposition



2 Late Cretaceous—Early Tertiary coastal plain. No apparent sea floor spreading. Cretaceous deposited across eroded edge of Vincent thrust.



3 East Pacific Rise east of Coast Ranges. Sea floor spreads westward, attenuating Franciscan crust and breaking apart sediment-veneered granitic blocks.

TECTONIC EVOLUTION OF SOUTHERN CALIFORNIA

Figure 2. Diagrammatic crustal section of edge of continent in southern California in (1) early Late Cretaceous, (2) early Miocene, (3) latest Miocene.

range of 1 to 16 km, with most of the activity shallower than 10 km (Brune and Allen, 1967; McEvilly and Casaday, 1967).

The sea-floor-spreading model does not account for the Plio-Pleistocene tectonics overprinted on the Miocene rift basins. These younger structures include sharp folds and thrust faults, in sharp contrast to the normal fault tectonics of the Miocene. The structures may result from vertical adjustments after Miocene rifting, such as attenuation of ductile Franciscan beneath the rift basins and isostatic adjustment of the granitic rafts subsequent to rifting.

Conclusions Regarding History of the Pacific Basin

From the point of view of California, the

history of the Pacific Basin was as follows (Fig. 2):

(1) Northeast sea-floor spreading of the Darwin Rise, as old as Jurassic, and as young as Turonian and possibly younger in the Cretaceous;

(2) Formation of the Murray fracture zone later than Maestrichtian (Late Cretaceous) time, but no later than Domengine (middle Eocene) time;

(3) Eastward migration of the crest of the East Pacific Rise at a rate of 5.6 cm/yr until it reached its present site east of the Peninsular Ranges in Delmontian (latest Miocene) time; and then westward sea-floor spreading, resulting in formation of the Gulf rift and crustal attenuation and breakup of the southwest corner of North America during Miocene time.

References Cited

- Allen, C. R., St.-Amand, Pierre, Richter, C. F., and Nordquist, J. M., 1965, Relationship between seismicity and geologic structure in the southern California region: *Seismol. Soc. America Bull.*, v. 55, p. 753-797.
- Allison, E. C., 1968, One hundred million years at the rim of the Pacific: northern Baja and southern Alta, California (abs.): *Geol. Soc. America Spec. Paper 101, Abstracts for 1966*.
- Bailey, E. H., Irwin, W. P., and Jones, D. L., 1964, Franciscan and related rocks, and their significance in the geology of western California: *California Div. Mines and Geology Bull.* 183, 177 p.
- Bazeley, W. J. M., 1961, 175 miles of lateral movement along the San Andreas fault zone since lower Miocene?: *Pacific Petroleum Geologist*, v. 15, p. 2-3.
- Blake, M. C., Jr., Irwin, W. P., and Coleman, R. G., 1967, Upside-down metamorphic zonation, blueschist facies, along a regional thrust in California and Oregon: *U.S. Geol. Survey Prof. Paper 575-C*, p. C1-C9.
- Bowen, O. E., 1966, Stratigraphy, structure and oil possibilities in Monterey and Salinas quadrangles, California, in Rennie, E. W., *Editor*, A symposium of papers presented at the fortieth annual Pacific Section A.A.P.G. Convention—1965: Bakersfield, California, p. 48-67.
- Brown, J. A., 1967, Probable thrust contact between Franciscan Formation and Great Valley sequence northeast of Santa Maria, California (abs.): *Geol. Soc. America, 63rd Annual Meeting, Cordilleran Section, Program*.
- Brune, J. N., and Allen, C. R., 1967, A micro-earthquake survey of the San Andreas fault system in southern California: *Seismol. Soc. America Bull.*, v. 57, p. 277-296.
- Cohen, L. H., Condie, K. C., Kuest, L. J., Mackenzie, G. S., Meister, F. H., Pushkar, Paul, and Steuber, A. M., 1963, Geology of the San Benito Islands, Baja California, Mexico: *Geol. Soc. America Bull.*, v. 74, p. 1355-1370.
- Cox, Allan, Doell, R. R., and Dalrymple, G. B., 1964, Reversals of the earth's magnetic field: *Science*, v. 144, p. 1537-1543.
- Cummings, J. C., Touring, R. M., and Brabb, E. E., 1962, Geology of the northern Santa Cruz Mountains, California: *California Div. Mines and Geology Bull.* 181, p. 179-220.
- DeLisle, Mark, Morgan, J. R., Heldenbrand, Jay, and Gastil, R. G., 1965, Lead-alpha ages and possible sources of metavolcanic rock clasts in the Poway Conglomerate, southwest California: *Geol. Soc. America Bull.*, v. 76, p. 1069-1074.
- Dibblee, T. W., Jr., 1950, Geology of southwestern Santa Barbara County, California: *California Div. Mines and Geology Bull.* 150, 95 p.
- Dietz, R. S., 1962, Ocean basin evolution by sea-floor spreading: *Am. Geophys. Union Geophys. Mon. Ser. no. 6*, p. 11-12.
- Doell, R. R., and Dalrymple, G. B., 1966, Geomagnetic polarity epochs—A new polarity event and the age of the Brunhes-Matuyama boundary: *Science*, v. 152, p. 1060-1061.

- Ehlig, P. L.**, 1968, Causes of distribution of Pelona, Rand, and Orocochia Schists along the San Andreas and Garlock faults, *in* Dickinson, W. R., and Grantz, Arthur, *Editors*, Proceedings of conference on geologic problems of San Andreas fault system: Stanford Univ. Pubs. Geol. Sci., v. 11, p. 294-306.
- Ernst, W. G.**, 1965, Mineral parageneses in Franciscan metamorphic rocks, Panoche Pass, California: Geol. Soc. America Bull., v. 76, p. 879-914.
- Evernden, J. F., Savage, D. E., and James, G. T.**, 1964, Potassium-argon dates and the Cenozoic mammalian chronology of North America: Am. Jour. Sci., v. 262, p. 145-198.
- Gastil, R. G., and Allison, E. C.**, 1966, An Upper Cretaceous faultline coast (abs.): Am Assoc. Petroleum Geologists Bull., v. 50, p. 647-648.
- Gilluly, James**, 1963, The tectonic evolution of the western United States: Geol. Soc. London Quart. Jour., v. 119, p. 133-174.
- Hackel, Otto**, 1966, Summary of the geology of the Great Valley: California Div. Mines and Geology Bull. 190, p. 217-238.
- Hall, C. A., and Corbató, C. E.**, 1967, Stratigraphy and structure of Mesozoic and Cenozoic rocks, Nipomo quadrangle, southern Coast Ranges, California: Geol. Soc. America Bull., v. 78, p. 559-582.
- Hall, C. A., Turner, D. L. and Surdam, R. C.**, 1966, Potassium-argon age of the Obispo Formation with *Pecten lompocensis* Arnold, southern Coast Ranges, California: Geol. Soc. America Bull., v. 77, p. 443-446.
- Hamilton, E. L.**, 1956, Sunken islands of the Mid-Pacific Mountains: Geol. Soc. America Mem. 64, 97 p.
- Hamilton, Warren, and Myers, W. B.**, 1966, Cenozoic tectonics of the western United States: Rev. Geophysics, v. 4, p. 509-549.
- Hess, H. H.**, 1962, History of ocean basins, *in* Engel, A. E. J., and others, *Editors*, Petrologic studies: A volume in honor of A. F. Buddington: New York, Geol. Soc. America, p. 599-620.
- Hill, M. L., and Dibblee, T. W., Jr.**, 1953, San Andreas, Garlock and Big Pine faults, California—a study of the character, history and tectonic significance of their displacements: Geol. Soc. America Bull., v. 64, p. 443-458.
- Hsü, K. J.**, 1966, Franciscan rocks of the Santa Lucia Range, California, and the *argille scagliose* of the Apennines, Italy: a comparison in style of deformation (abs.): Geol. Soc. America Spec. Paper 87, Abstracts for 1965, p. 210-211.
- Hsu, K. J., Edwards, George, and McLaughlin, W. A.**, 1963, Age of the intrusive rocks of the southeastern San Gabriel Mountains, California: Geol. Soc. America Bull., v. 74, p. 502-512.
- Irwin, W. P.**, 1964, Late Mesozoic orogenies in the ultramafic belts of northwestern California and southwestern Oregon: U.S. Geol. Survey Prof. Paper 501-C, p. C1-C9.
- Jennings, C. W.**, 1962, Long Beach Sheet, Geologic Map of California.
- Kleinpell, R. M.**, 1938, Miocene stratigraphy of California: Tulsa, Oklahoma, Am. Assoc. Petroleum Geologists, 450 p.
- Krause, D. C.**, 1967, Magnetic evidence for western Caribbean basin origin by Late Cretaceous crustal spreading (abs.): Am. Geophys. Union Trans., v. 48, p. 133.
- Lee, D. E., Thomas, H. H., Marvin, R. F., and Coleman, R. G.**, 1964, Isotopic ages of glaucophane schists from Cazadero, California (abs.): Geol. Soc. America Spec. Paper 76, Abstracts for 1963, p. 210-211.
- McEvelly, T. V., and Casaday, K. B.**, 1967, The earthquake sequence of September, 1965 near Antioch, California: Seismol. Soc. America Bull., v. 57, p. 113-124.
- Menard, H. W.**, 1964, Marine geology of the Pacific: New York, McGraw-Hill, 271 p.
- Moore, J. G.**, 1959, The quartz diorite boundary line in the western United States: Jour. Geology, v. 67, p. 198-210.
- Page, B. M.**, 1966, Geology of the Coast Ranges of California: California Div. Mines and Geology Bull. 190, p. 255-276.
- Rusnak, G. A., and Fisher, R. L.**, 1964, Structural history and evolution of Gulf of California, *in* van Andel, T. H., and Shor, G. G., *Editors*, Marine geology of the Gulf of California: Am. Assoc. Petroleum Geologists Mem. 3, p. 144-156.
- Stuart, D. J., Roller, J. C., Jackson, W. H., and Mangan, G. B.**, 1964, Seismic propagation paths, regional travel times, and crustal structure in the western United States: Geophysics, v. 29, p. 178-187.
- Vine, F. J.**, 1966, Spreading of the ocean floor: new evidence: Science, v. 154, p. 1405-1415.
- Wilson, J. T.**, 1965, Transform faults, oceanic ridges, and magnetic anomalies southwest of Vancouver Island: Science, v. 150, p. 482-485.

- Yeats, R. S.**, 1968, Rifting and rafting in the southern California borderland; *in* Dickinson, W. R., and Grantz, Arthur, *Editors*, Proceedings of conference on geologic problems of San Andreas fault system: Stanford Univ. Pubs. Geol. Sci., v. 11, p. 307-322.
- Yerkes, R. F., McCulloh, T. H., Schoellhamer, J. E., and Vedder, J. G.**, 1965, Geology of the Los Angeles Basin, California—an introduction: U.S. Geol. Survey Prof. Paper 420A, 57 p.

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