GEOLOGIC STRUCTURE ON THE CONTINENTAL MARGIN, FROM SUBBOTTOM PROFILES, NORTHERN AND CENTRAL CALIFORNIA

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The region offshore from northern and central California is a common type of continental margin, although it is atypical for the Pacific Ocean. Most of the margin of the Pacific Ocean basin is of the marginal depression or trench type, with narrow shelves and coastal plains, steep continental slopes, and a marginal depression or trench at the base of the slope. The Pacific margin off much of North America, on the other hand, is morphologically more similar to the margins of the Atlantic and Indian Oceans, with broad to intermediate width shelves, a typical continental slope, and a rise or series of deep-sea fans at the base of the slope. The area of investigation of this study is shown by submarine contours on figure 1, and by a physiographic diagram in figure 2. If a bordering oceanic depression or trench ever lay at the base of the slope in this area, it has been filled and buried beneath the Delgada and Monterey Fans, which together constitute the continental rise in this vicinity.

This article presents incomplete results of a study in progress on this region,[1] summarized from Curray (1965) and Curray and Nason (in press). It is based on continuous acoustic reflection profiling along the survey lines shown in figure 1, supplemented by bathymetry and other work of the Scripps Institution with modified Rayflex "Arcer" (or sparker-type) equipment, with input energy to the spark source of 20,000 joules, pulsing interval of 2 or 4 seconds, and bandpass filtering of the returning energy between 73 and 120 cycles per second.

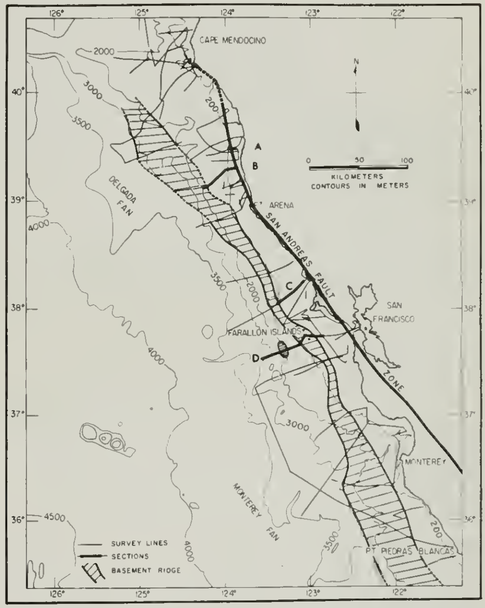

Figure 1. Chart of the area of investigation, showing reflection profile lines, locations of sections A through D, and some geological features. The continental shelf is approximately from the shoreline to 200 m, the continental slope is from 200 to 3,000 m, and the continental rise (Delgada and Monterey Fans) is below about 3,000 m.

SHALLOW STRUCTURE OF THE CONTINENTAL MARGIN

Gross structural features of the upper, predominantly sedimentary, portion of the continental margin have been delineated by the continuous acoustic reflection profiles shown in figure 1. Some examples of these profiles are included as figures 3, 4, 5, and 6, and others have been discussed by Curray (1965, figs. 2, 3, and 4). These figures include photographs and line tracings of major reflectors from the original records. No allowance has been made for variation in ship's speed, nor has any allowance been made for variation in the speed of sound with depth in the sediment and rock column. Thus, the horizontal scales are an average for each section, and the vertical scales show round trip travel time of the sound energy and depth at the velocity of sound in sea water (approximately 1500 m/sec). Actual sound velocities in the sediment and rock are unknown, but a usable approximation lending itself to easy calculation is 2 km/sec. Thus 1 second of penetration beneath the sea floor would represent about 1 km of section.

[1] Contribution from the Scripps Institution of Oceanography, University of California, La Jolla, California. Financial support was furnished by the National Science Foundation and the Office of Naval Research. The following have contributed greatly to this study by assisting in collecting and interpreting the reflection records: D. G. Moore, S. M. Smith, P. J. Crampton, R. D. Nason, C. C. Daetwyler, and many others.

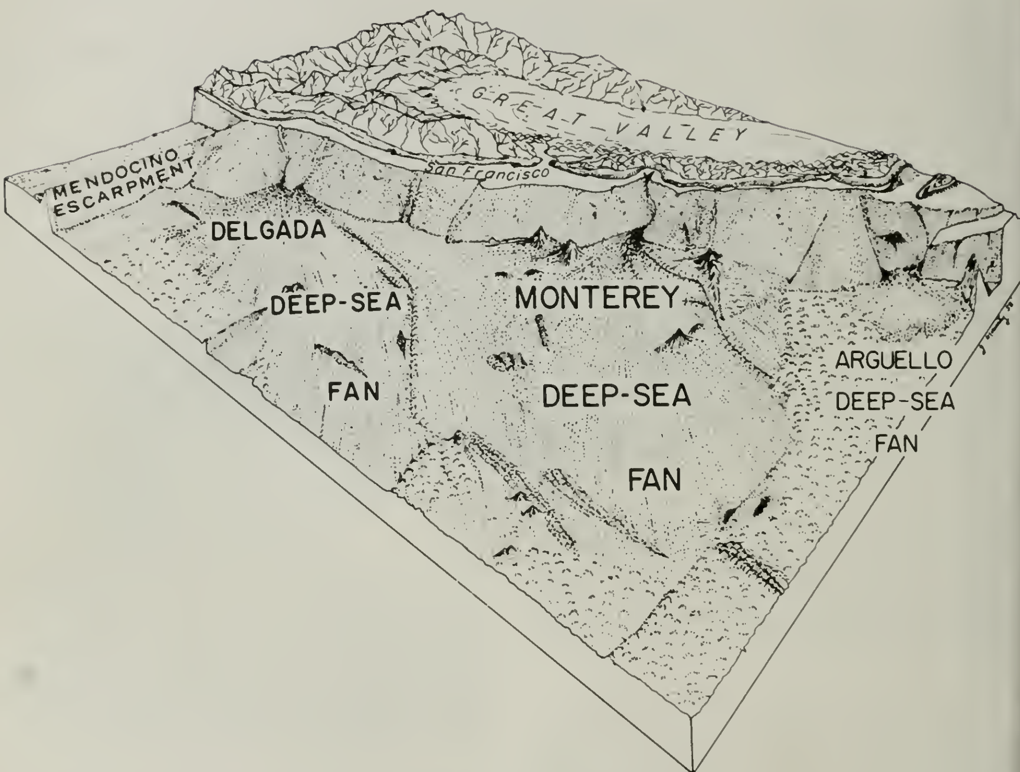

Figure 2. Physiographic diagram of area of investigation. Vertical exaggeration approximately 20x. From Menard (1960).

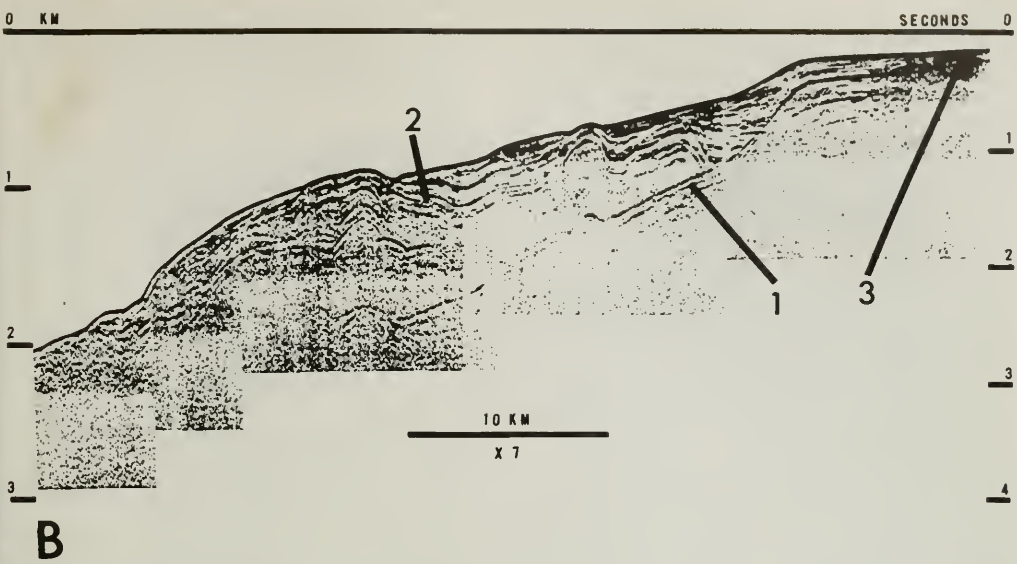

Figure 3. Acoustic reflection profile along line B of figure 1. Scale on right is round trip travel time, scale on left is approximate water depth at 1500 m/sec sound velocity. Note the following: (1) multiple of sea floor and sub-surface reflecting horizons, (2) reflecting horizons beneath the sea floor, with folds, unconformities, and truncation at the sea floor, but no evidence of major faults, (3) disturbed zone on the inner shelf probably representing the San Andreas fault zone.

Line B (fig. 3) extends across the shelf and down the slope seaward from the town of Mendocino, about 10 miles south of Fort Bragg. The slope here is underlain by a thick section of gently folded sedimentary rock, presumably Tertiary in age. Cretaceous (Franciscan) rock crops out along the coast, and some of the adjacent lines show the surface of this Cretaceous section dipping seaward beneath the shelf until it is lost in the disturbed zone of the seaward extension of the San Andreas fault. Other profiles in this area show a deeply submerged ridge of basement rock under the lower slope below a water depth of about 2,000 m.

Line D (fig. 4) is a tracing of a record off San Francisco that extends across the outer shelf, between the Farallon Islands, and down to the base of the slope. This record is replotted without vertical exaggeration in the lower part of this figure. Of special interest is the rather thick fill of sediment underlying the shelf and the thick fill underlying the continental rise at the base of the slope at a water depth of about 3,000 m. Most of the slope is underlain by a ridge of basement rock, known here to be the Cretaceous quartz diorite that crops out on the Farallon Islands and the Cordell Bank just to the north (Hanna, 1951, 1952; Chesterman, 1952; and Curtis, and others, 1958). This same ridge of basement rock can be observed under the outer shelf or slope in all but a few of the lines, and is presumed by correlation to be more or less continuous (fig. 1). The nature of its upper surface appears to be the same in all these records, but the possibility nevertheless exists that the age and lithology are not the same all the way along.

The depth below sea level to the top of this ridge varies from north to south. It lies about 2,000 m below sea level at the north, probably is even deeper seaward of the section shown in line B (fig. 3), is 250 m below sea level off Point Arena, and is at the sea floor or above sea level in the Farallon Islands. Farther south it is at about 500 m depth in Monterey Canyon, where granitic rock has been dredged (Shepard and Emery, 1941), and at about 1,000 m off Point Piedras Blancas. The best developments of the continental rise, Delgada and Monterey Fans, lie adjacent to the more deeply buried parts of the ridge. Each of these lobes is identified with a major canyon system, which is presumably the source of the bulk of the sediments of the fans (Menard, 1960). These have developed where the ridge is deepest and sediments may pass most easily over its top. Loading due to increased deposition may have caused subsidence and further deepened the ridge.

Another notable feature seen on figure 4 is the section of contorted sedimentary rocks underlying the slope. Miocene marine sediment has been dredged from this slope by Hanna (1952) and Uchupi and Emery (1963), so this slumped contorted mass is known to consist, at least in part, of Miocene rocks. It has presumably slumped part way down the slope because of oversteepening and instability.

FAULTS

One of the interesting problems in this region pertains to the position of the seaward extension of the San Andreas fault zone from where it leaves the coast at Point Arena. During the 1906 earthquake, surface rupture occurred along the fault zone from east of Monterey to Point Arena. Displacement also occurred along a fault at Shelter Cove, south of Cape Mendocino (about 40° N., fig. 1), and on this basis Lawson and others (1908) believed the fault zone curved to follow near the coastline from Point Arena to Shelter Cove. Shepard and Emery (1941) and Shepard (1957) also believed the fault zone followed the coast, although Tocher (1956) and Benioff (1962) thought on the basis of earthquake epicenters that the fault ran straight across the shelf, down the slope, and across the Gorda Escarpment off Cape Mendocino. Some of the evidence presented by Curray and Nason (in press) to prove that the fault zone curves as shown in figure 1 is reviewed here.

If the fault zone continued straight from Point Arena, it would cross the upper slope in line B, shown in figure 3, approximately between points 1 and 2. Two folds occur here, with possible secondary faults on their flanks, but the overlying younger sediments show no displacement or disturbance. Even though the dominant displacement on the San Andreas fault is horizontal, the fault should be visible in this and the other survey lines on the slope. This slope, and the others in this region, are remarkably devoid of faults of any kind in contrast to the shelf. In the same figure, a disturbed zone on the inner shelf is pointed out by point 3.

Figure 5 from a traverse along line A, shows a section on the shelf offshore from Fort Bragg. Note the zone of disturbed sediments and the seaward-facing escarpment at 3. This zone lines up with a similar disturbed zone in each successive survey line made of this shelf, and the escarpment is aligned with the escarpments of the other tracings. In some cases they face seaward as here, in others they face landward. This zone on the shelf is believed to be the San Andreas fault zone. It is headed toward the vicinity of Shelter Cove in the northernmost survey line that crosses it (about 39°50′ N.). North of Shelter Cove it apparently skims the coastline, cuts off the head of Delgada Canyon, and runs into Mattole Canyon at Punta Gorda, south of Cape Mendocino (40° 15′ N.). Immediately north of line A, in Noyo Canyon it causes a right-angle bend which appears to result from right-lateral displacement.

Faults appear to occur elsewhere on the shelf, but are especially well developed between Monterey and south of Point Arena. The slope, however, is here

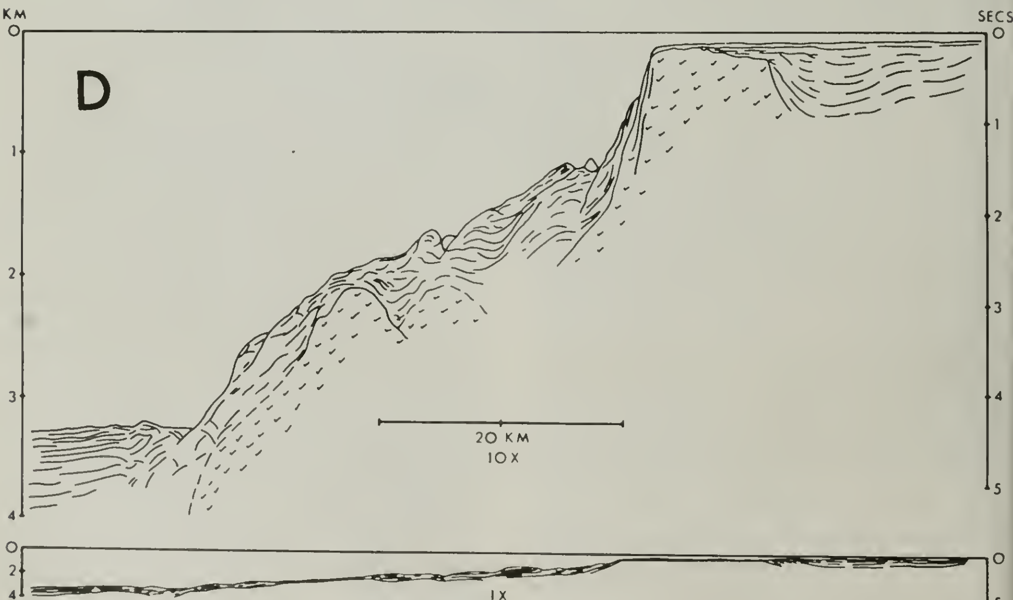

Figure 4. Line drawing of acoustic reflection record along line D of figure 1, passing between Farallon Islands on shelf edge. Upper section has vertical exaggeration 10:1; lower section is natural scale. Note locations of granitic rock (Cretaceous quartz diorite), sediment fill underlying continental shelf, sediment fill at base of slope underlying continental rise, and contorted nature of sedimentary rock (at least in part Miocene) overlying and slumping down on granitic rock on the slope.

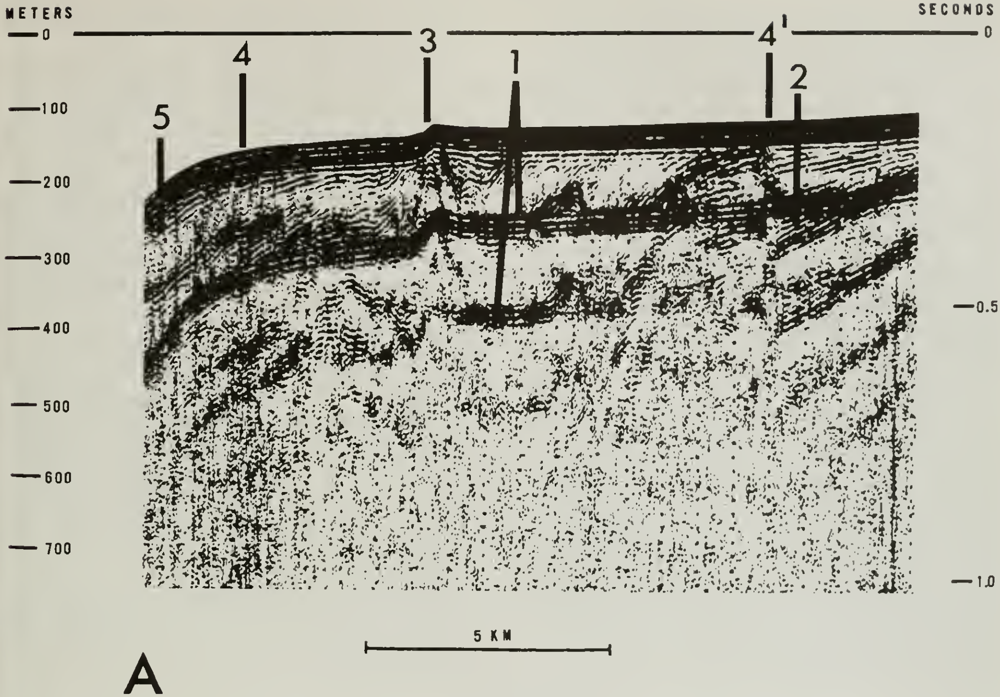

Figure 5. Acoustic reflection profile along line A on figure 1, showing disturbed region of San Andreas fault zone on the continental shelf. Note the following: (1) multiples of sea floor and sub-bottom reflectors, (2) probable top of Cretaceous, (3) 18 m. (60 feet) west-facing escarpment trending along fault zone, (4) to (4') disturbed contorted fault zone, and (5) undisturbed seaward dips, probably Tertiary, which continue on down the slope from here as in figure 3. Vertical exaggeration 15x.

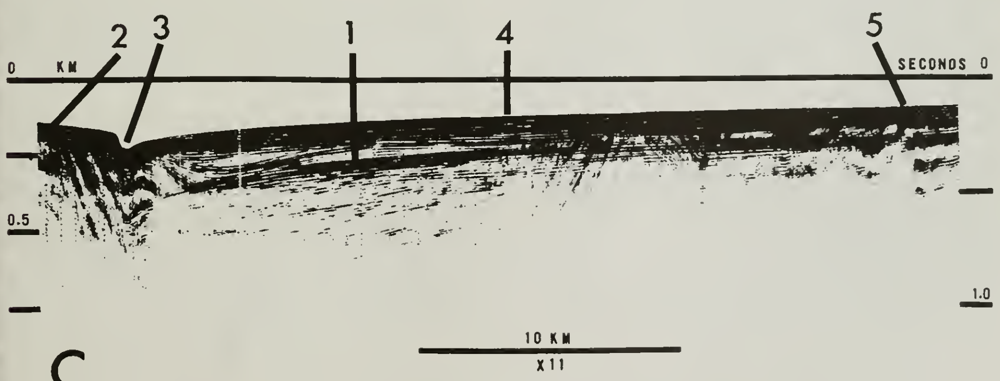

Figure 6. Acoustic reflection profile along line C on figure 1, showing the continental shelf off Bodega Bay. Note the following: (1) multiple of sea floor, (2) Cretaceous quartz diorite of Cordell Bank, (3) Bodega Canyon running along the contact between the quartz diorite and the sedimentary fill, presumed to be Pleistocene and Pliocene, (4) abrupt discontinuity, probably a fault of sedimentary fill against folded sediment section, probably partly Miocene as on Point Reyes, (5) probable fault contact against quartz diorite of Bodega Head.

again rather remarkably devoid of faults except for those due to gravity slides and slumps. The abrupt discontinuities in line C, figure 6, are probably partly due to faulting. Bodega Canyon, which is at point 3, on figure 6, also makes a right-angle bend on the outer shelf, to curve behind the quartz diorite of Cordell Bank shown at point 2. This discontinuity, as well as those at points 4 and 5, appears to be at least partly due to faulting, although they all can be shown to pass out into folds toward the south.

The shelf north of the point of Monterey is thoroughly cut up by faults, which probably tie in with some of the major fault zones mapped on land, for example, the Palo Colorado, Sur Thrust, Tularcitos, Nacimiento, etc. (Jennings and Strand, 1959). The pattern of faulting is much too complex, however, to suggest correlations on the basis of the reconnaissance coverage of this survey.

DISCUSSION AND CONCLUSIONS

This reconnaissance study has been based mainly on continuous acoustic reflection profiles, supplemented by consideration of the bathymetry and a few samples of rock dredged from the sea floor. No samples from drilling beneath the sea floor are available to confirm or deny the interpretations based on the reflection profiles; therefore, the conclusions are rather tenuous. The need for subsurface samples by drilling is obvious, and the possibilities of extrapolation of land geology by combined use of drilling samples and reflection records are tremendous.

Despite these limitations, however, some conclusions on the gross structure and details of the geology are justified:

1. The gross structure underlying the continental shelf and slope is dominated by a ridge of basement rock, which is at least partly Cretaceous granitic rock. This ridge has localized sediment deposition during the Tertiary, forming two thicker accumulations—one underlying the shelf and upper slope and the other under the continental rise at the base of the slope. The latter consists of two main lobes or fans, the Delgado and Monterey Fans, adjacent to the deeper and lower parts of the ridge. This is basically the same as the structure that lies off eastern United States north of Cape Hatteras (Drake and others, 1959), although it is not as well developed.

2. The Tertiary and Quaternary sediments underlying the steeper portions of the slope, generally on the seaward flank of the basement ridge, have locally slumped forming great slide masses as much as a kilometer thick and many kilometers in lateral dimension.

3. The San Andreas fault zone curves eastward from Point Arena to follow the shelf to the vicinity of Shelter Cove. From there it is presumed to continue close to the shoreline, which is therefore a fault line scarp, to Punta Gorda where it runs down Mattole Canyon.

4. Many other faults lie on the shelf with probable connections to faults mapped on land, but in the rocks on the continental slope relatively few faults have been observed.

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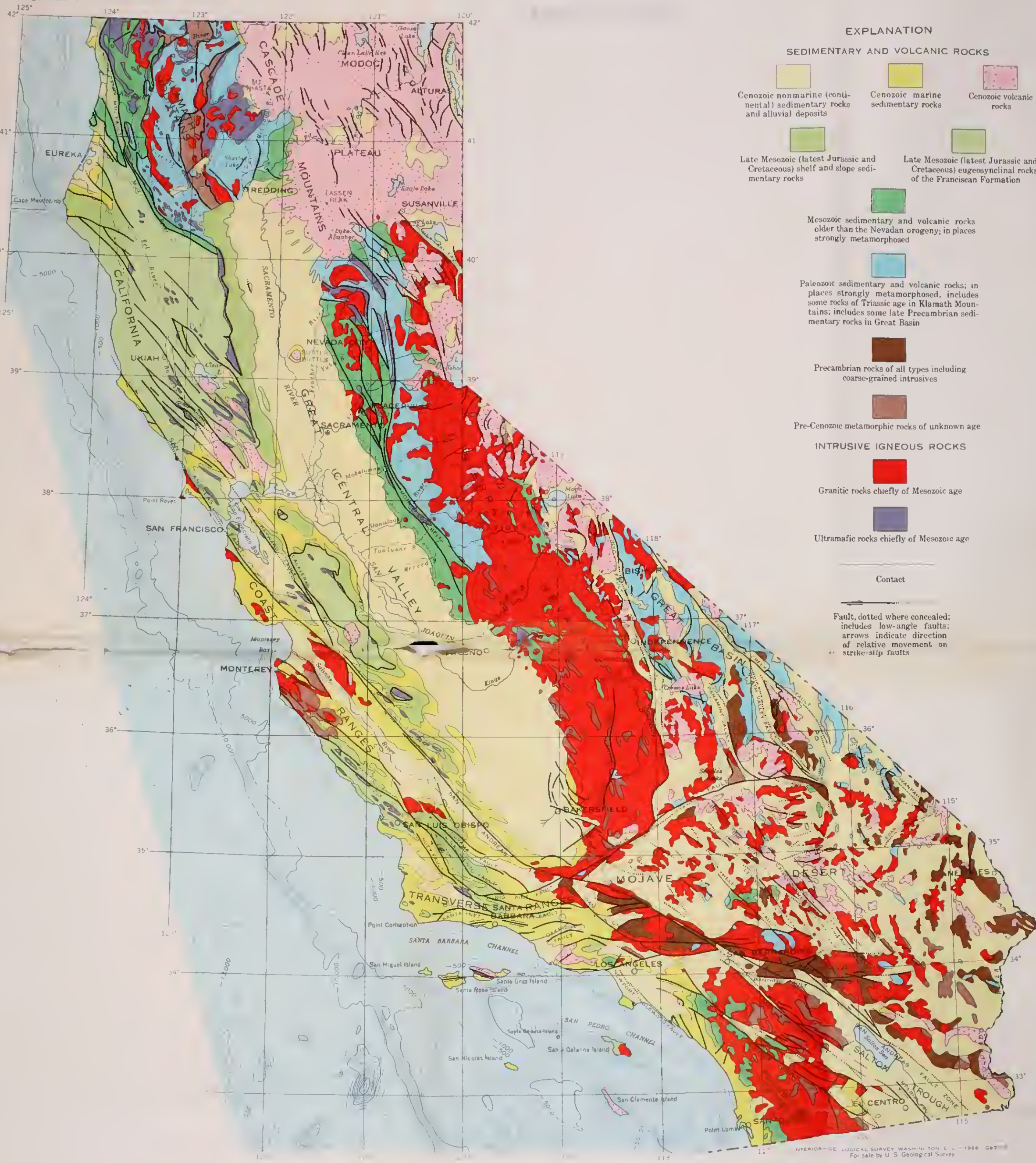
MAP I-512



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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

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