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MAPS AND SEISMIC PROFILES SHOWING GEOLOGIC STRUCTURE OF THE NORTHERN CHANNEL ISLANDS PLATFORM, CALIFORNIA CONTINENTAL BORDERLAND

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INTRODUCTION

During 1973 the U.S. Geological Survey conducted a detailed reflection profiling survey around the northern Channel Islands (Vedder, 1975; Wagner, 1975) with profile spacing of approximately one mile (1.6 km). The reflection profiles obtained during this survey form the main basis for this study, although augmented by additional data from older and more recent surveys (Greene, Silver, and von Huene, 1975; Moore and Beyer, 1975; Moore and McCulloch, 1975; and Wolf, 1975). R. E. von Huene, H. G. Greene, and R. W. Rowland kindly made available unpublished profiles from their cruises on the R/V DAVIS, 1964; R/V POLARIS, 1970; and R/V LEE, 1974 and 1976. The tracklines for these various surveys are shown in figure 1. Micropaleontological age determinations from U.S. Geological Survey seafloor samples (Vedder and others, 1974; Vedder, Arnal, and others, 1976; Vedder, Taylor, and others, 1976), made by R. E. Arnal, David Bukry, and J. A. Barron, form a indispensable aid in interpreting the offshore reflection-stratigraphic sequence used in this paper.

This study was undertaken to help solve some major tectonic problems, such as: (1) the relation of the northwest-trending structures of the Peninsular Ranges province to the east-west structures of the Transverse Ranges province, (2) the offshore continuations of the major faults on the northern Channel Islands and lateral offsets on these faults, and (3) the nature of the western termination of the Transverse Ranges province.

Numerous discussions with J. G. Vedder have been helpful in establishing the offshore stratigraphic sequence and the age of major unconformities, and his help is greatly appreciated. Comments and suggestions by Vedder and R. F. Yerkes, who read a draft of this paper, are gratefully acknowledged. I am particularly indebted to Pamela Utter for her assistance in organizing the illustrations and supervising the drafting.

REGIONAL SETTING

The area mapped (figs. 2, 3, and sheet 1) is part of the California Continental Borderland, defined as the submerged part of the continent (and associated islands) between the coastline to the east and Patton Escarpment to the west and between Point Conception to the north and Isla Cedros to the south at latitude 28°15' N. (Shepard and Emery, 1941; Moore, 1969; Vedder, 1976). For the purpose of this report it is convenient to extend the boundaries of the onshore provinces into the borderland. Thus, the area including the northern Channel Islands and Santa Barbara Basin is considered part of the Transverse Ranges physiographic and structural province (Vedder and others, 1969, p. 1; Jahns, 1973, p. 12), and the area to the south of the islands is considered part of the Peninsular Ranges province (Jahns, 1954, p. 19; Jahns, 1973, p. 15; Yerkes and others, 1965, p. A13). The boundary between the two provinces is placed at the base of the steep south-facing northern slopes of Santa Monica and Santa Cruz Basins, but this natural boundary is broken by the Santa Rosa-Cortes Ridge (fig. 3). For this reason, previous authors (Yerkes and others, 1965, p. A12; Vedder and others, 1969, p. 2) have terminated the boundary at the east flank of the Santa Rosa-Cortes Ridge. In this paper the boundary is arbitrarily continued westward across this ridge to a point near the west end of Santa Barbara Basin (fig. 2).

The main physiographic features of the area (sheet 1) are the Channel Islands platform and Santa Barbara Basin of the Transverse Ranges province and, to the south of the islands, Santa Monica Basin (Junger and Wagner, 1977) and Santa Cruz Basin, separated by the Santa Cruz-Catalina Ridge. The Santa Rosa-Cortes Ridge, which borders the Santa Cruz Basin to the west, has a low west flank and is here not bordered by a typical basin but rather by a gentle westward-tilted plain. West of the map area is the basin of San Miguel Gap, which has been discussed by von Huene (1969).

REFLECTION SEQUENCE AND STRATIGRAPHY

A gross reflection-stratigraphic sequence has been established by correlating unconformities and record character between profiles. Divisions thus identified have been translated into the recognized stratigraphic sequence of the area by correlations of reflection intervals with seafloor samples and by comparison with the geology on adjacent islands. The stratigraphy of the northern Channel Islands is described in two collections of papers (Weaver, 1969d; Howell, 1976). Descriptions and age determination of seafloor samples used in this investigation are given by Vedder and others (1974), Vedder, Arnal, and others (1976), and Vedder, Taylor, and others (1976). Some of the reflection profiles used to establish the reflection sequence are from the saddle between Santa Cruz and San Nicolas Basins (fig. 3), south of the area of detailed mapping.

On the basis of unconformities recognized on the reflection profiles, the stratigraphic sequence has been divided into five major intervals: (1) basement, (2) Upper Cretaceous through lower Miocene, (3) middle Miocene, (4) upper Miocene through lower Pliocene, and (5) upper Pliocene through Holocene. The geology of the Channel Islands and mainland (sheet 1) has been modified from the California State geologic maps

(Jennings, 1959; Jennings and Strand, 1969) to conform with the divisions used offshore.

Basement Reflection

A prominent basal reflection, generally outlining the base of earlier (in terms of reflection time) continuous and coherent reflections is observed in a broad belt from the Arguello Plateau (fig. B, sheet 1) to the west side of the Santa Rosa-Cortes Ridge and along the east flank of Santa Cruz Basin. The term "acoustic basement" that often is applied to this reflection horizon is somewhat of a misnomer, since deeper reflections frequently are observed. This reflection horizon has been tied into an outcrop of blueschist, similar to that of the Catalina Schist, on a low-relief ridge here referred to as the Kelez Ridge (sheet 1), 9 km southwest of Santa Rosa Island (Vedder and others, 1974, p. 6) and shown on profile K-760 (sheet 4). Basement rock, described as saussuritized diabase (Vedder and others, 1974, p. 6), crops out on the north end of San Clemente Ridge (profile K-995, sheet 2).

On Santa Cruz Island the basement complex, consisting of schist intruded by diorite and tonalite, crops out in a long narrow belt south of the Santa Cruz Island fault (Weaver, 1969a; Weaver and Nolf, 1969; Hill, 1976; sheet 1). This schist is in the greenschist facies, in contrast to the blueschist facies of the Catalina Schist, and differs from it in both lithology and metamorphic grade (Hill, 1976, p. 42). The relation between these two metamorphic terranes is unknown.

Catalina Schist has been reported from the Union Oil Co. Gherini well on the northeast end of Santa Cruz Island (McLean, Howell, and Vedder, 1976, p. 303); otherwise no basement rocks have been reported north of the Santa Cruz Island fault, and no basement reflections have been noted north of the islands.

Upper Cretaceous through Lower Miocene Interval

Only fragments of this catch-all interval are observed on the reflection profiles at any one place. The area in the saddle between Santa Cruz and San Nicolas Basins (outside the area of detailed mapping) is considered the type area because profiles here (OC-94, K-995, L-115, sheet 2) show exceptionally well the relations with overlying and underlying formations. The interval pinches out to the east by buttressing against the basement (OC-94) and by truncation by overlying middle Miocene strata (L-115). In this area the upper part of the sequence is Eocene, as established from its correlation to the exposed section of San Nicolas Island and to seafloor samples surrounding the island. In the Santa Cruz Basin, the base of this interval and its eastward pinchout are not seen, but the pinchout must occur somewhere near the center of the basin because the interval underlies middle Miocene strata on the southwest flank, whereas middle Miocene strata lie directly on basement on the northeast flank (sheet 5).

Reflections from Upper Cretaceous strata have not been observed with certainty in this area, although they may form the lower part of the wedge in the saddle between Santa Cruz and San Nicolas Basins. The Upper Cretaceous is assumed to underlie the Santa Rosa-Cortes Ridge, as it is represented by more than 1,925 m of strata on San Miguel Island (Weaver, 1969b, p. 14) and by more than 1,450 m in the test well on Cortes Bank (Paul and others, 1976, p. 27-29, fig. VI-2). It has also been penetrated by two wells on the west end of Santa Cruz Island (Howell and others, 1976, p. 398-399, 402).

The greater part of the observed reflections from this interval are believed to be from Eocene strata, which occur on all three of the large northern Channel Islands and on San Nicolas Island. On San Miguel and Santa Rosa Islands, Paleocene and Eocene strata are approximately 1,500 m thick (Weaver and Doerner, 1969, p. 30), and on San Nicolas Island, Vedder and Norris (1963, p. 15) estimate a minimum of 1,525 m of Eocene strata.

Along the west flank of Santa Cruz Basin and locally along the crest of the Santa Rosa-Cortes Ridge, the top of this interval is shown by an abrupt change from strong middle Miocene reflections to weaker reflections below without a distinct reflection separating the two (L-112 and B-30, sheet 5). The reflections within the two intervals generally are parallel along the flank, although locally slightly discordant (L-101, sheet 5).

The interval crops out at the crest of an anticline on top of the Santa Rosa-Cortes Ridge (K-783, sheet 4), but samples of micaceous claystone obtained here were barren of age-diagnostic fossils.

Along the western edge of the crest of the ridge near the southern limit of the map area, Paleocene and Eocene(?) microfossils are present in samples from an elongate north-northwest-trending outcrop of interbedded sandstone and siltstone uplifted along a fault on its east side. This outcrop continues along the ridge, extending like a peninsula southward on the west side of the main ridge (fig. A, sheet 1).

The Santa Rosa-Cortes Ridge is bounded on the west by a major fault zone, the Ferrelo fault zone (new name). An angular unconformity is shown between reflections from middle Miocene and older strata (profile K-770, sheet 4), immediately east of this fault zone. No Upper Cretaceous to Eocene strata are known to occur to the west (J. G. Vedder, oral commun., 1977), although a thin interval (approximately 200 m) occurs between basement and middle Miocene strata within the fault zone (profiles K-770, K-783, sheet 4).

An area west of San Miguel Island with a hummocky topography and no or only poor reflections has been assigned to the Upper Cretaceous through lower Miocene reflection-stratigraphic interval (sheet 1). Only one pre-Miocene age determination (Eocene) has been made on microfossils from this area, although a number of unfossiliferous samples of Eocene-type sandstone were collected. Richardson and Castle Rocks, which are composed of dacite (Palmer, 1965), project above sea level in this area, indicating that some of the irregular seafloor topography may be outcrops of volcanic rocks. West of this area (profile K-802, sheet 3) well-stratified middle Miocene reflections overlie a zone of weak chaotic reflections and are separated from it by a strong reflection. This deeper zone has been assigned to the Upper Cretaceous through lower Miocene reflection interval on the basis of its relation to the hummocky area to the east, although it cannot be distinguished from the basement of Arguello Plateau, from which it is separated by the Ferrelo fault zone.

Eocene rock has been reported in an elongated area from 2 to 10 km west of Fraser Point on Santa Cruz Island (Vedder and others, 1974, sheet 3; P. J. Fischer, 1977, unpub. data) but cannot be recognized on the seismic profiles.

On the crest of the Santa Rosa-Cortes Ridge approximately 10 km south of the Santa Rosa Island, upper Oligocene and lower Miocene strata (Zemorrian and Saucesian from foraminifers, lower Miocene from nannofossils) crop out in a small area and are overlain by lower and middle Miocene strata (Saucesian and Relizian) (profile L-64, sheet 4). Fragmentary data from the same profile give additional indications of an unconformity between middle Miocene and underlying strata, but only in the outcrop area is there any age determination for the deeper horizons. This is meager evidence for including lower Miocene in this reflection-stratigraphic interval, especially since no such unconformity is reported from the Channel Islands to the north, although there is a sharp break between the Monterey shale and the San Miguel volcanics of Weaver and others (1969) close to the Saucesian-Relization boundary (J. G. Vedder, oral commun., 1977). The evidence is based on the further observation that lower Miocene strata are not known to occur above the unconformity; the bulk of the microfaunal determinations above the unconformity are Relization and Luisian, with occasional ones being Saucesian.

Middle Miocene Interval

On the basis of the stratigraphy of the islands as well as reflection stratigraphy, the middle Miocene sequence can be divided into three parts. On Santa Cruz Island north of the median fault, the section consists of a volcanic sequence (Nolf and Nolf, 1969) overlain by the Monterey Shale (Weaver and Meyer, 1969, p. 97-99; Avila and Weaver, 1969, p. 53-55). Along the mainland coast east of the islands, there is a structurally complex area containing interbedded sandstone and volcanic rocks of the Topanga Group of Yerkes and Campbell (in press). The relation of this group to the middle Miocene sequence on the islands is unknown. South of the fault, the middle Miocene is represented by the volcaniclastic Blanca Formation (Weaver and others, 1969; Fisher and Charlton, 1976; Howell and McLean, 1976, McLean, Crowe, and Howell, 1976; McLean, Howell, and Vedder, 1976). The relation of the Blanca to the formations north of the fault is unknown, but it is probably in part time equivalent of the volcanic sequence, but that sequence appears not to be the source of the volcanic rocks in the Blanca (Fisher and Charlton, 1976, p. 239; Howell and others, 1976, p. 394). The Blanca Formation becomes finer grained westward and on Santa Rosa Island grades into and is interbedded with the Monterey Shale (Howell and McLean, 1976, p. 267). Weaver's and others' (1969, p. 87) Beechers Bay Member of the Monterey on Santa Rosa Island is, according to McLean, Howell, and Vedder (1976, p. 248), the equivalent of the Blanca Formation.

Offshore, the middle Miocene sequence, on the basis of reflection character, can be divided into (1) an interval of strong parallel and coherent reflections correlative with the Monterey shale, (2) an interval of weak coherent to chaotic reflections at least in part correlative with the Blanca Formation, and (3) north of the islands a strong irregular acoustic basement reflection correlative with the top of the volcanic sequence. The Topanga Group on the mainland undoubtedly extends some distance offshore but cannot be recognized on the reflection profiles. An area near shore where the stratigraphy is uncertain has been designated middle Miocene rocks, undivided (sheet 1).

North of Santa Cruz Island the volcanic-Monterey sequence can be seen on several profiles (K-613, K-636, K-638, sheet 3) with internal structures truncated by an overlying unconformity. On profile K-60? (sheet 3) the volcanic rocks appear to be absent, as the base of the Monterey Shale lacks the characteristics of the Monterey-volcanic contact. Farther west evidence for the volcanic sequence disappears and the base of the Monterey cannot be defined. On the south side of the islands, the Monterey is well shown along the flanks of the Santa Cruz Basin (sheet 5), where it is unconformable on basement on the east flank and on Upper Cretaceous through lower Miocene rocks on the west flank. Except for the north flank of Santa Monica Basin, which consists of volcanic rocks, the Monterey can be traced in a broad band along the flanks and west plunge of the Channel Islands Platform around the core of older rocks (sheet 1). Profile K-713 (sheet 3) shows the Monterey on the two flanks of the platform in the area west of San Miguel Island.

At the west end of the Channel Islands platform (profile K-802, sheet 3) and southeast of San Nicolas Island outside the area of detailed mapping (east end profile K-995, sheet 2) there is a distinct unconformity within the middle Miocene shale with faults terminating at the unconformity. This unconformity is not recognized in the area which constitutes the main part of this report.

A belt of chaotic to coherent weak reflections extends from the crest of the Santa Cruz-Catalina Ridge along the upper part of the north flank of Santa Cruz Basin into a broad area on the Santa Rosa-Cortes Ridge. On the Santa Cruz-Catalina Ridge this reflection interval, which here generally shows weak coherent reflections (profiles L-101 and K-403, sheet 5), has, on the basis of sparse seafloor samples, been correlated with the Blanca Formation (Vedder and Howell, 1976, p. 334; Junger and Wagner, 1977, p. 2). On profile K-403 (sheet 5) this reflection interval is overlain conformably by a reflection interval typical of the Monterey, whereas on profile K-345 (sheet 5) it changes laterally into the Monterey sequence. Along the north slope of Santa Cruz Basin this belt, here of chaotic appearance, is adjacent to outcrops of the Blanca on Santa Cruz Island, and samples of the Blanca Formation have been obtained from both walls of Santa Cruz Canyon (Vedder and Howell, 1976, p. 335). It is therefore concluded that the reflections in this belt are correlative with the Blanca Formation. The character changes laterally, downdip toward the basin, into reflections typical of the Monterey. Profile OC-97 (sheet 5) shows a pocket of well-bedded reflections grading laterally into chaotic ones, indicating interbedding of Blanca and Monterey strata.

In a broad area of chaotic middle Miocene reflections on the Santa Rosa-Cortes Ridge (on accompanying maps designated Monterey and Blanca Formations, undivided), an isolated area in the northwest corner yielded samples of Blanca lithology (Vedder and Howell, 1976, p. 335); otherwise the lithology in this area, as shown from seafloor samples is typical of the Monterey Shale (J. G. Vedder, oral commun., 1977). The cause of the chaotic reflections here could partly be tectonic (closely spaced small faults and tight folds), but the local presence of coherent reflections above chaotic ones in a small syncline (profile K-772, sheet 4) suggests that they have stratigraphic and lithologic significance.

The close parallelism of the border of this belt of poor reflections with the present-day structure indicates that the present structure expressed by the Santa Cruz Basin and adjoining ridges was initiated in middle Miocene time. Arnal (1976, p. 72) reached a similar conclusion in his study of paleobathymetry as expressed by foraminiferal assemblages.

North of Santa Rosa Island is a hummocky area showing poor to no reflections in the hummocks and fair reflections from the smooth areas between. Yeats (1970, p. 2149) described samples from one of these hummocks which he assigned to the San Onofre Breccia; however, J. G. Vedder (oral commun., 1977) considers the samples to represent the lower part of the Blanca Formation. The intervening smooth areas are interpreted to be underlain by the Monterey Formation.

On the west end of the island platform there are poor middle Miocene reflections near the center of the platform and good reflections toward its flanks (profile K-713, sheet 3). The high-resolution profile K-709 (sheet 3) shows well-bedded reflections above poorly developed ones in a local syncline. Although the conditions here appear similar to those on the Santa Rosa-Cortes Ridge it should not be assumed that the causes are the same. No attempt has been made to map the distribution of the two types of reflections.

Upper Miocene through Lower Pliocene Interval

No upper Miocene or lower Pliocene strata have been recognized on the northern Channel Islands (Weaver, 1969c, p. 123), nor have any been sampled on the seafloor north of the islands. North of Santa Cruz Island, small pockets between middle Miocene and upper Pliocene or Quaternary strata (profile K-638, sheet 3) are believed to belong to this interval. A U.S. Geological Survey report (1975) refers to this interval as upper Miocene (line 636, plate 3). North of Santa Rosa and San Miguel Islands several wedges of basin sediments progressively buttress against underlying horizons (profiles K-652 and K-700, sheet 3). The deepest of these wedges directly above the middle Miocene strata is here referred to as the upper Miocene through lower Pliocene interval. A U.S. Geological Survey report (1975) considers this wedge of sediments to be lower Pliocene (line 731, plate 3).

Over large areas along the slope south of San Miguel Island and along the crest of the Santa Rosa-Cortes Ridge, the middle Miocene is overlain unconformably by a well-bedded sequence, locally tectonically deformed but distinctly less so than the underlying middle Miocene strata. This interval forms a thin blanket draped over the Santa Rosa-Cortes Ridge (profile L-64, sheet 4; only crestal part shown). Locally it is very thin and can be recognized only on high-resolution profiles. The base forms a sharp unconformity with highly deformed underlying middle Miocene and older strata. In the area to the west, south and west of San Miguel Island, this formation lies chiefly in structural lows on top of the middle Miocene strata, and the unconformity is mostly expressed by buttressing against the flanks (K-760 and K-768, sheet 4; K-713, sheet 3).

Where a distinct unconformity is absent, the internal appearances of the middle Miocene Monterey Shale and upper Miocene through lower Pliocene sequence on the reflection profiles are identical, and correlations are based on the regional settings. Also, the upper Miocene through lower Pliocene interval can be confused with terrace and slope deposits, but such local misidentifications have little effect on the overall structural interpretation.

Paleontologic age determinations for this reflection-stratigraphic interval are sparse, but where available, they invariably are Mohnian, mostly upper Mohnian. Where rocks of Mohnian age have been sampled, they are, with one questionable exception (K-709, sheet 3) associated with relatively undisturbed post-middle Miocene strata. On the high-resolution profile K-709 (sheet 3), well-bedded strata overlie and are in fault contact with chaotic ones of middle Miocene age. Although a Mohnian age is assigned to the samples from the well-bedded strata, these are here assigned to the middle Miocene Monterey Shale on the basis of their folded character.

The relations between middle Miocene and younger strata similar to those on the north end of the Santa Rosa-Cortes Ridge is strikingly shown south of San Nicolas Island (profile K-926, sheet 2). Here the age determinations for the younger strata are consistently Mohnian.

Along the northeast flank of Santa Cruz Basin, folded middle Miocene strata are overlain by relatively undisturbed strata filling structural lows and buttressing against their flanks (profile L-112, sheet 5), similar to the condition along the Santa Rosa-Cortes Ridge and west to the Arguello Plateau. These beds can be traced into the section beneath the center of Santa Cruz Basin, where they appear conformable with middle Miocene strata, and farther west, where they buttress against the middle Miocene rocks of the west flank of the basin (profile L-112, sheet 5).

The Long Beach sheet of the geologic map of California (Jennings, 1962) shows three Pliocene sample localities slightly south of the area described in this report. The samples consist of Holocene sediments containing a reworked Pliocene foraminiferal fauna (Resig, 1958) which presumably was locally derived. Only four species ranging from Repettian to Wheelerian are reported from these samples. Although the weight of the evidence indicates late Pliocene age, "these forams could well be shallow-water equivalent of the Repettian" (R. E. Arnal, written commun., 1977). The early Pliocene age would be in accord with the stratigraphy in Santa Monica Basin (Junger and Wagner, 1977). These beds thus are younger than beds with a similar relation to underlying middle Miocene beds on the Santa Rosa-Cortes Ridge (see fig. 4 for diagram of relation).

Upper Pliocene through Holocene Interval

Except for the Potato Harbor Formation of Weaver and Meyer (1969, p. 99-103) and a recently discovered remnant on Santa Rosa Island (J. G. Vedder, oral commun., 1977), upper Pliocene deposits are absent from the northern Channel Islands; however, Quaternary terrace deposits occur extensively on all of these islands.

In the eastern part of the Santa Barbara Basin, south of the Midchannel fault zone, this sequence lies directly on middle Miocene strata except for local pockets of upper Miocene through lower Pliocene strata (profiles K-636 and K-638, sheet 3).

Along the flank of the island platform north of Santa Cruz and Anacapa Islands is a series of terraces of various ages. Profile K-613 (sheet 3) shows two terraces, but other profiles indicate an intermediate one (the three-second sweep of the deep-penetration profiles gives insufficient details, and the quarter-second high-resolution profiles have insufficient penetration to study these terraces adequately). Fischer (1976, p. 43) mentions four and possibly five terrace deposits that are subdivisions of the upper and younger of the terraces shown here. Basin deposits that buttress into the foreset beds of the deepest terrace are roughly time-equivalent to a horizon under the Oxnard shelf, where horizontal strata of the Santa Barbara Formation change upward to crossbedded strata of the San Pedro Formation; thus the deepest terrace is late Pliocene or early Pleistocene in age (fig. 5).

The transgressions and regressions shown by individual terraces within the upper group (Fischer, 1976, p. 43) appear to represent eustatic changes of sea level during late Pleistocene and Holocene time.

In the western part of the Santa Barbara Basin along the north slope of the Channel Island platform, as well as in Santa Cruz Basin, the upper Pliocene through Holocene strata overlie and buttress against strata of the upper Miocene through lower Pliocene interval and against middle Miocene strata.

Unconformities Reviewed

There is no direct evidence for the unconformity at the base of the Upper Cretaceous section, but regional relations suggest that one is present. In the western Santa Ynez Mountains a questionable unconformity has been inferred at the base of the Upper Cretaceous Jalama Formation of Dibblee (1950, p. 61). In the Los Angeles region there is a pronounced unconformity between basement rocks and overlying Upper Cretaceous strata (Yerkes and others, 1965, p. A16).

The next unconformity upward in the section as interpreted on the seismic profiles is at the base of the middle Miocene strata. Rocks below the unconformity range in age from Paleocene through Eocene and Oligocene(?) to early Miocene as determined from seafloor samples. Undoubtedly there are unconformities in this thick section similar to those at other places in southern California (Dibblee, 1950, p. 25 and 32; Dibblee, 1966, p. 11; Yerkes and others, 1965, p. A24 and A26). However, in the Santa Ynez Mountains south of the Santa Ynez fault there is a continuous section from Upper Cretaceous through upper Miocene (Dibblee, 1966, p. 11). The Upper Cretaceous through Eocene sequence is conformable on San Miguel Island, but a questionable unconformity between Upper Cretaceous and Paleocene strata is indicated in the Richfield Santa Cruz Island #2 well on the Christi anticline, southwest Santa Cruz Island (Doerner, 1969, p. 17; Howell and others, 1976, p. 407). A pronounced angular unconformity occurs on the southwest part of Santa Cruz Island between Eocene and lower Miocene strata (Doerner, 1969, p. 28; Fisher and Charlton, 1976, p. 229; Howell and others, 1976, p. 403; McLean, Howell, and Vedder, 1976, p. 250 and 251). This unconformity is not recognized from the seismic data for the northern Santa Rosa-Cortes Ridge.

The unconformity between lower and middle Miocene strata seems to be well defined on the northern part of the Santa Rosa-Cortes Ridge where upper Oligocene and lower Miocene rocks of Zemorrian and Saucesian age crop out in a small erosional window unconformably below a middle Miocene section containing rocks similar to those in the Blanca Formation (Vedder and Howell, 1976, p. 335) of early and middle Miocene age (L-64, sheet 4). Although this is the only place on the northern part of the ridge where lower Miocene rocks have been sampled, the observation that the oldest rocks above the unconformity consistently are of Saucesian to Relizian age seems to confirm the conclusion that the unconformity occurred during some interval within the Saucessian Stage. This unconformity is not recognized on Santa Cruz Island, but sedimentation there during the Saucesian Stage shows abrupt facies changes and indicates regional tectonic movements (J. G. Vedder, oral commun., 1977). Also the basal part of the Blanca Formation of probable

Saucesian age (Howell and McLean, 1976, p. 267) onlaps basement in south-central Santa Cruz Island (Howell and others, 1976, p. 406). In the western Santa Ynez Mountains the Tranquillon Volcanics of Dibblee (1950), of late Saucesian age (considered to be equivalent to the basal part of the Monterey), is unconformable on Rincon claystone of Zemorrian to Saucesian age (Dibblee, 1950, p. 33-34), which lends support to the age determination for the unconformity on the Santa Rosa-Cortes Ridge.

A regional post-Luisian erosional surface seems evident from a combination of seismic interpretations and seafloor samples. At an isolated location northwest of San Miguel Island, Mohnian samples have been collected from a horizon that from its well-bedded and folded nature is believed to belong below the unconformity (profile K-709, sheet 3). On the Santa Rosa-Cortes Ridge, the post-unconformity strata are Mohnian, and therefore the unconformity is believed to have occurred during the Mohnian Stage. On the west flank of the Santa Cruz-Catalina Ridge, rocks above the unconformity are believed to be Pliocene (Repettian) from meager microfaunal evidence, and their buttress relation to the Santa Rosa-Cortes Ridge confirms that they are younger than the Mohnian strata on this ridge (fig. 5). Still farther east on Point Dume and the Palos Verdes Hills, the upper Miocene is conformable on the middle Miocene (Woodring and others, 1946; Campbell and others, 1970). On the east flank of San Pedro Basin, lower Pliocene strata are unconformable on upper Miocene strata (Junger and Wagner, 1977, p. 3) indicating great variation of timing of tectonic events between middle Miocene and early Pliocene across the borderland.

An unconformity inferred to be between lower and upper Pliocene strata has been observed only in the subsurface, and its time of occurrence can only be postulated from regional geology. No subaerial uplift or erosion were involved; it is a buttress unconformity caused by rapid basin subsidence during a relatively short period of time.

The sequence of reflection-stratigraphic intervals established for the area surrounding the northern Channel Islands corresponds closely to the phases of the geologic evolution of the Los Angeles basin as described by Yerkes and others (1965, p. A16-A18), except for the upper Pleistocene to Holocene phase, which is not represented in the area of this study although it is in the northern Santa Barbara and Ventura basins.

STRUCTURE

The outstanding structural feature of the area is the large, complexly folded and faulted anticlinal uplift of the Channel Islands with the general east-west trend of the Transverse Ranges province. To the north, this uplift is adjoined by the Santa Barbara Basin. To the south it is bounded by the northwest-trending, anticlinally folded Santa Cruz-Catalina and Santa Rosa-Cortes Ridges and the associated Santa Monica and Santa Cruz Basins.

The northern Channel Islands anticline extends from the mainland coast at Laguna Point, along the buried Anacapa Ridge to Anacapa Island and thence westward for 135 km, until it terminates by a northwest plunge into the southwestern part of Santa Barbara Basin (fig. B, sheet 1). The general anticlinal nature of the platform is well demonstrated by profile K-713 (sheet 3), which shows a central core of older rocks flanked by middle Miocene strata.

The overall structural and physiographic trend is slightly north of west, but it shows a distinct curvature concave to the north such that the west end of the platform has a trend between those of the Transverse and Peninsular Ranges.

Northern Channel Islands Faults

Pronounced east-west-trending medial faults occur on both Santa Cruz and Santa Rosa Islands. The Santa Cruz Island fault has nearly a straight west-northwest trend, whereas the Santa Rosa Island fault is curved concave to the north, similar to the curvature of the north slope of the island platform.

The offshore Santa Cruz Island fault (profile OC-97, sheet 5) has been traced into the Santa Monica Basin, where it is believed to connect with the Dume fault along the north flank of the basin, which in turn connects with the onshore Santa Monica fault (Junger and Wagner, 1977). Immediately east of Santa Cruz Island it separates the Monterey Shale to the north from the Blanca Formation to the south and dips 55-65° southward. The age relation between the Blanca and the Monterey is not exactly known. They are in part contemporaneous and in part the Blanca Formation is the older, suggesting reverse faulting.

The westward offshore continuation of the Santa Cruz Island fault cuts Quaternary deposits with a 15-m vertical separation on top of Miocene volcanic rocks (Junger, 1976b, p. 419 and 423). It can be traced westward for only 5 km; beyond this point the profiles have a nonbedded character (volcanic and Eocene rocks) along its inferred projection (sheet 1), which probably explains why it is not evident on the profiles. There are several faults farther west on its general trend, but they appear discontinuous and cannot be correlated with a through-going fault. If the fault did continue with a large post-middle Miocene lateral displacement, then the platform slope should be offset where it is cut by the fault. But such an offset is not apparent, and it is therefore concluded that the Santa Cruz Island fault does not continue as a major post-middle Miocene fault along the island platform north of Santa Rosa Island.

On Santa Cruz Island streams have been deflected as much as 300 m in a left-lateral sense (Roy Patterson, oral commun., 1977); these deflections suggest lateral displacement of this magnitude in late Quaternary time. Juxtaposition of the Blanca Formation against volcanic rocks across the Santa Cruz Island fault is best explained by a late middle Miocene lateral offset on this fault, as the volcanic rocks north of the fault appear not to be the source of the volcaniclastic Blanca

Formation to the south (Howell and others, 1976, p. 394; McLean and others, 1976, p. 300), but as the source of the Blanca Formation is unknown (McLean and others, 1976, p. 303) no estimates can be made of the magnitude of such and offset.

The eastward offshore continuation of the Santa Rosa Island fault joins the Santa Cruz Island fault approximately where the latter cuts the coastline. In the area between the faults is the small Carrington pull-apart basin (Junger, 1976b). The fault's westward offshore continuation has been traced with a trend slightly north of west for a distance of 20 km to a point south of the west end of San Miguel Island where it turns sharply to the northwest for another 20 km from where continuity is lost. As with the Santa Cruz Island fault, there is no appreciable displacement of the bathymetry or structure contours along the northwest plunge of the platform to indicate post-Miocene lateral displacement of more than a few kilometers. If the fault splays northwestward, the displacement could be distributed on several branches such that an offset in the structural contours would not be evident, but as a whole the evidence is against such an explanation.

Area North of Channel Islands

In the area north of Santa Cruz Island, an erosional surface on middle Miocene rocks dips gently northwest to a point approximately in mid-channel where it terminates against the Midchannel fault zone (fig. B, sheet 1; profiles K-636 and K-638, sheet 3) immediately south of the Twelvemile anticline. Early Pliocene strata crop out on the crest of the anticline (Fischer, 1976, p. 38), indicating a Pliocene uplift north of the fault, but Miocene strata are down-dropped north of the fault (Curran and others, 1971; Weaver, 1969d, structure cross sections).

Two profiles (K-636 and K-638, sheet 3) 1-1/2 km apart show abrupt changes along regional strike. On K-638, the western line, gently dipping Miocene beds south of the fault extend to the fault, whereas on K-636 the dip of the Miocene steepens into the fault. On K-636, the post-middle Miocene unconformity is on top of volcanic rocks, and the unconformity is folded into an anticline not expressed in the overlying horizons, whereas on K-638, Monterey strata intervene showing several internal folds but none on the unconformity. The distribution of volcanic rocks below the unconformity shown on the structure map (fig. B, sheet 1) indicates a structural high in late middle Miocene time with a west-northwest trend parallel to the Santa Cruz Island fault. Other east-west folds and faults within the middle Miocene strata generally terminate at the unconformity, indicating late middle Miocene deformation with a Transverse Ranges trend, although on profile K-638 (sheet 3) a fault cuts the upper Miocene-lower Pliocene sequence.

North of the west end of Santa Cruz Island (fig. B, sheet 1; long. 119°50' W.) the post-middle Miocene surface is folded into a broad north-trending arch (because of the distribution of seismic lines the exact trend is in doubt), here referred to as the Diablo arch, which also is expressed by gravity data (U.S. Geol. Survey, 1975, plate 6) although with a slightly different trend.

The Midchannel fault zone represents the south boundary of thick upper Miocene and lower Pliocene deposits of the western Ventura and eastern Santa Barbara Basins, which have been intensely deformed in late Pleistocene time (McCulloh, 1969, p. 32; Vedder and others, 1969, p. 11; Nagle and Parker, 1971, p. 280). The Twelvemile anticline is the southernmost structure showing deformation of Quaternary deposits (profiles K-636 and K-638, sheet 3).

The upper surface of the deeper of the two terraces north of Santa Cruz Island dips 2° N., in contrast to the surface of the upper terrace, which is horizontal (profiles K-606 and K-613, sheet 3). The age of the deeper terrace is believed to be very early Pleistocene (see description of terraces, p. 5), and the gentle dip on top of this terrace is thus a measure of the deformation, or rather lack of it, in Quaternary time.

The trend of the Twelvemile anticline and of the Midchannel fault system is N. 70° W.; it converges eastward with the east-west trend of the Channel Islands platform, and the dip of the post-middle Miocene erosional surface steepens correspondingly (structure map, fig. B, sheet 1). The south flank of the Twelvemile anticline forms the western half of the north flank of the long bathymetric depression in the southeast part of the Santa Barbara Basin (the apparent steepness of the flanks of this depression is deceptive on the bathymetric map, sheet 1, because of the change from 50-m to 10-m contour intervals along the 200-m contour), but the eastern part of the flank is depositional, being formed by a progradational delta front offshore from the Oxnard Plain, as is the south flank, which is formed by the foreset beds of the terrace north of the islands. The Midchannel fault system is generally near the middle of this depression rather than at the base of its north slope (see fig. A, sheet 1).

North of the westernmost part of Santa Cruz Island (sheet 1, long. 119° 50' W.), several changes take place. There is a distinct change in the trend of the bathymetric slope north of the islands, and the deep terrace deposits north of Santa Cruz and Anacapa Islands terminate here, and consequently the depositional slope north of Santa Cruz Island changes to a structural dip slope north of Santa Rosa Island (compare profile K-700 with profiles K-606, K-636, and K-638, sheet 3). The bathymetric expression of the Twelvemile anticline terminates slightly east of this line, and the bathymetric basin broadens. The post-Miocene structural platform north of Santa Cruz Island plunges abruptly westward north of an east-west fault (profile K-652, sheet 3). This westward dip constitutes the west flank of the Diablo arch. Although no deep information for the west-central part of the basin is available, indications are that the tectonic basin broadens to the west as does the bathymetric basin. This conclusion is based on the observation that late Miocene and early Pliocene strata pinch out southward and buttress against middle Miocene strata, in contrast to the area to the east, where only minor pockets of these strata occur north of the Midchannel fault. The regional contouring of the south flank of the basin also supports this interpretation (fig. B, sheet 1).

Santa Rosa-Cortes Ridge

The stratigraphy of the northern part of the Santa Rosa-Cortes Ridge appears to be a southward continuation of that of Santa Rosa Island, and no structural break is evident between the two areas in spite of the fact that on a regional scale they may be considered to belong to two different physiographic and structural provinces. The northern part of the Santa Rosa-Cortes Ridge is an asymmetrical anticline with a structural relief of approximately 2,500 m (after restoring sediments removed by Quaternary erosion on the crest) on the structurally undisturbed east flank into Santa Cruz Basin (profiles L-112 and B-30, sheet 5; K-783 and K-787, sheet 4; and structure contour map, fig. B, sheet 1), and approximately 1,000 m on the structurally complex west flank, which is bounded by the Ferrelo fault zone (profiles K-770 and K-783, sheet 4; and tectonic map, fig. B, sheet 1).

The crest of the ridge shows numerous small faults within the middle Miocene section (Greene, Clarke, and others, 1975, p. 41) that cannot be traced from profile to profile and are not shown on the accompanying maps. A few prominent faults on the crest and near the top of the east flank have north-northeast trends with the west sides down, resulting in a local thickening of the Miocene section along the east side of the crest (profiles K-783 and K-787, sheet 4).

Ferrelo Fault Zone

On the west side of Santa Rosa-Cortes Ridge, the Ferrelo fault can be followed with a northwest trend for approximately 50 km from the southern limit of the area mapped to a point south of the east end of San Miguel Island, where it turns sharply to an east-west trend for 20 km to a point south of the west end of this island where it again turns to a northwest trend for 30 km to the limit of the mapped area (fig. A, sheet 1). It can, furthermore, be traced south of the area mapped as a pronounced lineament (Junger, 1976a) for a distance of 150 km or more to the area west of Cortes Bank.

Moore (1969, p. 40) places the boundary between his outer belt of faulting and central zone of broad folds along this lineament, and Yeates (1976, p. 460) similarly makes it a tectonic boundary between his "Island Block" and "Outer Borderland". Taylor (1976, p. 18) shows the western limit of Paleogene sediments here as questionably fault controlled. This zone has thus for some time been considered an important boundary between areas of different tectonic styles and stratigraphic sequences.

The southernmost 25-km segment of the fault within the area mapped appears as a zone of several distinct faults cutting the top of the basement, pre-middle Miocene, and middle Miocene strata (profiles K-770 and K-783, sheet 4), though at no place are pre-middle Miocene strata and basement rocks seen in fault contact on the reflection profiles.

Profiles K-770 and K-783 (sheet 4) both show a 200-m to 300-m interval of pre-middle Miocene strata between the basement and middle Miocene section in the fault zone, whereas a short distance to the east there may be as much as 3,300 m of pre-middle Miocene strata above the basement (Taylor, 1976, p. 17). These rocks, in the fault zone, are believed to be of Paleocene age by correlation with Paleocene outcrops in the fault zone 7 to 9 km to the south. To the west, middle Miocene strata rest directly on the basement.

The west slope of Santa Rosa-Cortes Ridge jogs westward 15 km south of South Point (Santa Rosa Island) with a corresponding echelon offset of the fault, resulting in its appearing twice on profile K-770 (sheet 4).

The Ferrelo fault zone appears on several lines near the west end of the island platform (profiles K-728, sheet 4; K-697, K-713, and D-22, sheet 3), but in the long intervening area south of San Miguel and Santa Rosa Islands, there is little direct evidence of faults (profiles K-740, K-760, K-768, sheet 4). Profile K-740 shows that the upper part of the middle Miocene sequence is not faulted, but in the lower part, faults are indeterminate because of complications in the reflection profile where there is an abrupt change in dip. On profile K-802 (sheet 3) a fault is inferred to terminate at an unconformity within the Miocene. A similar unconformity is observed south of the area mapped (east end, profile K-995, sheet 2) and in the intervening area is vaguely suggested by questionable faults in the lower part of the Miocene section.

Where the fault cannot be identified on profiles, it can be located fairly accurately from auxiliary data, consisting of a fairly consistent lateral sequence of structures from west to east, or south to north, depending on location. These are (1) a large anticline (the Kelez anticline) with a basement core and middle Miocene strata generally buttressing against the flank (profiles K-740 and K-760, sheet 4), (2) a syncline with middle Miocene strata resting directly on basement and overlain by upper Miocene and lower Pliocene strata, and (3) disappearance of the basement reflection and concomitant change in style of folding of middle Miocene strata from open folds to the west (or south) to tighter folds to the east (or north). Toward the northern part of the area, between profiles K-740 and K-728 (sheet 4), the anticline and adjoining syncline disappear, but the change in style of folding concomitant with disappearance of the basement reflection persists. The fault, where evident, occurs where this change in folding takes place (profiles K-713, sheet 3; K-728, sheet 4). On the surface geologic-tectonic map (sheet 1), this boundary is marked by a dash-dot line.

At the west end of the area, profile D-22 (sheet 3) shows the Ferrelo fault separating the strongly folded middle Miocene strata of the northwest plunge of the island platform from the basement rocks of the Arguello Plateau. Evidence for the fault itself is obscured by overlapping reflections from opposite sides, and it is indeterminate whether it actually cuts the upper part of the middle Miocene sequence, but the change in reflection character between the two areas is conspicuous.

Other faults and folds in the area of the west flank of the Santa Rosa-Cortes Ridge and the flank of the island platform south and west of San Miguel Island are parallel to the Ferrelo fault. The Kelez anticline, with a basement core, which crops out along the Kelez ridge, is the most prominent fold of the area. It changes from a northwest to an east-west trend, similar to the change in trend of the Ferrelo fault zone. The continuity of the crest is broken where the change in trend takes place. The anticline here is replaced with a structural terrace. It dies out where the Ferrelo fault changes from an east-west to northwest trend at the west end of San Miguel Island.

Eocene samples have been obtained from Nidever Bank 25 km west of San Nicolas Island (south of the area mapped). This bank appears to be west of the lineament defining the Ferrelo fault to the south, but otherwise, no Upper Cretaceous, Paleocene, or Eocene samples have been obtained west of this fault (J. G. Vedder, oral commun., 1977). On the basis of bathymetry, a branch of the Ferrelo fault could extend along the west flank of this bank, placing these samples in the fault zone.

The presence of Paleocene strata directly on basement in the fault zone indicates that the fault represents the western limit of Upper Cretaceous deposition, and it is reasonable to assume that the western limit of Paleocene and Eocene deposits was similarly fault controlled. The alternatives are that these deposits originally extended farther west and were subsequently removed either by erosion before Oligocene time, since rocks of this age rest directly on the basement to the west (J. G. Vedder, oral commun., 1977; Crouch, unpub. data), or that large lateral fault displacement has shifted such deposits out of the area. Neither of these alternatives appears tenable. No such unconformity has been observed in the surrounding region; and the lateral offset on the fault would have to exceed 250 km since the same stratigraphic relations across the fault exist for this distance. At present there is no evidence for such a large displacement.

In summary, the Ferrelo fault constitutes the boundary between areas with different tectonic styles and stratigraphic sequences, indicating a major fault. It is believed to have been active from Upper Cretaceous through Eocene time, and during this time interval, to have controlled the western limit of deposition in a sedimentary basin to the east. The fault disrupts the upper part of the middle Miocene section for only part of its assumed length, and only rarely does it cut upper Miocene strata. After cessation of faulting, the deep-seated Ferrelo fault continued to control the location of major folds such as the west flank of the Santa Rosa-Cortes Ridge and south flank of the Channel Islands platform south of San Miguel Island, and influenced the style of minor folds on opposite sides of the fault.

Santa Cruz Basin and Santa Cruz-Catalina Ridge

The rocks beneath the central trough and west flank of the Santa Cruz basin are weakly deformed (profiles B-30, L-101, and L-112, sheet 5). The thickness of the middle Miocene strata is nearly uniform along the west flank, but the section thickens abruptly near the base of the slope and in the central trough, though the actual thickness in the basin is indeterminate because the base of the middle Miocene is not observed here. The thickening indicates a narrow depositional trough in the early middle Miocene (profiles L-112, B-30, sheet 5) which filled during this time, after which deposition continued over an extensive flat seafloor. In contrast to the west flank, the east flank of the basin is tectonically strongly deformed. Profile B-30 (sheet 5), the least disturbed of the profiles shown here, indicates depositional thickening of middle Miocene strata from the flank into the basin similar to the condition on the west flank, but there also appears to be pronounced local variation, in part due to middle Miocene deposition over an irregular basement surface and in part due to local structural growth during middle Miocene time (profile L-112, sheet 5).

On most of the profiles the basement reflection terminates near the crest of the Santa Cruz-Catalina Ridge. In contrast, profile K-345 (sheet 5) shows an eastward dip on the basement surface under the crest, indicating a thick section of the Blanca Formation under the structurally complex northwest corner of Santa Monica Basin, whereas middle Miocene strata are believed to be absent under the southern part of the basin (Junger and Wagner, 1977, p. 2-3).

The north end of the San Clemente Ridge, culminating in Santa Barbara Island and Osborn Bank and welded to the Santa Cruz-Catalina Ridge (fig. 3), plunges beneath the southeast corner of Santa Cruz Basin where the basin is strongly deformed by folding and thrust faulting (profile L-114, sheet 2). The thrust faults appear to die out into flexures toward the top of the middle Miocene section. These structures continue to the north where they occur along the structural base of the east flank of the basin (buried by later sediments). Structural conditions vary considerable from profile to profile. Thus, on profile B-30 (sheet 5) a single flexure occurs at the base of the slope with relatively minor folds higher on the slope. On profile L-101 (sheet 5), two flexures are seen at the base of the slope going into reversed faults at depth, followed upslope by a large anticline. On profile L-112 (sheet 5) thrust faults cut the top of the middle Miocene section. Upslope from them are two other faults forming a horst and graben structure, and farther upslope is a large anticline with a core of basement rocks. The dips of the thrust faults vary from 25° on L-114 (sheet 2) in the southern part of the basin to 55-60° on L-112 (sheet 5) in the northern part. The upper part of the slope locally shows numerous faults that cut the basement surface (profile K-403, sheet 5) and are not continuous from profile to profile.

Toward the north end of the basin where it joins the east-west slope south of Santa Cruz Island, the northwest fault trend terminates and is followed for a short distance to the west by a fault with a more westerly trend (sheet 1). This fault gradually curves into a slightly more northerly trend and cuts into the east-west slope where it either dies out or the evidence for its presence is lost. Farther west, another northwest-trending fault follows the lower reaches of Santa Cruz Canyon (southwest end of profile OC-97, sheet 5). How far it continues up the canyon is unknown, but it cannot cross the area between Santa Cruz and Santa Rosa Islands because the Santa Rosa Island fault and Carrington basin extend east-west across this area. Between these last two northwest-trending faults the north slope continues into the basin unbroken by faults (fig. B, sheet 1).

The relation between faults of a northwest and a more westerly trend is obscure, and several interpretations are possible: (1) The west-trending fault may be a continuation of the westernmost of the faults shown on profile L-112, or (2) a continuation of the easternmost of these faults, or (3) it may truncate the sequence of faults forming the horst and graben structure. The last interpretation is indicated on the maps (sheet 1), but if it is correct the faults must terminate a short distance to the east.

There is no apparent discontinuity indicating the presence of faults between the northwest-trending structures on the east slope and east-west structures on the north slope, but structures which appear continuous on the map generally change character at the break, such as from a broad high-amplitude anticline on the east slope to a narrow, low-amplitude one on the north slope; the actual complex conditions are by necessity oversimplified on the small scale of the structure map (fig. B, sheet 1).

From the fact that Pliocene strata, only slightly deformed, fill synclinal depressions on the erosional surface of the middle Miocene, it can be concluded that the depressions were formed before the tilting of the slopes into their present position. Thus, the local structures are of pre-Pliocene age, and the slopes of Pliocene age.

The Blanca Formation in a belt along the Santa Cruz-Catalina Ridge appears to change facies into Monterey-type rock basinward, though at places, the Monterey appears to overlie the Blanca Formation. Thus, the lateral contact between the two formations appears to change from a northwest to an east-west trend where the two slopes now meet, indicating that these trends existed in middle Miocene time as depositional features.

RECAPITULATION

In the western part of the northern Channel Islands platform, the Santa Rosa-Cortes Ridge, and the Santa Cruz and San Nicolas Basins, a sequence of sediments ranging in age from Late Cretaceous to early Miocene as much as 3,300 m thick was laid down in a long trough bounded on the west by the Ferrelo fault zone and on the east buttressing against a gently west-dipping slope along the present Santa Cruz-San Clemente ridge system. The former extent eastward of these deposits is unknown as the present eastern limit is erosional. The extent of this basin north of the northern Channel Islands also is unknown. After deformation, uplift and erosion of these deposits near the end of early Miocene time, the area subsided regionally and a sequence of fine-grained sediments and volcaniclastic and volcanic rocks was laid down over a broad area in middle Miocene time. A proto-Santa Cruz Basin and Santa Rosa-Cortes Ridge appear to have formed at this time, as did initial east-west structural and depositional trends. After deposition of middle Miocene strata, the area was deformed, uplifted, and regionally eroded. In late Miocene time, the area west of the present crest of the Santa Rosa-Cortes Ridge subsided, and relatively thin late Miocene deposits formed in local depressions. There is no indication of upper Miocene strata on the east flank of Santa Cruz Basin. In late Miocene or early Pliocene time, the present Santa Rosa-Cortes Ridge was formed, while the area to the east was still submerged. Early Pliocene sediments were deposited in this eastern area and buttressed against the newly formed east flank of the Santa Rosa-Cortes Ridge. Later in Pliocene time, the present Santa Cruz-Catalina Ridge was formed. The south flank of the Channel Islands platform west of Santa Rosa-Cortes Ridge appears to have been formed at the same time as this ridge, whereas the flank into Santa Cruz Basin appears to have been formed at the time of the Santa Cruz-Catalina Ridge. The north slope of the platform probably was formed in the late Miocene to early Pliocene, though here evidence is lacking for exact timing. Except for a slight tilting of an early Quaternary terrace in Santa Barbara Basin and minor faults cutting Quaternary deposits, there appears to have been little Pliocene or Quaternary tectonic activity.

The general distinction between the Peninsular Ranges and Transverse Ranges provinces is obvious from physiographic and structural maps of southern California. On land the boundary between the provinces follows the Raymond Hills-Santa Monica fault and forms an abrupt topographic break. This boundary can be followed along the offshore Dume fault on the north side of Santa Monica Basin (Junger and Wagner, 1977), but farther west this fault is believed to continue into the Santa Cruz Island fault, which is north of obvious east-west physiographic and structural trends such as the slope south of Santa Cruz Island and the west-trending slope west of Santa Rosa-Cortes Ridge. The Santa Cruz-Catalina Ridge appears to butt into the east-west physiographic trend south of Santa Cruz Island, but minor structures and a contact between Miocene sedimentary facies are not broken here; they appear merely to change trend. The main obstacle to drawing a sharp boundary is the absence of east-west physiographic and structural features across the north end of the Santa Rosa-Cortes Ridge and the apparent continuity of the geology from Santa Rosa Island to this ridge. West of the Santa Rosa-Cortes Ridge and south of San Miguel Island, the Ferrelo fault and the Kelez anticline appear continuous from the north-northwest Peninsular Ranges trend to the east-west Transverse Ranges trend; there is no tectonic break between the two trends. It thus appears impossible to draw a fully logical boundary.

REFERENCES

Arnal, R. E., 1976, Miocene paleobathymetric changes of the Santa Rosa-Cortes Ridge area, California Continental Borderland, in Howell, D. G., ed., Aspects of the geologic history of the California Continental Borderland: American Association of Petroleum Geologists, Pacific Section, Miscellaneous Publication 24, p. 60-79.

Avila, F. A., and Weaver, D. W., 1969, Mid-Tertiary stratigraphy, Santa Rosa Island, in Weaver, D. W., ed., Geology of the northern Channel Islands: American Association of Petroleum Geologists and Society of Economic Paleontologists and Mineralogists, Pacific Sections, Special Publication, p. 48-67.

Campbell, R. H., Blackerby, B. A., Yerkes, R. F., Schoellhamer, J. E., Birkeland, P. W., and Wentworth, C. M., 1970, Preliminary geologic map of the Point Dume quadrangle, Los Angeles County, California: U.S. Geological Survey Open-file Report.

Curran, J. F., Hall, B. K., and Herron, R. F., 1971, Geology, oil fields and future petroleum potential of the Santa Barbara Channel area, California, in Cram, I. H., ed., Future petroleum provinces of the United States--Their geology and potential: American Association of Petroleum Geologists Memoir 15, v. 1, p. 192-221.

Dibblee, T. W., Jr., 1950, Geology of southwestern Santa Barbara County, California--Point Arguello, Lompoc, Point Conception, Los Olivos, and Gaviota quadrangles: California Division of Mines and Geology Bulletin 150, 95 p.

______ 1966, Geology of the central Santa Ynez Mountains, Santa Barbara County, California: California Division of Mines and Geology Bulletin 186, 99 p.

Doerner, D. P., 1969, Lower Tertiary biostratigraphy of southwestern Santa Cruz Island, California, in Weaver, D. W., ed., Geology of the northern Channel Islands: American Association of Petroleum Geologists and Society of Economic Paleontologists and Mineralogists, Pacific Sections, Special Publication, p. 17-29.

Fischer, P. J., 1976, Late Neogene-Quaternary tectonics and depositional environments of the Santa Barbara Basin, California, in Fritsche, A. E., ed., Papers from the Neogene Symposium: American Association of Petroleum Geologists and Society of Economic Paleontologists and Mineralogists, Pacific Sections Annual Meeting, San Francisco, April 1976, Proceedings, p. 33-52.

Fisher, R. V., and Charlton, D. W., 1976, Mid-Miocene Blanca Formation, Santa Cruz Island, California, in Howell, D. G., ed., Aspects of the geologic history of the California Continental Borderland: American Association of Petroleum Geologists, Pacific Section, Miscellaneous Publication 24, p. 228-240.

Greene, H. G., Clarke, S. H., Jr., Field, M. E., Linker, F. I., and Wagner, H. C., 1975, Preliminary report on the environmental geology of selected areas of the southern California Continental Borderland: U.S. Geological Survey Open-file Report 75-596, 69 p.

Greene, H. G., Silver, E. A., and von Huene, Roland, 1975, Seismic reflection profiles USNS BARTLETT, Nov. 1972 cruise, offshore central and southern California: U.S. Geological Survey Open-file Report 75-121, 75 p.

Hill, D. J., 1976, Geology of the Jurassic basement rocks, Santa Cruz Island, California, in Howell, D. G., ed., Aspects of the geologic history of the California Continental Borderland: American Association of Petroleum Geologists, Pacific Section, Miscellaneous Publication 24, p. 16-46.

Howell, D. G., 1976, Aspects of the geologic history of the California Continental Borderland: American Association of Petroleum Geologists, Pacific Section, Miscellaneous Publication 24, 561 p.

Howell, D. G., and McLean, Hugh, 1976, Middle Miocene paleogeography, Santa Cruz and Santa Rosa Islands, in Howell, D. G., ed., Aspects of the geologic history of California Continental Borderland: American Association of Petroleum Geologists, Pacific Section, Miscellaneous Publication 24, p. 266-293.

Howell, D. G., and McLean, Hugh, and Vedder, J. G., 1976, Cenozoic tectonism on Santa Cruz Island, in Howell, D. G., ed., Aspects of the geologic history of the California Continental Borderland: American Association of Petroleum Geologists, Pacific Section, Miscellaneous Publication 24, p. 392-417.

Jahns, R. H., 1954, Investigations and problems of southern California geology, in Jahns, R. H., ed., Geology of southern California: California Division of Mines Bulletin 170 (part 1), chapter 1, p. 5-29.

______ 1973, A profile of southern California geology: American Association of Petroleum Geologists, Society of Economic Paleontologists and Mineralogists, and Society of Exploration Geophysicists, Pacific Sections, Guidebook, p. 1-22.

Jennings, C. W., 1959, Geologic map of California, Olaf Jenkins edition, Santa Maria sheet: California Division of Mines and Geology, scale 1:250,000.

______ 1962, Long Beach Sheet, geological map of California: California Division of Mines and Geology, scale 1:250,000.

Jennings, C. W., and Strand, R. G., 1969, Geologic map of California, Olaf Jenkins edition, Los Angeles sheet: California Division of Mines and Geology, scale 1:250,000.

Junger, Arne, 1976a, Tectonics of the southern California borderland, in Howell, D. G., ed., Aspects of the geologic history of the California Continental Borderland: American Association of Petroleum Geologists, Pacific Section, Miscellaneous Publication 24, p. 486-498.

______ 1976b, Offshore structure between Santa Cruz and Santa Rosa Islands, in Howell, D. G., ed., Aspects of the geologic history of the California Continental Borderland: American Association of Petroleum Geologists, Pacific Section. Miscellaneous Publication 24, p. 418-426.

Junger, Arne, and Wagner, H. C., 1977, Geology of the Santa Monica and San Pedro Basins, California Continental Borderland: U.S. Geological Survey Miscellaneous Field Studies Map MF-820, scale 1:250,000.

McCulloh, T. H., 1969, Geologic characteristics of the Dos Cuadras offshore oil field, in Geology, Petroleum development and seismicity of the Santa Barbara Channel region, California: U.S. Geological Survey Professional Paper 679-C, p. 29-46.

McLean, Hugh, Crowe, B. M., and Howell, D. G., 1976, Source of Blanca Formation volcaniclastic rocks and strike-slip faulting on Santa Cruz Island, in Howell, D. G., ed., Aspects of the geologic history of the California Continental Borderland: American Association of Petroleum Geologists, Pacific Section, Miscellaneous Publication 24, p. 294-308.

McLean, Hugh, Howell, D. G., and Vedder, J. G., 1976, Miocene strata on Santa Cruz and Santa Rosa Islands--A reflection of tectonic events in the southern California borderland, in Howell, D. G., ed., Aspects of the geologic history of the California Continental Borderland: American Association of Petroleum Geologists, Pacific Section, Miscellaneous Publication 24, p. 241-253.

Moore, D. G., 1969, Reflection profiling studies of the California Continental Borderland--Structure and Quaternary turbidite basins: Geological Society of America Special Paper 107, 142 p.

Moore, G. W., and Beyer, L. A., Seismic reflection profiles, R/V KELEZ, Nov.-Dec. 1973, continental borderland of southern California: U.S. Geological Survey Open-file Report 75-330, 43 p.

Moore, G. W., and McCulloch, D. S., 1975, Acoustic reflection profiles, M/V OIL CITY, June 1969, offshore southern California: U.S. Geological Survey Open-file Report 75-347.

Nagle, H. E., and Parker, E. S., 1971, Future oil and gas potential of onshore Ventura Basin, California, in Cram, I. H., ed., Future petroleum provinces of the United States--Their geology and potential: American Association of Petroleum Geologists Memoir 15, v. 1, p. 254-297.

Nolf, B., and Nolf, P., 1969, Santa Cruz Island volcanics, in Weaver, D. W., ed., Geology of the northern Channel Islands: American Association of Petroleum Geologists and Society of Economic Paleontologists and Mineralogists, Pacific Sections, Special Publication, p. 91-94.

Palmer, H. D., 1965, Geology of Richardson Rock, northern Channel Islands, Santa Barbara County, California: Geological Society of America Bulletin, v. 76, no. 10, p. 1197-1202.

Paul, R. C., Arnal, R. E., Baysinger, J. P., Claypool, G. E., Holte, J. L., Lubeck, C. M., Patterson, J. M., Moore, R. Z., Sletene, R. L., Sliter, W. V., Taylor, J. C., Tudor, R. B., and Webster, F. L., 1976, Geological and operational summary, southern California deep stratigraphic test OCS-CAL 75-70 no. 1, Cortes Bank area offshore California: U.S. Geological Survey Open-file Report 76-232, 65 p.

Resig, J. M., 1958, Ecology of Foraminifera of Santa Cruz Basin, California: Micropaleontology, v. 4, no. 3, p. 287-308.

Shepard, F. P., and Emery, K. O., 1941, Submarine topography off the California coast--Canyons and tectonic interpretation: Geological Society of America Special Paper 31, 171 p.

Taylor, J. C., 1976, Geologic appraisal of the petroleum potential of offshore southern California--The borderland compared to onshore coastal basins: U.S. Geological Survey Circular 730, 41 p.

U.S. Geological Survey, 1975, Draft environmental statement: Oil and gas development in the Santa Barbara Channel, Outer Continental Shelf off California: DES 35-75.

Vedder, J. G., 1975, Acoustic reflection profiles, R/V KELEZ, May-June 1973, Leg 3, offshore southern California: U.S. Geological Survey Open-file Report 75-265, scale 1:250,000.

______ 1976, Precursors and evolution of the name California Continental Borderland, in Howell, D. G., ed., Aspects of the geologic history of the California Continental Borderland: American Association of Petroleum Geologists, Pacific Section, Miscellaneous Publication 24, p. 6-11.

Vedder, J. G., Arnal, R. E., Bukry, J. D., and Barron, J. A., 1976, Preliminary descriptions of pre-Quaternary samples, R/V LEE, March 1976, offshore southern California: U.S. Geological Survey Open-file Report 76-629, 15 p.

Vedder, J. G., Beyer, L. A., Junger, Arne, Moore, G. W., Roberts, A. E., Taylor, J. C., and Wagner, H. C., 1974, Preliminary report on the geology of the continental borderland of southern California: U.S. Geological Survey Miscellaneous Field Studies Map MF-624, 9 sheets, 34 p.

Vedder, J. G., and Howell, D. G., 1976, Review of the distribution and tectonic implications of Miocene debris from the Catalina Schist, California Continental Borderland and adjacent coastal areas, in Howell, D. G., ed., Aspects of the geologic history of the California Continental Borderland: American Association of Petroleum Geologists, Pacific Section, Miscellaneous Publication 24, p. 326-340.

Vedder, J. G., and Norris, R. M., 1963, Geology of San Nicolas Island, California: U.S. Geological Survey Professional Paper 369, 65 p.

Vedder, J. G., Taylor, J. C., Arnal, R. E., and Bukry, J. D., 1976, Maps showing locations of selected pre-Quaternary rock samples from the California Continental Borderland: A supplement to samples described in Vedder and others, (1974): U.S. Geological Survey Miscellaneous Field Studies Maps MF-737, 3 maps.

Vedder, J. G., Wagner, H. C., and Schoellhamer, J. E., 1969, Geologic framework of the Santa Barbara Channel region, California: U.S. Geological Survey Professional Paper 679-A, 11 p.

von Huene, R. E., 1969, Geologic structure between Murray fracture zone and the Transverse Ranges: Marine Geology, v. 7, p. 475-499.

Wagner, H. C., 1975, Seismic reflection profiles, R/V KELEZ, May 1973, Leg 2, offshore southern California: U.S. Geological Survey Open-file Report 75-205, 60 p., scale 1:250,000, 1 microfilm.

Weaver, D. W., 1969a, The pre-Tertiary rocks, in Weaver, D. W., ed., Geology of the northern Channel Islands: American Association of Petroleum Geologists and Society of Economic Paleontologists and Mineralogists, Pacific Sections, Special Publication, p. 11-13.

______ 1969b, The Cretaceous rocks, in Weaver, D. W., ed., Geology of the northern Channel Islands: American Association of Petroleum Geologists and Socity of Economic Paleontologists and Mineralogists, Pacific Sections, Special Publication, p. 14-16.

______ 1969c, Paleogeographic implications and geologic history, in Weaver, D. W., ed., Geology of the northern Channel Islands: American Association of Petroleum Geologists and Society of Economic Paleontologists and Mineralogists, Pacific Sections, Special Publication, p. 115-124.

______ 1969d, Geology of the northern Channel Islands: American Association of Petroleum Geologists and Society of Economic Paleontologists and Mineralogists, Pacific Sections, Special Publication, 200 p.

Weaver, D. W., and Doerner, D. P., 1969, Lower Tertiary stratigraphy, San Miguel and Santa Rosa Islands, in Weaver, D. W., ed., Geology of the northern Channel Islands: American Association of Petroleum Geologists and Society of Economic Paleontologists and Mineralogists, Pacific Sections, Special Publication, p. 30-47.

Weaver, D. W., Griggs, G., McClure, D. V., and McKey, J. R., 1969, Volcaniclastic sequence, south-central Santa Cruz Island, in Weaver, D. W., ed., Geology of the northern Channel Islands: American Association of Petroleum Geologists and Society of Economic Paleontologists and Mineralogists, Pacific Sections, Special Publication, p. 85-90.

Weaver, D. W., and Meyer, G. L., 1969, Stratigraphy of northeastern Santa Cruz Island, in Weaver, D. W., ed., Geology of the northern Channel Islands: American Association of Petroleum Geologists and Society of Economic Paleontologists and Mineralogists, Pacific Sections, Special Publication, p. 95-104.

Weaver, D. W., and Nolf, B., 1969, Map: Geology of Santa Cruz Island, California, in Weaver, D. W., ed., Geology of the northern Channel Islands: American Association of Petroleum Geologists and Society of Economic Paleontologists and Mineralogists, Pacific Sections, Special Publication.

Wolf, S. C., 1975, Seismic reflection profiles, R/V POLARIS, March 1972, offshore southern California, Point Conception cruise: U.S. Geological Survey Open-file Report 76-166, 22 p.

Woodring, W. P., Bramlette, M. N., and Kew, W. S. W., 1946, Geology and paleontology of the Palos Verdes Hills, California: U.S. Geological Survey Professional Paper 207, 145 p.

Yeats, R. S., 1970, Stratigraphic evidence for Catalina Schist basement north of Channel Islands, California: Geological Society of America Bulletin, v. 81, no. 7, p. 2147-2152.

______ 1976, Extension versus strike-slip origin of the southern California borderland, in Howell, D. G., ed., Aspects of the geologic history of the California Continental Borderland: American Association of Petroleum Geologists, Pacific Section, Miscellaneous Publication 24, p. 455-485.

Yerkes, R. F., and Campbell, R. H., Stratigraphic nomenclature of the central Santa Monica Mountains, Los Angeles County, California: U.S. Geological Survey Bulletin 1457-E, in press.

Yerkes, R. F., and McCulloh, T. H., Schoellhamer, J. E., and Vedder, J. G., 1965, Geology of the Los Angeles basin, California--An introduction: U.S. Geological Survey Professional Paper 420-A, 57 p.

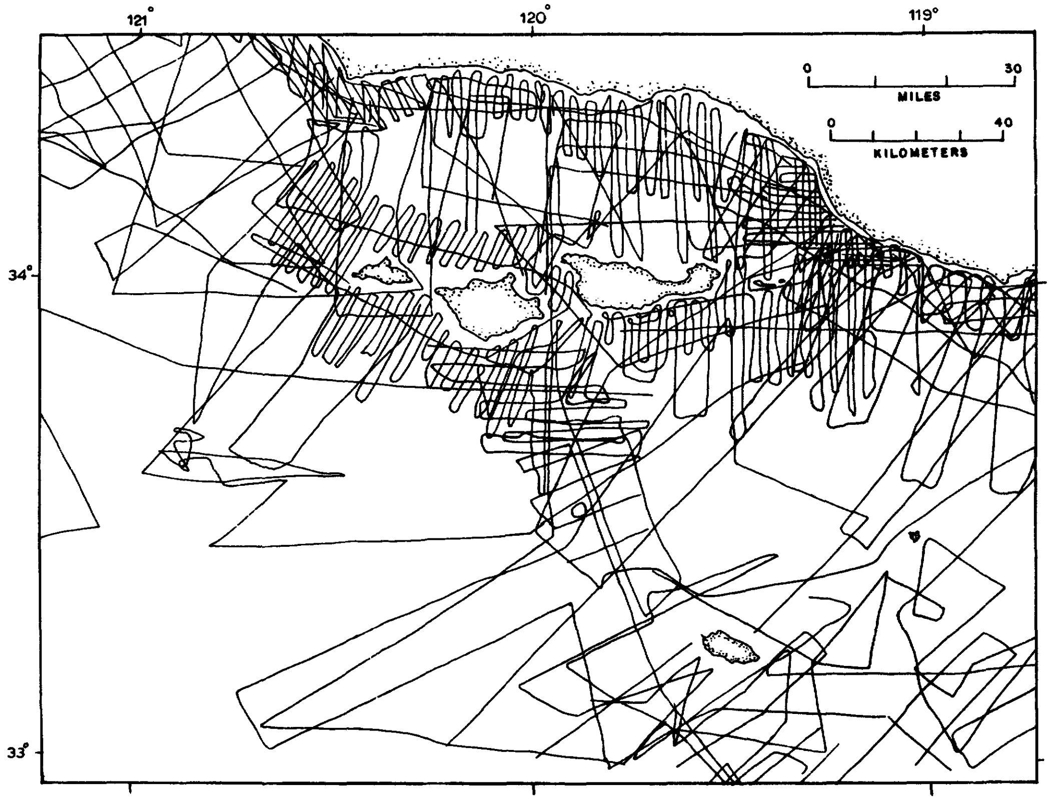
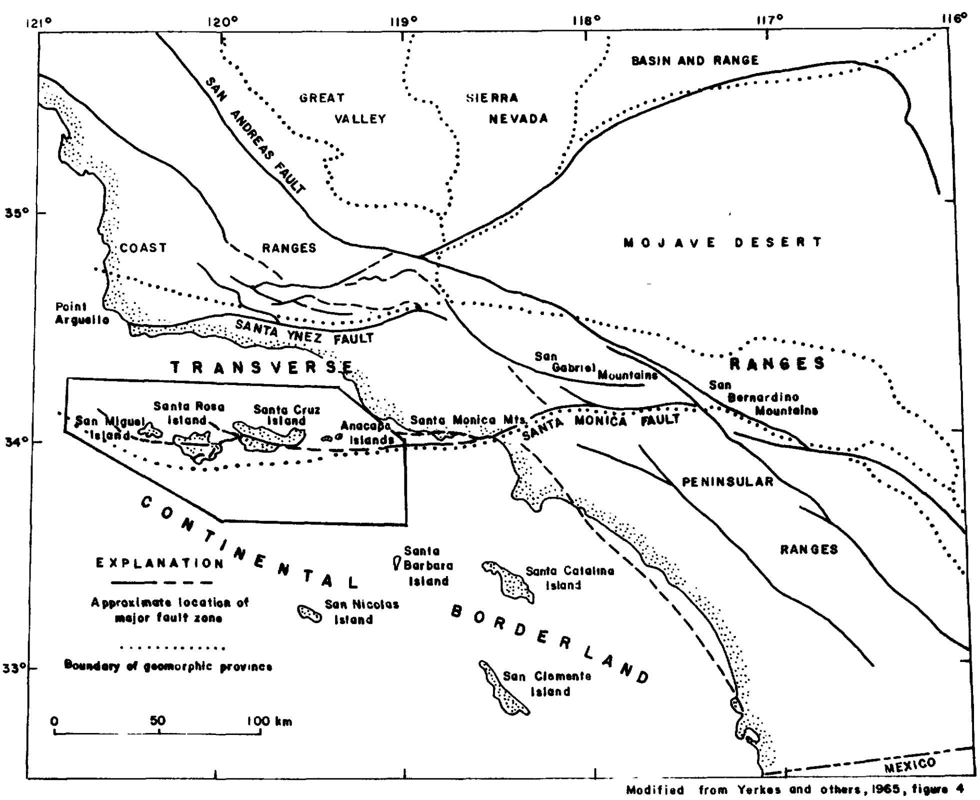


Figure 1. Geophysical tracklines surrounding Northern Channel Islands.



Modified from Yerkes and others, 1965, figure 4

Figure 2. Relation of Northern Channel Islands area to major physiographic provinces.

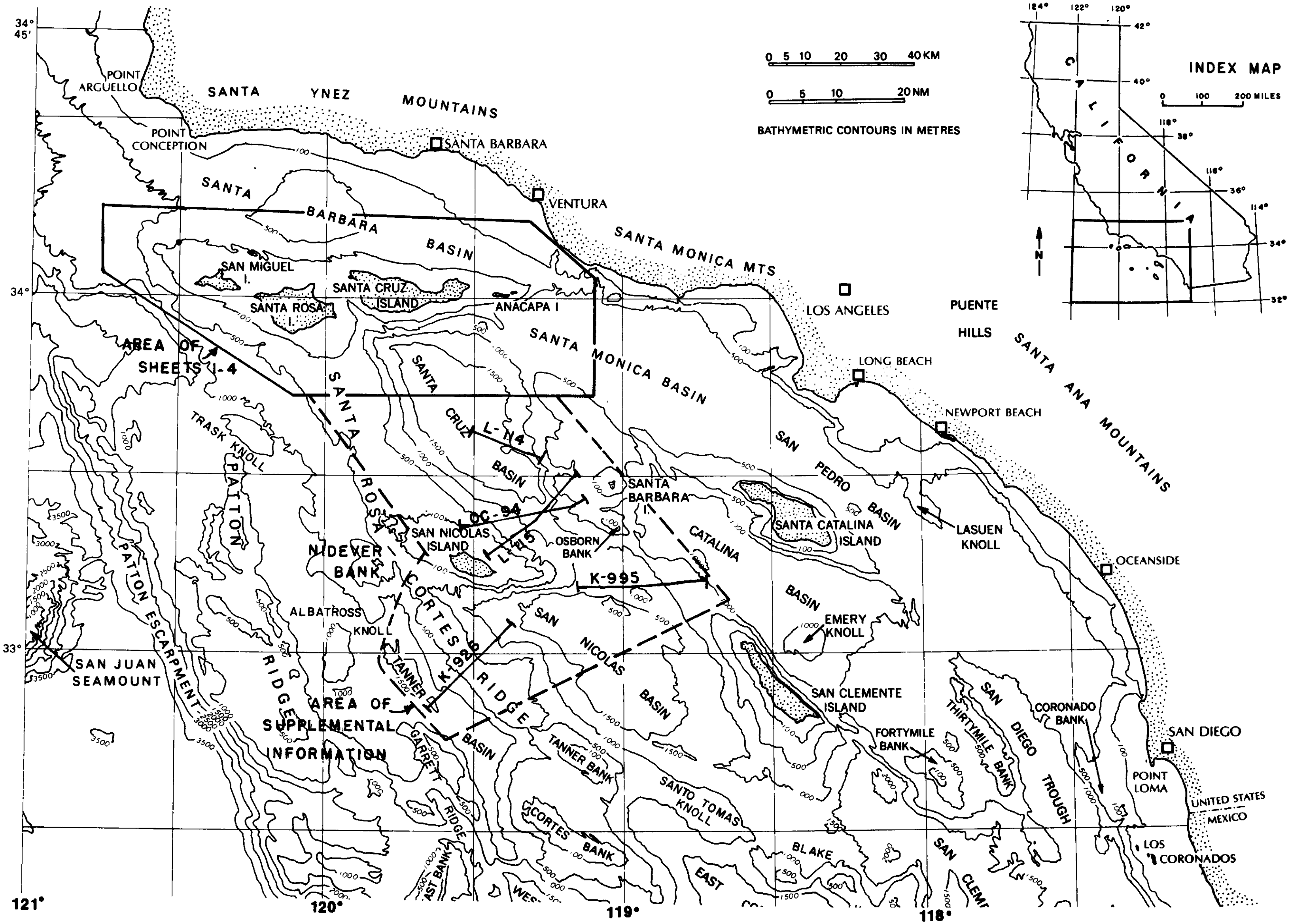


Figure 3. Topographic map of California Continental Borderland (Vedder and others, 1974), showing area of detailed mapping in solid line and area of supplemental information in dashed line. Tracklines indicate location of seismic profiles shown on sheet 2.

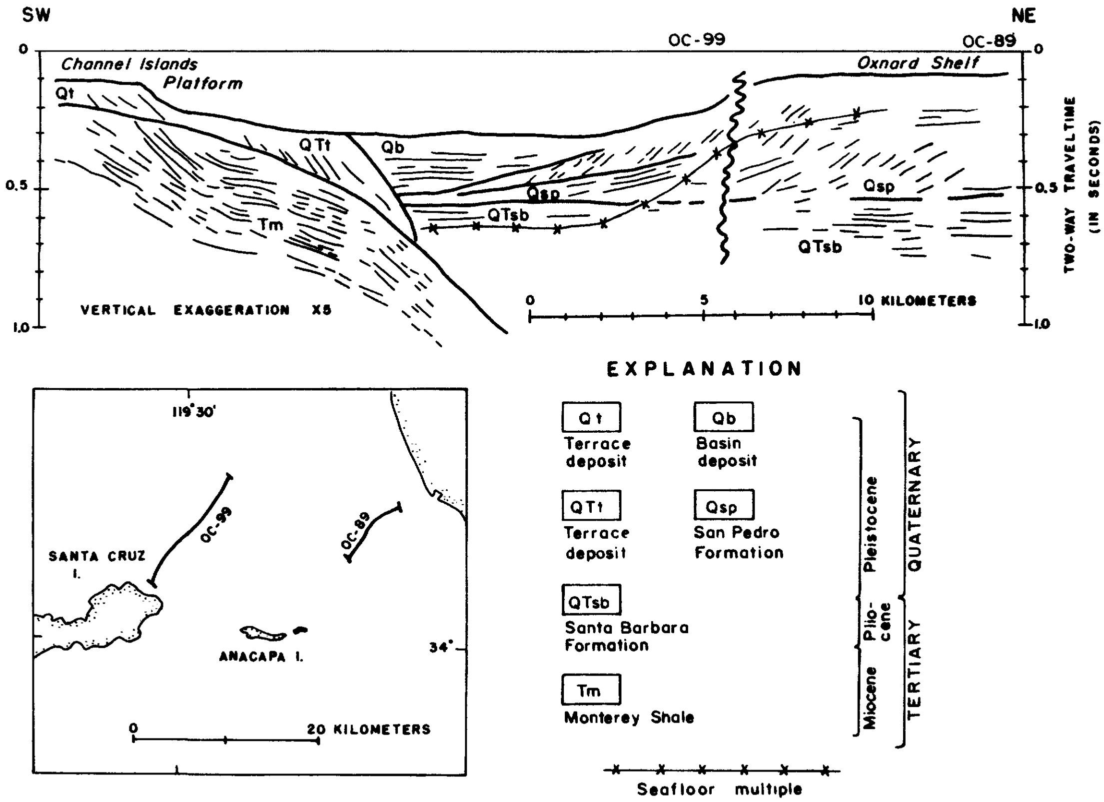


Figure 4. Composite line drawing, profiles OC-89 and OC-99.

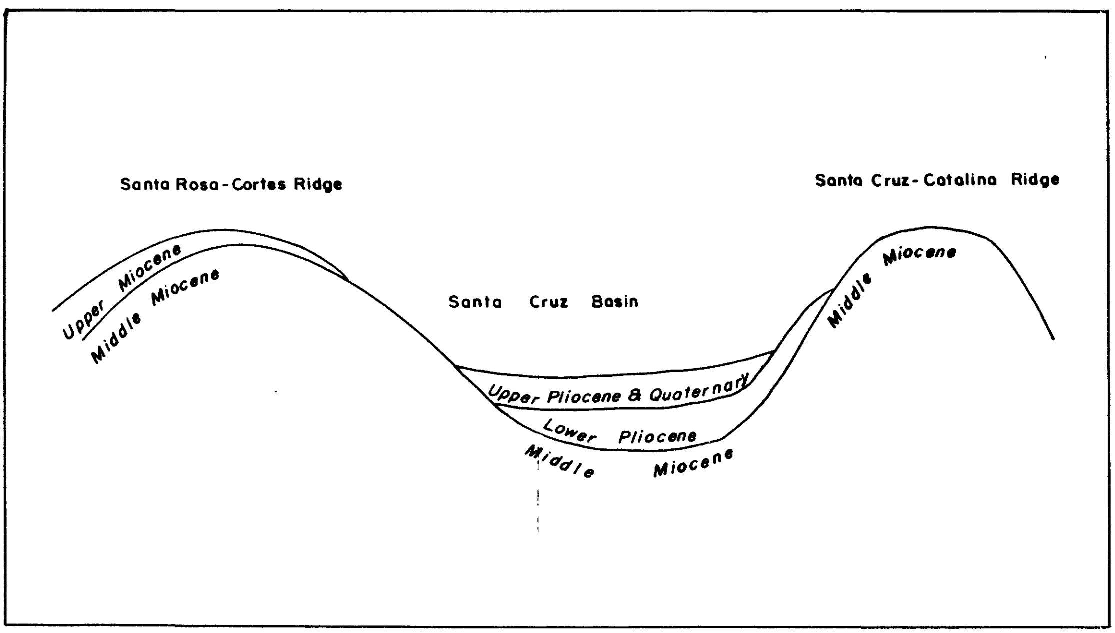


Figure 5. Diagrammatic structure section from northern Santa Rosa-Cortes Ridge to northern Santa Cruz-Catalina Ridge, showing relation between middle Miocene and post-middle Miocene strata.

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