UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

A SUMMARY REPORT OF THE REGIONAL GEOLOGY, ENVIRONMENTAL GEOLOGY, OCS RESOURCE APPRAISAL, PETROLEUM POTENTIAL, AND OPERATIONAL CONSIDERATIONS IN THE AREA OF PROPOSED LEASE SALE 73, OFFSHORE CALIFORNIA

Edited by

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SUMMARY

This report reviews geological, geophysical and technological data pertinent to proposed Lease Sale 73. Under consideration is the entire continental margin of California that is bounded on the west by the 2500 meter isobath. This area encompasses the whole of the southern California Borderland, the continental shelves of central and northern California, and the upper part of the continental slope from Mexico on the south to Oregon on the north. The area includes both leased and unleased tracts and lies adjacent to highly productive coastal basins of central and northern California . Because the geology of the south and north parts of this large area differ, they are considered separately in this report.

In the southern part of proposed Lease Sale 73 (Chapt. 1, Santa Barbara channel and the area to the south) factors that have contributed to petroleum generation in the onshore basins, such as thickness, burial depth and hydrocarbon content, are less favorable in parts of the offshore region. Nevertheless, regional geologic and geophysical mapping together with data from stratigraphic test wells and bottom samples suggest that source beds, reservoir rocks and traps are present beneath the borderland. Strata of Miocene age are widespread within the area and contain fair to excellent potential source rocks. Eocene and early Miocene sandstone beds in the Cortes Bank test well and late Miocene and Pliocene rocks in the Point Conception test well have porosities that are within the range of good reservoir rocks. Late middle Miocene through Pliocene sandy turbidites of reservoir quality possibly occur in some outer borderland basins. Additional prospective targets are fractured Miocene shale beds that may be present in the deeper basins and on the down-flank margins of major uplifts. Numerous structural and stratigraphic traps, which formed in response to late Cenozoic wrench tectonics, are distributed throughout the borderland.

Active seismicity, seafloor instability, sediment erosion, subsidence susceptibility, and hydrocarbon seeps may present problems in the exploration and development of the southern part of the lease sale area. Unstable ground and active faults are evident along ridge and shelf areas throughout the borderland. The northern slope of Santa Barbara Channel, the western flank of Santa Rosa-Cortes Ridge, and the eastern edge of the San Diego Trough are particularly susceptible to slumping. Inundation of coastal lowlands and future installations on banks possibly could result from both locally generated and external tsunamis. Sparse sediment cover and rock outcrops devoid of sediment along the crest of the Santa Rosa-Cortes Ridge attest to strong current action.

In the northern part of proposed Lease Sale 73, (Chapt. 2, north of Point Conception), five shallow sedimentary basins on the shelf have received most attention as potential areas of recoverable hydrocarbons. Chances for finding large structurally controlled traps in these basins do not appear great. Many of the most attractive structures were drilled following the 1963 lease sale, and there was no resulting production. Although there are some basal and deep water sands of reservoir quality in the prospective section in some of the basins, there is a general lack of thick coarse clastic rock units that form the productive reservoirs in the southern California offshore basins. Principal source rocks in the basins appear to be cherty Miocene shales, however, these rocks generally thin northward, and are not reported from the northermost basin. There may be some potential for production from older rocks beneath the basins, where remnants of clastic marine Eocene rocks survived on extensive pre-Miocene erosion of the shelves, however, these rocks are not widespread, and their structures are complex and difficult to define. Therefore petroleum production from these older rocks is considered moot. Most production from adjacent onshore basins has been low gravity crude from reservoirs developed in fractured Miocene shales. This production has been achieved largely by costly long-term well treatment and dense-drilling.

Basins in the northern part of the lease sale area are bounded by the San Andreas fault, the longest most seismically active strike slip fault on the continent and/or by seismically active subsidiary strike slip and thrust faults that are also capable of producing large earthquakes accompanied by surface rupture and strong seismic shaking. Unstable seafloor is found in most of the basins and on the adjacent continental slope. The presence of shallow gas, rapid deposition of fine-grained sediment, relatively young uplift and seismic shaking are thought to contribute to the soil failures. Shallow gas, some possibly over pressured, may pose problems during development of the basins, Tsunamis have caused damage along this coast; most resulted from distant earthquakes, but one may have been generated locally.

Petroleum resources for the proposed sale areas are estimated in aggregate at probability levels of 5 percent and 95 percent and are based in part upon volumetric and analog methods. The following amounts of oil and gas resources that could be recovered under present conditions of economy and technology are:

	Unconditional Estimates		
	95 Percent Probability	5 Percent Probability	Statistical Means
Oil (billions of barrels)	1.2	6.9	3.4
Gas (trillions of feet^3)	1.8	9.2	5.0

CHAPTER A

REGIONAL GEOLOGY, PETROLEUM POTENTIAL, AND ENVIRONMENTAL GEOLOGY IN THE SOUTHERN PART OF PROPOSED LEASE SALE 73, OFFSHORE SOUTHERN CALIFORNIA

By

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REGIONAL GEOLOGY, PETROLEUM POTENTIAL, AND ENVIRONMENTAL GEOLOGY IN THE SOUTHERN PART OF PROPOSED LEASE SALE 73, OFFSHORE SOUTHERN CALIFORNIA

INTRODUCTION

This chapter is a summary of data that will affect exploration and development in the area of the southern part of proposed OCS Lease Sale 73. The designated area extends from Point Conception to the United States-Mexico boundary and seaward to the foot of the continental slope (Fig. 1). As a result of the international treaty of May 4, 1978, the U.S.-Mexico boundary extends south of 32°N latitude and adds approximately 5,000 mi^2 (13,000 km^2) of new area to the 21,000 mi^2 (54,400 km^2) considered in the call for nominations for OCS Lease Sale No. 48.

Much of the geologic information in this report has been extracted from the summary reports prepared in advance of OCS Lease Sale 35 (Vedder and others, 1974a) and No. 48 (Vedder and others, 1976c). Significant new findings since transmittal of the summary report for OCS Lease Sale 48 are included herein. Tracklines for U.S. Geological Survey geophysical and rock sampling cruises since 1972 are shown in Figures 2 amd 3. Available geologic data from the new territory south of 32°N latitude is limited to 5 widely-spaced geophysical profiles and 7 dredge hauls.

As shown in Figure 1, the proposed lease sale area is divided into three regions: the Santa Barbara Channel, the inner basins and banks, and the outer basins and banks. Each subdivision is described separately under the sections of this report entitled regional geologic framework, appraisal of the OCS potential, petroleum resource appraisal, and environmental hazards.

Figure 1. Map of the region of proposed OCS Lease Sale 73. The three-mile line is shown by a solid line along the mainland coast and around the islands. The 200 meter and 750 meter depth contours are indicated by short-dashed curved lines. Boundaries of the area included in the Call for Nominations, OCS Lease Sale 48 are depicted by short-dashed straight lines. Stratigraphic columns in Figures 4, 5, and 7 are located at the numbered circles 1 through 20.

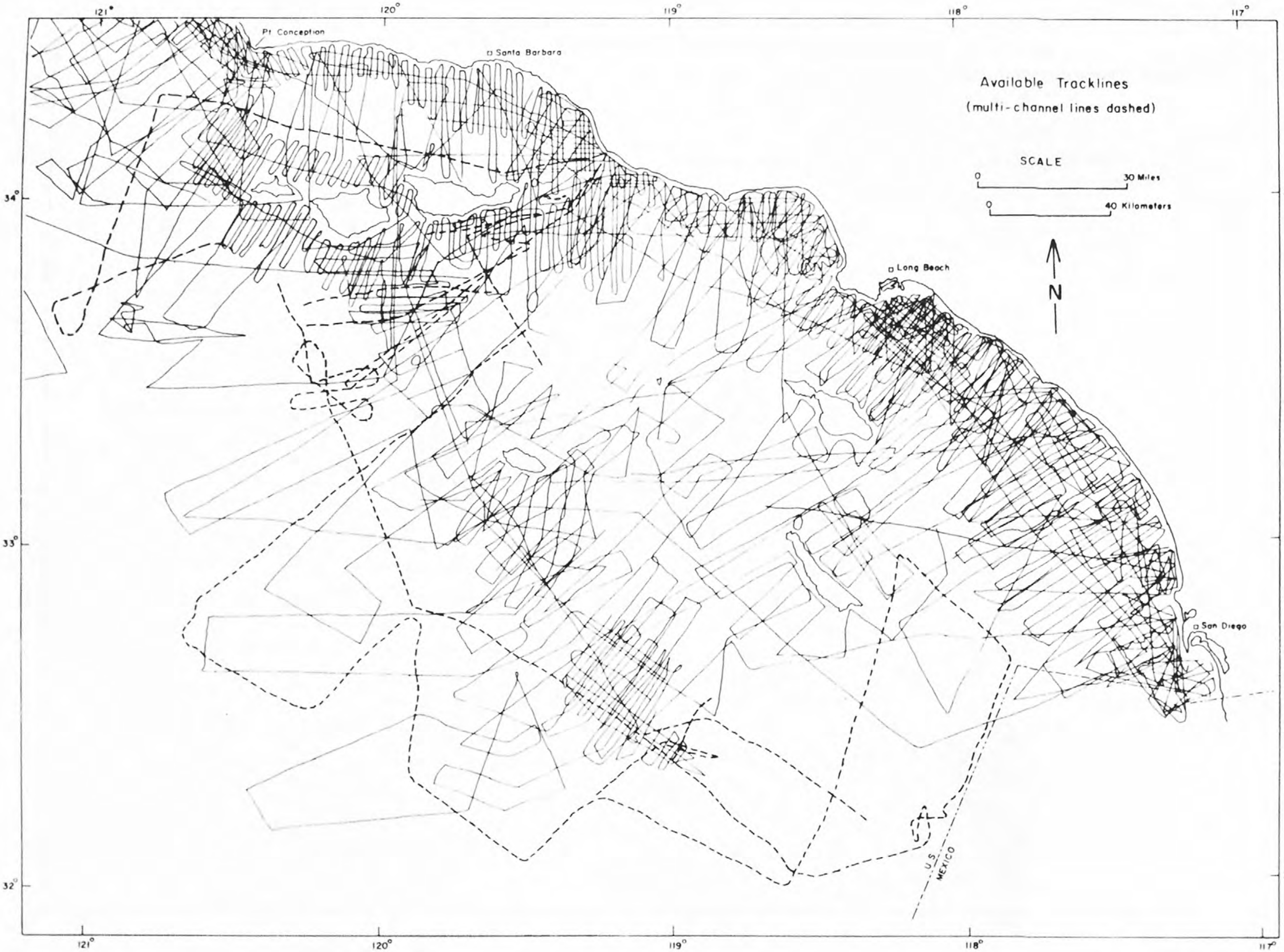

Figure 2. Ship tracklines along which nonproprietary geophysical data have been collected for the purpose of preparing the papers cited in this report.

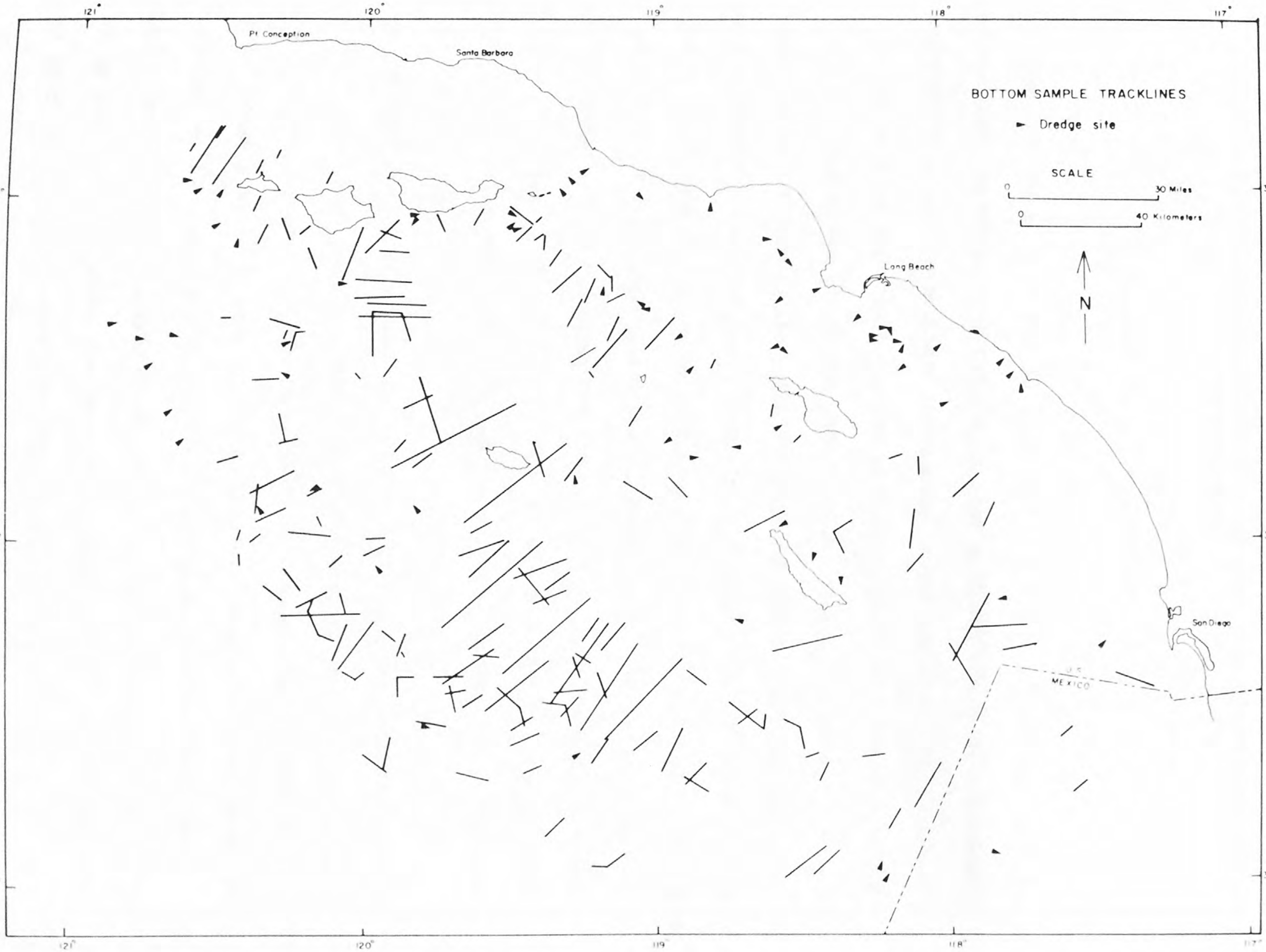

Figure 3. Dredge sites and ship tracklines along which bedrock cores were taken for the purpose of preparing the papers cited in this report. Descriptions of samples are recorded in Vedder and others (1974, 1976a, 1976b, 1977, 1979).

REGIONAL GEOLOGIC FRAMEWORK

General Setting

The southern part of proposed OCS Lease Sale 73 lies offshore from the structurally complex part of California that includes the western Transverse Ranges province and the northern Peninsular Ranges province. This offshore region commonly is referred to as the southern California borderland. The Neogene geologic evolution of the region is attributed to tectonic instability of the continental margin along the boundary between the Pacific and North American plates. As a result of right-lateral shear, which began along the plate boundary about 30 m.y. ago, a network of ridge and basin structures developed. Rapid erosion of the ridges and thick accumulation of sediment in the basins accompanied by volcanism began about 20 m.y. ago. Subsequent deformation in response to continued right shear, which resulted in the formation of local en-echelon zones of folds and faults, began about 12 m.y. ago and is continuing today.

Santa Barbara Channel. The geologic framework of the Santa Barbara Channel and Point Conception area has been described in reports by U.S. Geological Survey (1975), Campbell and others, (1975) and Cook and others (1979). Basement rocks similar to some types of the Coast Range Franciscan have been penetrated in the Union Gherini No. 1 well on the east end of Santa Cruz Island, north of the Santa Cruz fault, where greenstone was cored and dated at 152 ± 8 m.y. (Howell, McLean, and Vedder, 1976). Exposed basement rocks south of this fault were described elsewhere (Hill, 1976).

The only reports of Cretaceous sedimentary rocks beneath the Santa Barbara Channel are from exploratory wells near the middle of the channel

(Vedder and others, 1969; Weaver, 1969). The Richfield Santa Cruz No. 1 well, located at the west end of Santa Cruz Island and north of the Santa Cruz Island fault, drilled 2,000 feet (610 m) of conglomerate, sandstone, and shale of Late Cretaceous age (Weaver, 1969; Howell, McLean, and Vedder, 1976). The Richfield Santa Cruz No. 2 well, located south of the fault, penetrated 2,260 feet (689 m) of sedimentary rocks of similar age and lithology. West of the channel, deep stratigraphic test well OCS-CAl 78-164 No. 1 (Fig. 4) drilled Upper Jurassic or Lower Cretaceous mudstone and siltstone between 10,000 feet (3050 m) and the total depth of 10,571 feet (3224 m).

Paleogene rocks beneath the channel are believed to be widespread and may attain thicknesses of as much as 10,000 feet (3050 m) or more nearshore (Curran, Hall, and Herron, 1971; Campbell and others, 1975). Along the mainland coast, marine sandstone and claystone beds form the bulk of the Paleocene and Eocene sequences and locally are interlayered with conglomerate. The Oligocene section on shore grades westward from nonmarine to marine and is composed primarily of sandstone and siltstone (Dibblee, 1950; Curran, Hall, and Herron, 1971; Vedder and others, 1974). Much of the insular platform west of San Miguel Island is underlain by Upper Cretaceous and Paleogene strata (Junger, 1979). Folds occur in well defined trends, and individual anticlines commonly are arranged in echelon. High-angle faults, with apparent normal and reverse separations, are interspersed with those that have strike-slip components of movement (Lee and Vedder, 1973); Ellsworth and others, 1973; U.S. Geological Survey, 1975; Greene, 1975; Yerkes and others, 1979). Older structures may have controlled sediment dispersal as early as Eocene time, and at some places faults cut strata no younger than late Miocene and early Pliocene, particularly along the southern margin of the channel (Junger, 1979). On the other hand, domed late Pleistocene alluvium, uplifted

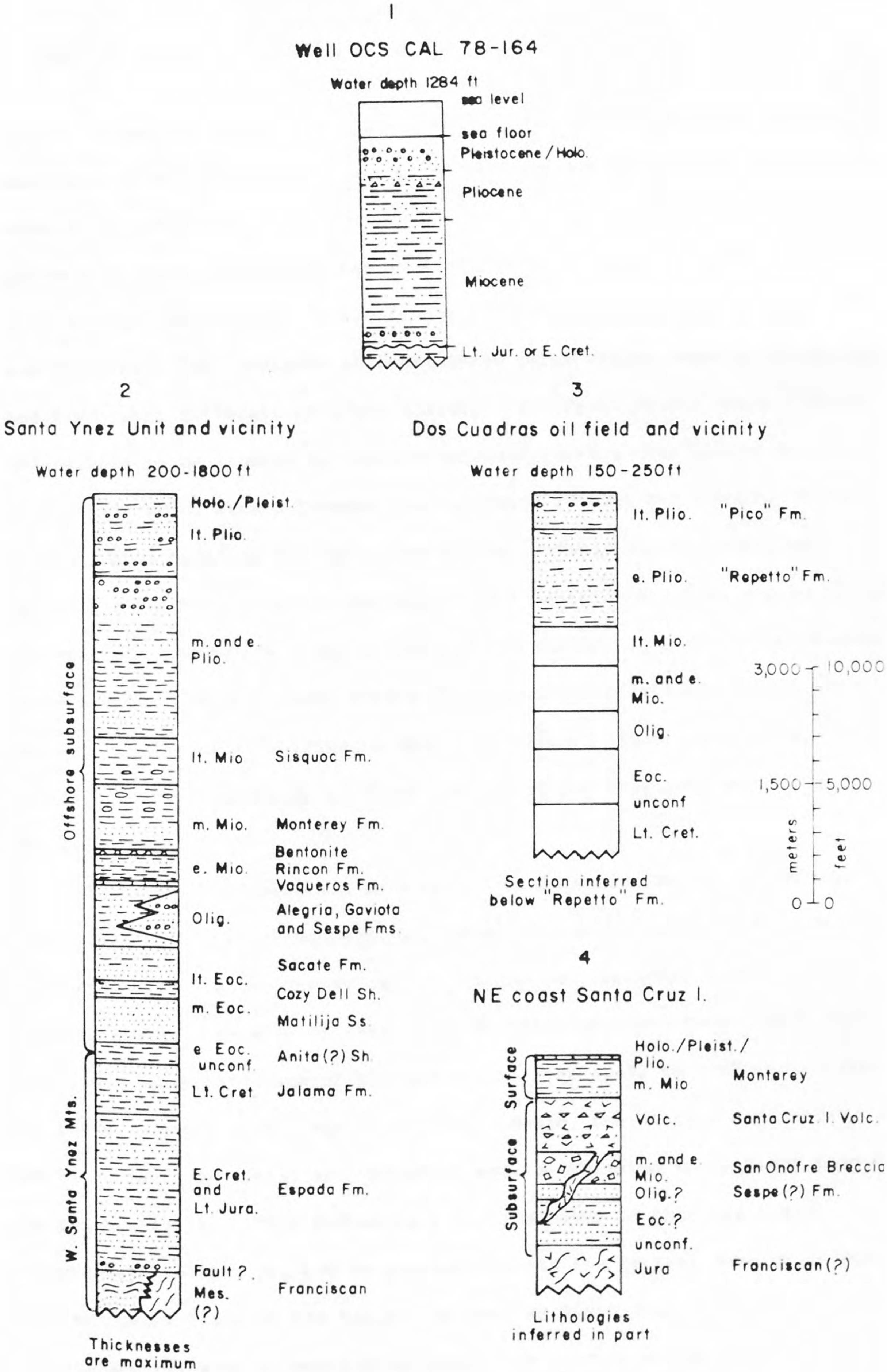

Figure 4. Stratigraphic columns, Santa Barbara Channel region. Provincial chronologies and named stratigraphic units are shown to the right of each column. The rock types, where known, are generalized and depicted by lithologic symbols.

and tilted marine terrace platforms, and faults that cut Holocene seafloor sediments attest to the youthfulness of tectonic activity along the mainland edge of the channel.

Borderland, inner basins and banks--The region that extends southeastward from Anacapa Island and inboard from the crests of Santa Cruz-Catalina Ridge and Thirtymile Bank contains at least three large basins, each of which has had a somewhat different geologic history. The Santa Monica and San Pedro Basins seem to be floored by Miocene volcanic rocks and/or schist basement with little or no strata beneath the volcanics (Junger and Wagner, 1977). The Gulf of Santa Catalina and San Diego Trough probably are underlain by Peninsular Ranges basement rocks along their easternmost edges and by schist and volcanics elsewhere (Fig. 5) (Howell and Vedder, in press). Unlike the western edges, where Miocene strata directly overlie Catalina Schist and volcanic rocks, as at Thirtymile Bank, the eastern edges are underlain by relatively thick sequences of Upper Cretaceous and Paleogene strata, as on the San Diego shelf.

In the deep northwestern part of the Santa Monica Basin, as much as 8,000 feet (2438 m) of latest Miocene, Pliocene and younger sedimentary rocks may have accumulated above the volcanics. Along the northeast slope, Miocene strata, composed chiefly of shale, are as thick as 2,600 feet (792 m) and along the southeast flank of the basin, they are 1,300 to 1,800 feet (396-549 m) thick. On the north edge of San Pedro Basin, the Miocene sedimentary section rests on schist and volcanics and is estimated to be 3,000 feet (914 m) thick (Fig. 3). This sedimentary section seems to thin basinward (southwestward) and may not be present beneath the central deep or on parts of the southwest flank of the basin. As much as 5,000 feet (1586 m) of Pliocene strata are believed to overlie volcanic rocks and/or schist basement in the

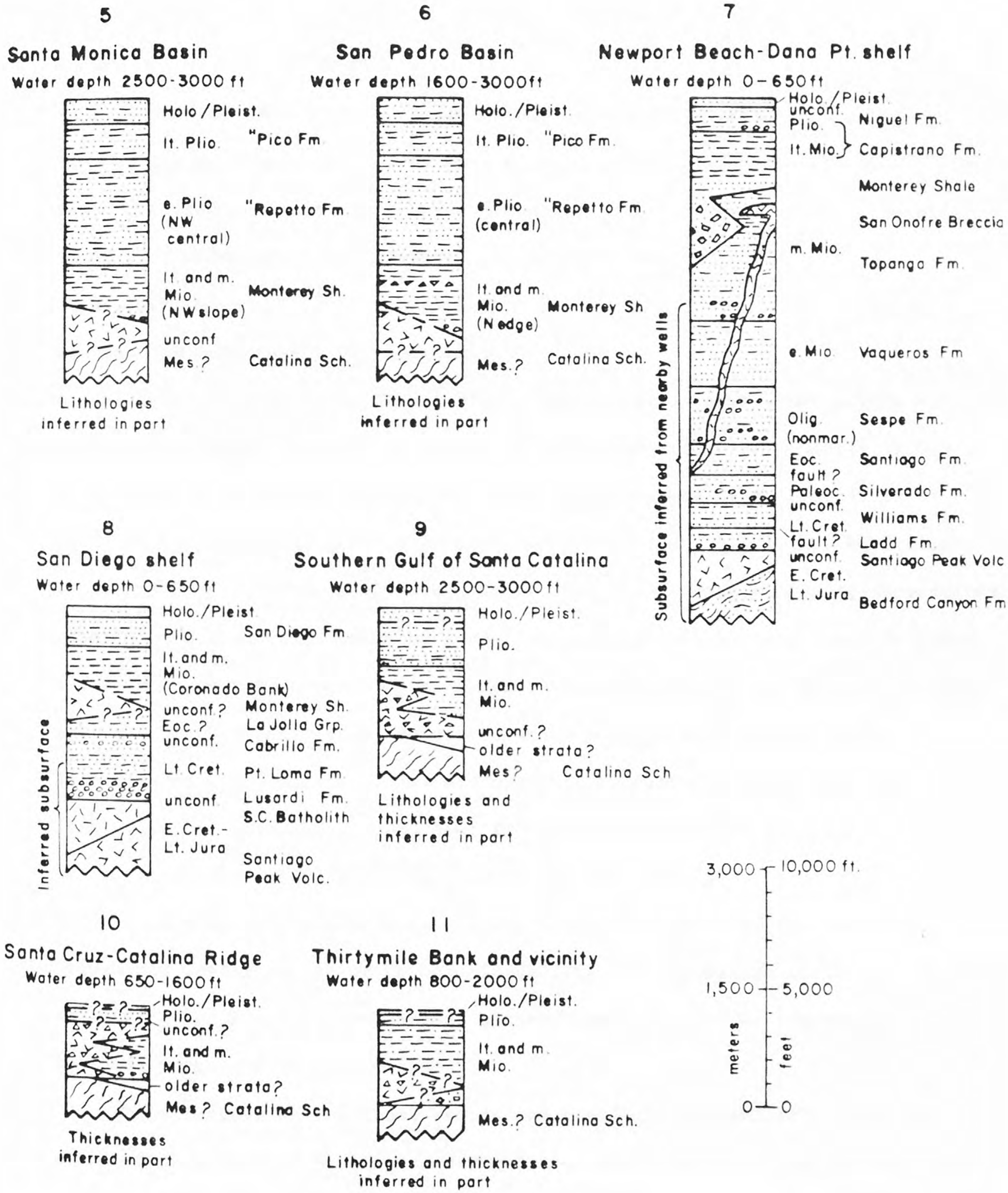

Figure 5. Stratigraphic columns, inner basins and banks. Provincial chronologies and named stratigraphic units are shown to the right of each column. The rock types are generalized and depicted by lithologic symbols.

central part of the San Pedro Basin (Junger and Wagner, 1977).

In the nearshore shelf area east of the offshore extension of the Newport-Inglewood fault zone, Upper Cretaceous and Paleogene strata consisting chiefly of sandstone, conglomerate, and mudstone unconformably overlie crystalline basement rocks. Near Laguna Beach, this pre-Miocene stratigraphic sequence is more than 7,000 feet (2134 m) thick in the subsurface sections on shore; and in the vicinity of San Diego, approximately equivalent strata are estimated to have a maximum thickness of 5,000 feet (1524 m). Nearly 11,000 feet (3353 m) of Miocene sandstone, shale, conglomerate, and breccia beds underlie the shoreline between Newport Beach and Laguna Beach, but equivalent strata on the San Diego shelf are thin or absent as a result of post-depositional erosion. Pliocene siltstone and sandstone units with minor conglomerate lenses are as much as 1,000 feet (305 m) thick east of Dana Point and about 1,250 feet (381 m) thick at San Diego. Relatively thin sequences of Miocene shale interlayered with volcanic flows are overlain by Pliocene silts and sands that locally may be as much as 4,000 feet (1219 m) thick beneath the central Gulf of Santa Catalina and 2,000 feet (610 m) thick beneath the central San Diego Trough. A Bouguer gravity anomaly along the eastern part of the San Diego Trough and western flank of Coronado Bank (Fig. 6) implies an eastward-thickening sequence of pre-Pliocene sedimentary rocks and/or low-density basement rocks (Beyer, in press).

The structure of the inner basins and banks is complex; folds near the mainland coast along the seaward extension of the Newport-Inglewood fault zone are comparatively small and steep-flanked, and faults occur both as zones of en echelon breaks or as single traces. Most folds and faults are oriented northwest. Some large, fault-bounded antiform structures, such as Coronado Bank, are broad and nearly symmetrical but little is known about their

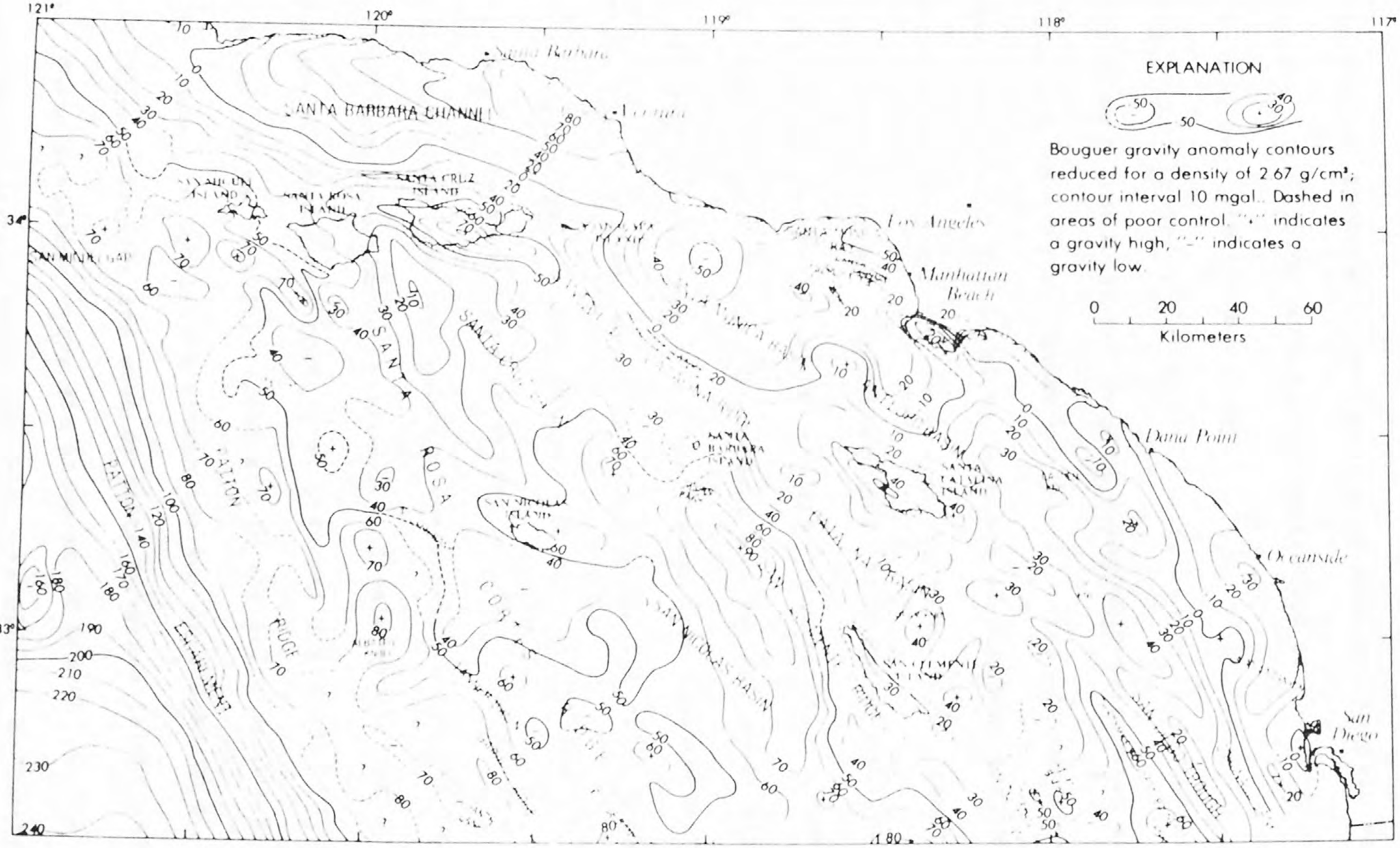

Figure 6. Bouguer gravity map of offshore southern California. From Beyer (in press).

development. Faults range in age from middle Miocene to Quaternary and presumably include those with strike-slip as well as dip-slip separations. The age of the small folds probably is restricted primarily to post-late Miocene to pre-late Pleistocene time.

Borderland, outer basins and banks--The outer borderland consists mainly of paired, northwest-trending, pre-Neogene lithologic belts that are blanketed by Miocene and younger strata. These two paired belts are correlated with the Franciscan complex and Great Valley sequence of northern and central California (Vedder and others, 1976; Crouch, 1978, 1979; Howell and Vedder, in press). Franciscan rocks form the acoustic basement underlying the continental slope and Patton Ridge and are characterized by compressional velocities of 5.1 to 6.1 km/s, discordant and discontinuous seismic reflectors, and diverse rock types that range from zeolite-bearing sandstones to blueschists. The Great Valley belt underlies the Santa Rosa-Cortes Ridge and Santa Cruz and San Nicolas Basins. In contrast to the Franciscan rocks, the Great Valley rocks are characterized by compressional velocities of 4.5 to 4.6 km/s, concordant and continuous seismic reflectors, and thick turbidite sequences of unmetamorphosed Cretaceous and Paleogene strata.

Low-grade metamorphic rocks that presumably are related to those exposed on and around Santa Catalina Island and in the Palos Verdes Hills have been sampled at numerous localities within the borderland south of the northern group of Channel Islands and west of Santa Catalina Island and the San Diego Trough. These schistose rocks are known to be present as far south as Sixtymile Bank. Arkosic wacke and argillite similar to Coastal belt Franciscan and "Knoxville" rock types occur southeast of San Nicolas Island, west of Tanner Basin, and from the northern Patton Ridge. Schistose rocks that resemble the Catalina Schist form the crest of a low, northwest-trending ridge about 5 miles southwest of Santa Rosa Island. Serpentine and metamorphosed ultramafic intrusive rocks much like those on Santa Catalina Island were recovered from the northern Patton Escapment and from the saddle on the ridge between Santa Barbara Island and San Clemente Island. On Santa Cruz Island, south of the median fault, greenschist-facies rocks of the Santa Cruz Island Schist are intruded by plagiogranite and diorite that have been dated at about 140 and 160 m.y; respectively.

South of the northern group of Channel Islands, seafloor outcrops of Cretaceous strata are sparse, and definite Lower Cretaceous samples have not been reported. Inasmuch as Upper Cretaceous strata were penetrated in wells on Santa Cruz and Santa Rosa Islands, they probably are present in the subsurface section immediately south of these islands. Mobil Santa Rosa No. 5 well drilled south of the median fault on Santa Rosa Island spudded in Eocene strata and bottomed in Upper (?) Cretaceous sedimentary rocks at a depth of 11,003 feet (3356 m). It seems likely that an Upper Cretaceous sedimentary section underlies Eocene strata on the San Nicolas Island platform. From there, these strata probably continue southeast beneath the Santa Rosa-Cortes Ridge into West Cortes and Velero Basins. Siltstone of Late Cretaceous age recently was sampled near the northwest end of Cortes Bank (Vedder and others, 1979). Nearly 4,000 feet (1219 m) of Late Cretaceous turbidites (Fig. 7) were penetrated in a deep stratigraphic test well (OCS-CAL 75-70 No. 1) near the southeast end of Cortes Bank. Cretaceous sedimentary rocks also are present in the vicinity of Nidever Bank and on Garrett Ridge.

Lower Tertiary rocks are sparsely distributed as seafloor outcrops on the outer borderland. Paleocene strata occur on the northwesternmost part of the Santa Rosa-Cortes Ridge and may be exposed on the shelf west of San Miguel

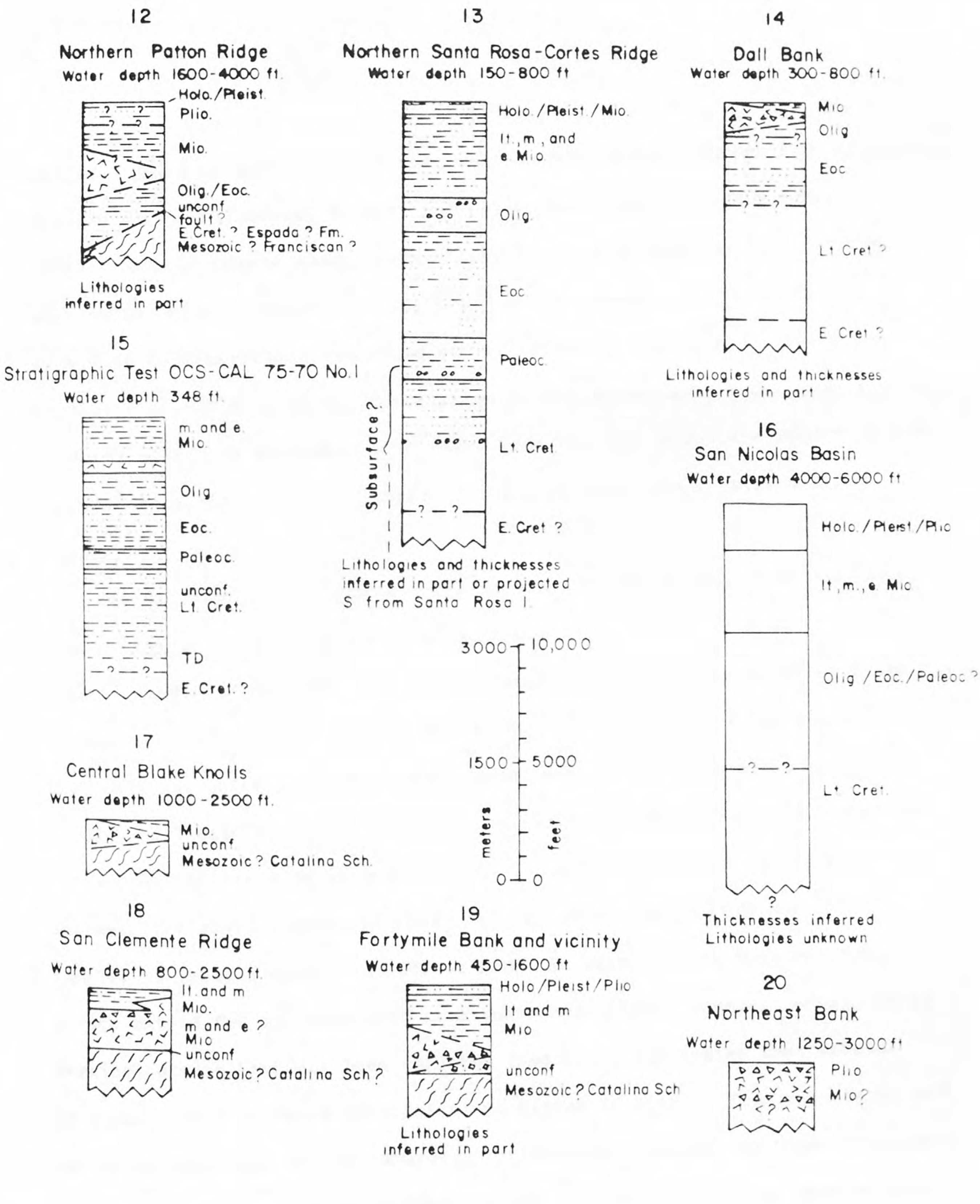

Figure 7. Stratigraphic columns, outer basins and banks. Provisional international chronologies are shown to the right of the columns. Most stratigraphic units are unnamed. Rock types, where known, are generalized and depicted by lithologic symbols. Except for the OCS-CAL 75-70 No. 1 well, thicknesses are estimated from acoustic-reflection profiles.

Island. The deep stratigraphic test well on southeastern Cortes Bank drilled through marine Oligocene, Eocene, and Paleocene strata (Paul and others, 1976). Beds of Eocene sandstone and claystone are present on the platform west of San Miguel Island, and the broad shelf around San Nicolas Island is underlain by interbedded sandstone and siltstone of Eocene age that extends northwest beyond Begg Rock. Correlative strata undoubtedly constitute a thick subsurface section southward from Santa Rosa Island. Oligocene sandstone and mudstone beds are exposed on Cortes and Tanner Banks and at places along the Patton Ridge.

The distribution of Eocene rocks in the subsurface section of the outer part of the borderland is not known with certainty, but strata of this age probably underlie younger rocks beneath most of the Santa Rosa-Cortes Ridge northwest of San Nicolas Island, where they may range from 4,000 to 7,000 feet (1219-2134 m) thick, and they extend under much of the same ridge southeast beneath Dall Bank to Tanner and Cortes Banks. Equivalent rocks underlie both Santa Cruz and San Nicolas Basins (Fig. 7), and they thin eastward and wedge out near the eastern edges of these basins. Even though they have been sampled no farther south than Cortes Bank, it seems likely that Paleogene strata extend far southeastward from that area beneath younger rocks. Early Tertiary strata have not been reported from the ridge system that extends southeastward from Santa Cruz Island to Sixtymile Bank or from the basins and banks directly east of it. However, remnants of Paleogene or Upper Cretaceous siltstone, sandstone, and conglomerate are intruded by Miocene igneous rocks at the southeast end of Santa Catalina Island (Vedder and Howell, 1979).

Much of the crest of the Santa Rosa-Cortes Ridge southward from Santa Rosa Island and northward from Begg Rock is composed of silty claystone of early Miocene age. Strata of the same age and similar composition are present on the shelf west of San Miguel Island and in the vicinity of Tanner and Cortes Banks. Correlative sedimentary rocks presumably blanket most of the Santa Rosa-Cortes Ridge southeast of the San Nicolas Island salient and underlie parts of Patton Ridge and the intervening basins. Sandstone of possibly early Miocene age occurs at Sverdrup Bank, Dall Bank, and the Cortes-Tanner Banks area.

Fine-grained strata of middle Miocene age, predominantly shale and claystone, form large expanses of the Santa Rosa-Cortes Ridge southeast of Santa Rosa Island and between San Nicolas Island and Santo Tomas Knoll. Shaly beds of the same age occur on the shelf west and northwest of San Miguel Island, on Santo Tomas and Shepard Knolls, on Garrett and Patton Ridges, and on ridges east of the northwestern part of Long Basin. Diatomaceous shale of middle and late Miocene age is locally present on and around San Clemente Island, in the vicinity of Santa Barbara Island, at Santa Catalina Island, and near Fortymile Bank. Coarse-grained sedimentary rocks of middle Miocene age seem to be sparse seaward of the mainland and northern island shelves. Strata of late Miocene age, chiefly diatomaceous mudstone, are more restricted than the middle Miocene strata along the outer ridges but are inferred to drape the slopes and pass beneath younger sediments that floor the outer basins.

These Miocene sedimentary sequences may attain thicknesses of 5,000 feet (1525 m) or more in some of the larger outer basins and may contain turbidite sands (Crouch and others, unpublished data). Some of the thinnest sections of Miocene strata are believed to be in the southern end of the Catalina Basin and in the region of Thirtymile and Fortymile Banks, where volcanic and basement rocks are exposed on the seafloor or are shallowly buried.

One of the commonest rock types on the borderland is volcanic rock, most of which is early and middle Miocene in age. Because these igneous rocks represent diverse conditions of emplacement ranging from aquagene tuffs and thick, extensive flows to local narrow, near-vertical intrusions and sill-like bodies, it is difficult to predict their volume and distribution. They are widespread along Santa Cruz-Catalina Ridge and San Clemente Ridge and around Santa Barbara Island and Fortymile Bank. Volcanic rocks are not as abundant on the Santa Rosa-Cortes Ridge although they form Northeast Bank and parts of Cortes and Tanner Banks. Along the Patton Ridge-Patton Escarpment, volcanics have been dredged at a number of sites, and their abundance seems to increase southward.

Exposures of Pliocene sedimentary rocks are much less common than Miocene strata on the outer borderland shelves and slopes and seem to be restricted primarily to the deep basins. Seaward of the islands, Pliocene strata have been recorded at only a few places in water less than 1,500 feet (457 m) deep. Estimates of thickness range from close to 2,000 feet (610 m) in the central parts of Santa Cruz and San Nicolas Basins to less than 500 feet (152 m) on the flanks. Thicknesses of Pliocene strata in the Catalina Basin generally are less than 1,000 feet (305 m). At DSDP Site 467 in San Miguel Gap, early Pliocene sands are overlain by Pliocene and younger hemipelagic strata. The predominant rock types among Pliocene samples are semiconsolidated mudstone, unconsolidated mud, and minor amounts of sand. Redeposited sediment in the form of slumped material or turbidites derived from bordering ridges, banks, and islands probably is present in the Pliocene sections of many of the basins.

Faults on the outer borderland show different kinds of slip and have varying ages. The dominant trend is northwest, but there are two conspicuous east-west zones; one in the vicinity of the northern group of Channel Islands, and the other south and east of San Nicolas Island. Strike-slip is indicated on some, such as the San Clemente fault; and normal and reverse displacements are indicated on many, such as faults along the southeastern edge of Santa Cruz Basin (Junger 1976, 1979). The ages of movement interpreted from acoustic-reflection profiles range from pre-Pliocene to Quaternary. Recurrent movement probably has occurred on many of these offshore faults. Pre-middle Miocene thrust faults are inferred in the basement rocks of Santa Catalina Island.

In general, large anticlines trend west-northwest at angles oblique to the major fault zones and at places seem to be arranged en echelon. Many are very large and symmetrical and have low dips on their flanks. Examples are those that underlie Tanner Bank and the San Nicolas Island platform. Along major upwarps such as the Santa Rosa-Cortes Ridge, numerous small folds are superimposed on the larger feature but seem to die out basinward. In many places, topographic highs reflect anticlinal structures. Broad, downwarped structural lows form both Santa Cruz and San Nicolas Basins. Some anticlines deform sediments as young as Pleistocene, as in the central San Nicolas Basin; others probably are as old as Miocene, as the main anticlinal structure on northwestern Santa Rosa-Cortes Ridge, where Miocene strata truncate Paleogene strata on both limbs. An unconformity between middle Miocene and late middle Miocene sequences on the flanks of central Santa Rosa-Cortes Ridge and on the crest of Patton Ridge suggests a widespread episode of deformation in middle Miocene time in the outer borderland.

PETROLEUM GEOLOGY

Distribution and Characteristics of Petroleum in Adjacent Developed Areas

The offshore areas in the southern part of proposed OCS Lease Sale 73 are adjacent to the two largest petroleum basins in the California coastal province west of the San Andreas fault. The borderland south of 34°N latitude has an inner basin area that is, in part, an extension of the Los Angeles basin. The Santa Barbara Channel between 34° and 34°30' N latitude is the offshore continuation of the Ventura basin. Other offshore basins, however, have stratigraphic and structural characteristics that differ from those that have onshore counterparts.

As of January 1, 1975, the cumulative production from all onshore California coastal basins totaled 9.9 billion barrels of oil (11.8 billion barrels of oil + gas expressed as BOE [Barrels of Oil Equivalent]. The remaining oil reserves, plus indicated reserves, from proven fields are estimated at 2.3 billion barrels (API, 1975). Production from the coastal basins is more than half of all the petroleum found in onshore California. According to Taylor (1976), the distribution of oil resources decreases from south to north as follows: Los Angeles basin (6.7 billion bbls.); Ventura basin (2.0 billion bbls.); Santa Maria (0.6 billion bbls.); Cuyama (0.3 billion bbls.); and Salinas and the north coastal basins (0.3 billion bbls.). Petroleum is concentrated in young reservoirs with 87 percent from late Miocene or younger rocks, 5.3 percent from middle Miocene, 4.7 percent from early Miocene, 2.8 percent from Oligocene, and 0.2 percent from Eocene strata. In each of the basins, most of the known petroleum occurs in a few fields. Five giant fields account for over 52 percent of all the petroleum produced from these basins, and 24 fields, each with cumulative production greater than 75 million barrels, account for over 86 percent (8.5 billion bbls. of oil). Approximately 80 percent of the petroleum is from turbidite sandstone reservoirs, 10 percent from shallow-water sandstone, 5 + percent from fractured siliceous shale, and 5 percent from nonmarine sandstone and conglomerate beds and fractured schist basement. Most of the fields are in faulted anticlinal traps of post-Miocene age; a few are in homoclines against major faults. Only two fields (of those larger than 20 million bbls.) are stratigraphic traps; both are in the Santa Maria basin.

The Ventura basin and its seaward extension, the Santa Barbara Channel, produce from reservoirs of Eocene through Pleistocene age. Total production amounts to 2.0 billion barrels of oil (2.6 billion barrels oil + BOE). The basin differs from both the Santa Maria and Los Angeles basins in that a thick section of Upper Cretaceous and lower Tertiary beds underlies younger strata. These older rocks are believed to contain the source beds for dry gas and account for the high gas-oil ratios that are nearly twice as high in this basin as those in other California basins (Taylor, 1976). Furthermore, almost all of the petroleum in the coastal basins from Eocene and Oligocene reservoirs is from the Ventura basin, but this amounts to only 0.35 billion barrels oil plus gas as BOE. Over half of all production in the basin has come from an anticlinal trend over 25 miles long that includes the Ventura field on the east and the Dos Cuadras field in the Federal OCS to the west. Most of the production from this structural trend is from turbidite sandstone reservoirs of early Pliocene age.

The Los Angeles basin has produced 66 percent of the petroleum in the California coastal basins. The source of this oil is believed to be the thick, organically rich Miocene and younger strata that extend throughout most of the basin. Eight of the ten largest fields in the coastal basins are in the Los Angeles basin (Wilmington, Long Beach, Huntington Beach, Santa Fe Springs, Brea-Olinda, Inglewood, Dominguez, and Coyote West). Of these, two extend offshore, and produce from deep-water turbidite sandstone sequences with net sand thicknesses exceeding 1,000 feet (305 m). All are structural traps, either anticlinal or homoclinal against major faults, and many are situated along regional structural highs such as the Newport-Inglewood trend.

Appraisal of the OCS Potential

Santa Barbara Channel--As a result of exploratory drilling following the OCS sale in 1968, the Santa Barbara Channel is relatively well known. Large areas leased in OCS Lease Sale 48 are in the central and deep parts of the channel and in the waters to the west. Twenty-four tracts along the south edge of the channel were eliminated from OCS Lease Sale 48 by the Secretary of the Interior, primarily because of environmental concerns. Shows of oil and gas in deep stratigraphic test well OCS-CAL 78-164 No. 1 west of Point Conception (Menard, 1978) attest to the presence of petroleum source rocks at or near the well site. In addition, high temperature gradients measured in the well, coupled with data on vitrinite reflectance and organic geochemical studies indicate a high oil-generating capacity.

Reservoirs, chiefly sandstone beds in the Sespe Formation, that produce from beneath the Oxnard Plain east of the channel, are potential reservoirs south of the seaward extension of the Oak Ridge fault. Other possible reservoirs benath the channel are sandstone zones in the early Miocene section, fractured shales of the Monterey Formation, and inferred post-late Miocene sandstone zones. Eocene and older sandstone zones are present but may not be primary objectives. Well data on recently discovered reservoirs in the offshore Santa Clara and Oak Ridge units are confidential.

In the central deep part of the channel and westward to the 750-meter (2461 feet) isobath potential reservoirs are expected to be similar to the late Miocene or older reservoirs in the Santa Ynez Unit. Some potential reservoirs may be present in Pliocene rocks west of Point Conception and in some of the outer basins. Thick sandstone beds in the Rincon Formation, known only in the South Elwood field (Dames and Moore, 1974), form the main reservoir in that field. The fractured shale there is less important, yet is a significant prospect because of its widespread occurrence. The nonmarine Sespe Formation grades westward into a shallow-marine facies in which potentially high quality sandstone reservoirs may be present. In the same area, the early Miocene Vaqueros Formation, the main sandstone reservoir in the coastal area west of Santa Barbara, generally is thin, but local thickening may occur. Eocene sandstone zones probably are thin-bedded distal turbidites with low reservoir potential; similar sandstones have poor productive history onshore.

Within the channel, the main Pliocene turbidite reservoirs are believed to be restricted to the northeastern edge in the Dos Cuadras field and areas to the east of it. Because these sandstone zones thin abruptly southward and westward, they are considered poor prospective reservoirs in the central part of the channel.

The main source rocks are believed to be the Miocene shales that are buried deeply enough over most of the basin to have become thermally mature. Structural traps similar to those in leased areas may be present in the unleased areas.

Southern California Borderland (OCS)--OCS Lease Sales 35 and 48 held in December, 1975, and June , 1979, respectively, included much of the available area to and beyond the 750-meter (2460 feet) water depth. Much of the nearshore area adjacent to the Los Angeles basin has been leased with the exclusion of Santa Monica Bay. However, only one field, Beta in San Pedro Bay, has been developed. Twenty-six tracts offshore from San Diego County were eliminated from OCS Lease Sale 48 by the Secretary of the Interior, primarily because of environmental concerns. Appraisals of the petroleum potential of the entire borderland recently have been prepared (Vedder and others, 1976; Taylor, 1976) and supplemented by information from the deep stratigraphic test wells, OCS-CAL 75-70 No. 1 at Cortes Bank (Paul and others, 1976) and OCS-CAL 78-164 No. 1 west of Point Conception (Cook and others 1979).

In the outer basin area seaward of the Channel Islands, the deep test well at Cortes Bank provided data that seemed to enhance the petroleum potential of this part of the borderland; yet exploratory drilling done since OCS Lease Sale 35 at Dall Bank, Tanner Bank, and Cortes Bank has been discouraging. The distribution of potential reservoir sandstones seaward from Cortes Bank is unknown. Potential source rocks occur in strata of late Eocene and Miocene age in OCS-CAL 75-70 No. 1 well. Organic matter in all analyzed Tertiary rocks is immature, but the same rocks might have generated petroleum in adjacent basins if sufficiently buried to have been subjected to high temperatures. Upper Cretaceous strata, known only from three widely scattered seafloor areas of the borderland, are more than 5,000 feet (1524 m) thick in the OCS-CAL 75-70 No. 1 well at Cortes Bank; but reservoir-quality rocks are present only in the upper part, and the source-rock potential is low. The lower 3,000 feet (914 m) of section in the well, below an unconformity or fault within the Upper Cretaceous strata, contains small amounts of mature organic matter. An exploratory well drilled 8 nautical miles (15 km) northwest of Santa Barbara Island proved unproductive.

Acoustic-reflection profiles and sonobuoy refraction data (Fig. 8) (Crouch and others, 1978) indicate that thicknesses of Miocene strata may be 5,000 feet (1525 m) or more in some of the larger outer basins and geochemical analyses of Miocene samples from DSDP Site 467 and scattered bottom samples (Taylor, 1976) indicate that these strata may have a high source rock potential. Moreover, late middle Miocene through Pliocene strata within these basins may include potential reservoir rocks in the form of sandy turbidites., For example, DSDP site 467 in San Miguel Gap penetrated late middle Miocene and early Pliocene sands (Haq, Yeats, and others, 1979). Pliocene and younger hemipelagic strata that overlie these potential reservoir rocks are as much as 3600 feet (1100 m) thick at places in the outer basins (Fig. 9). Water depths in these basins, however, generally are more than 3,600 feet (1100 m).

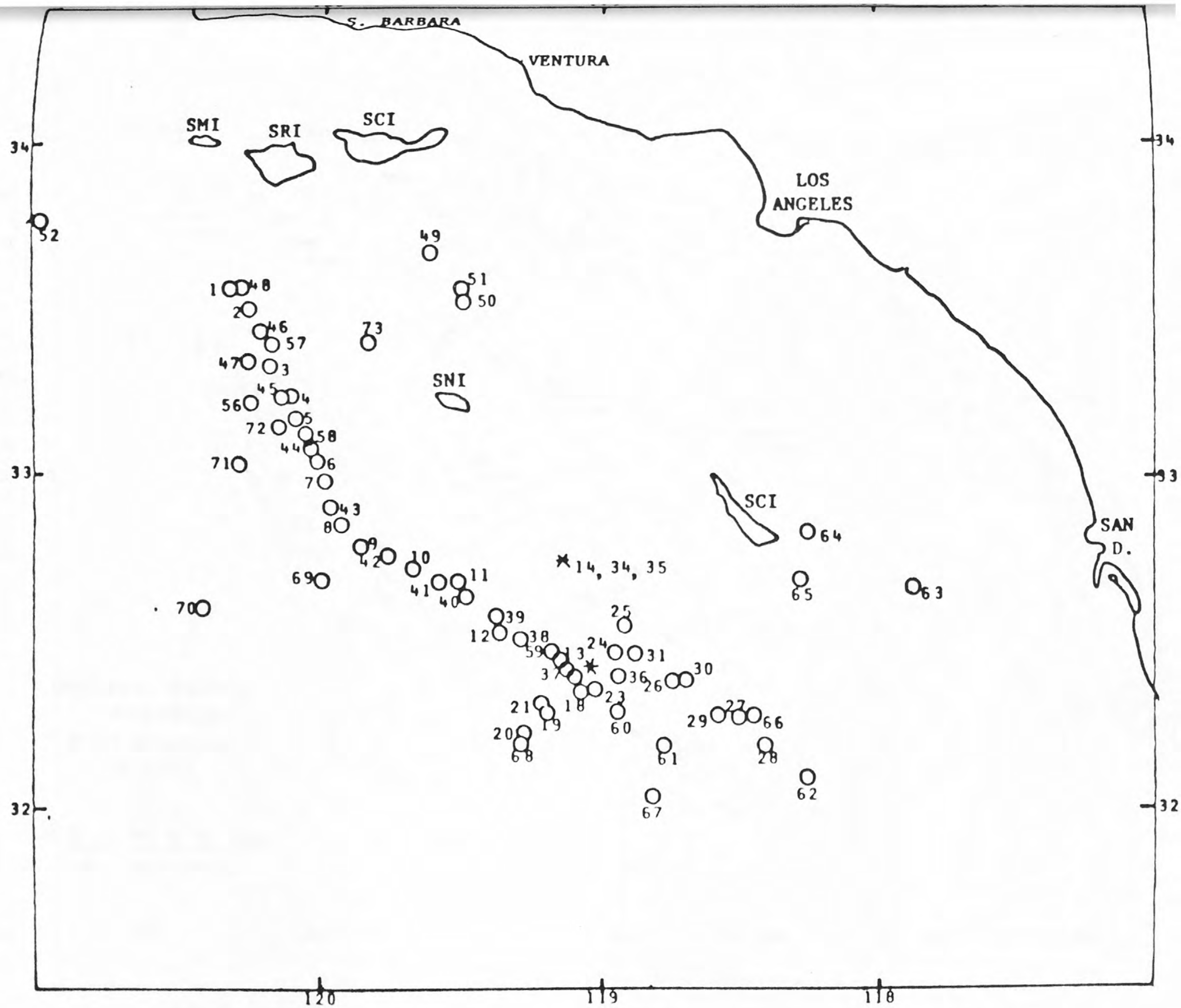

FIGURE 8 Location of sonobuoy refraction stations southern California borderland.

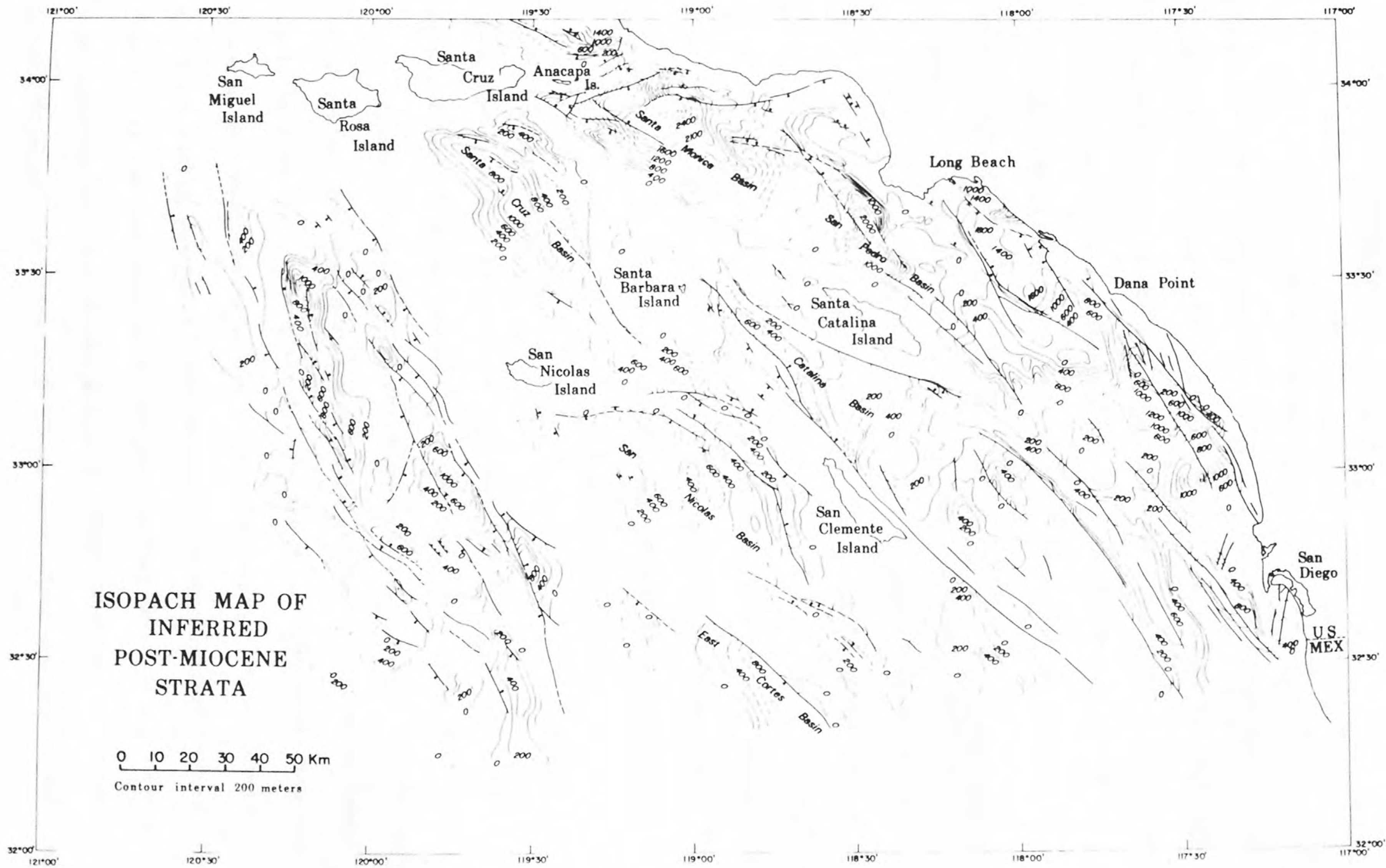

Figure 9. Revised isopach map of inferred post-Miocene strata. Modification and extension of an earlier map (Vedder and others, 1974) are based upon revisions in the San Diego Trough area and new data in the Patton Ridge-Patton Basin area. May include late Miocene and late Middle Miocene strata in some places.

ENVIRONMENTAL HAZARDS

Several areas within the southern California borderland have been investigated specifically for the delineation of potential environmental problems that could be detrimental to OCS petroleum exploration and production. These areas include the western and easternmost Santa Barbara Channel, the Santa Rosa-Cortes Ridge, Santa Monica Bay, the Gulf of Santa Catalina and the San Diego Trough. Most of the areas that have been studied in detail have been publicly reported (Vedder and others, 1969; Ziony and others, 1974; U.S. Geological Survey, 1975; Campbell and others, 1975; Greene and others, 1975; Green and others, 1978; Field and others, 1977) or are being prepared for publication. In general, the published studies are restricted to the shallow parts of the Santa Barbara Channel, to the Mugu-Santa Monica, San Pedro, and Newport-San Diego shelves, and to parts of the Santa Rosa-Cortes Ridge. The environmental phenomena assessed in these areas include faults, seismicity, sediment instability, sediment erosion and hydrocarbon seeps.

Santa Barbara Channel--The major faults in the channel region are the Santa Ynez, Red Mountain, Pitas Point, Oak Ridge--McGrath, northern and southern Santa Barbara slope, Santa Cruz Island, and Santa Rosa Island faults (Fig. 14). Several of these faults or associated faults either are active or potentially active, for they displace Holocene sediment or offset the seafloor (U.S. Geological Survey, 1975, plate 7). In the Point Conception area low-angle reverse or thrust faults define three or more major thrust sheets or nappes. These faults generally trend NW-SE in the northwestern part of the area, and E-W in the southwest part, suggesting that the area has undergone east-west compression. The thrust sheets or nappes were pushed westward during late Pliocene time. Seafloor displacement along conjugate faults and

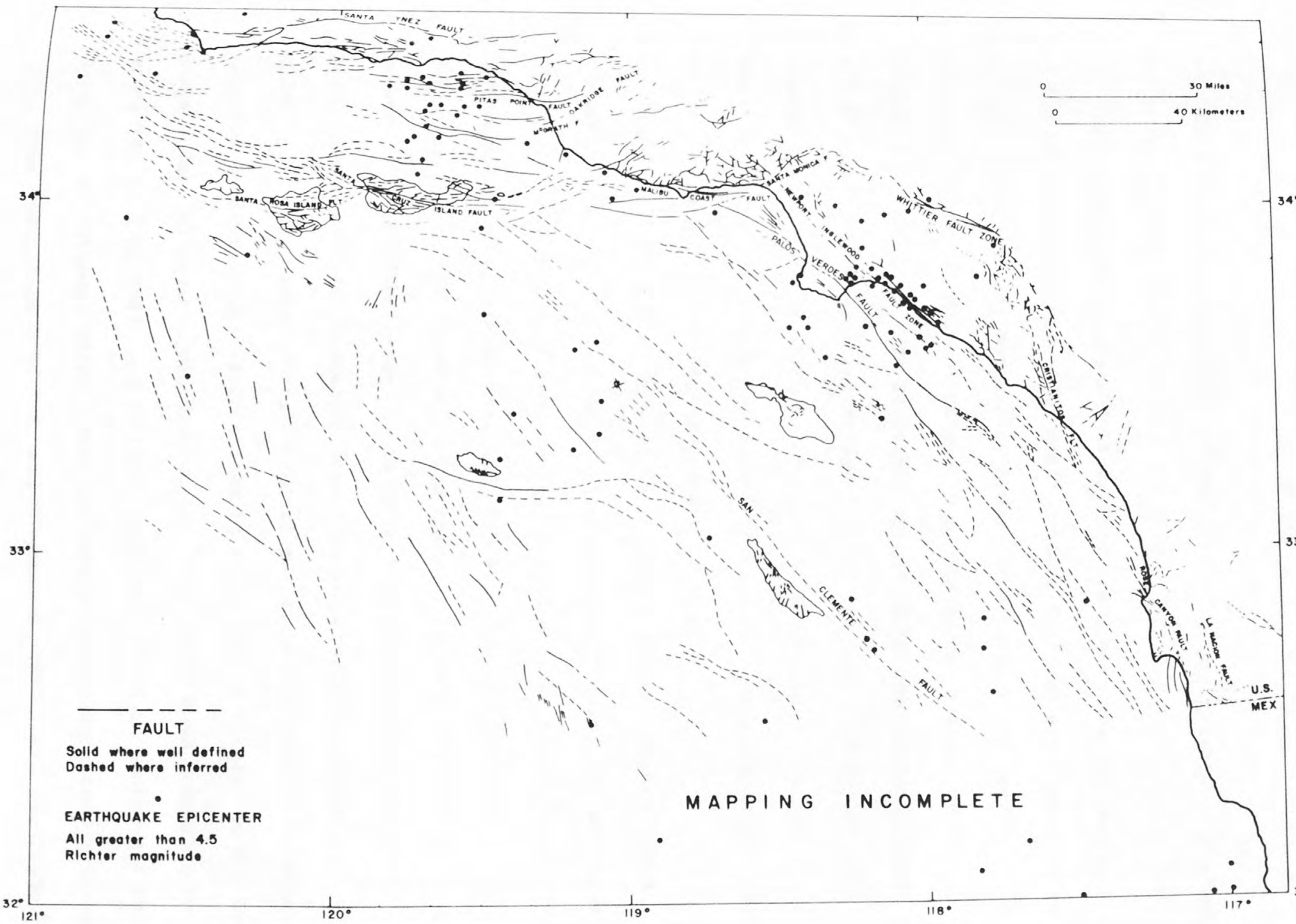

Figure 10. Map showing known and inferred faults in the coastal zone and borderland of southern California. Epicenters of earthquakes greater than Richter magnitude 4.5 are shown by solid circles for the period 1932-1973. Sources: Vedder and others, 1969; Hileman , Allen and Nordquist, 1973; Campbell and others, 1975; Greene and others, 1975; Jennings, 1975; Yerkes and Lee, 1979a; Lee and Yerkes, 1979; U.S. Geological Survey, unpublished data.

possible offset of Quaternary sediments suggest that thrusting of these nappes may be continuing today.

Many submarine slumps and landslides are present on the seafloor slopes of the Santa Barbara Channel. Most of these features are located along the mainland slope and are especially prominent between Point Conception and Goleta Point and in Hueneme Canyon (U.S. Geological Survey, 1975, fig. II-17; Greene, 1976, Fig. 4). In addition, buried disturbed strata observed in acoustic-reflection profiles at the foot of the Channel Islands platform suggest probable landsliding in the past (U.S. Geological Survey, 1975, p. II-145). In the Point Conception area a thick veneer of Pleistocene sediments is actively undergoing downslope creep and sliding.

Earthquakes recorded in the Santa Barbara Channel region indicate that the area is seismically active (Yerkes and Lee, 1979a,b; Lee and others, 1978, 1979). The epicenters of seismic events greater than Richter magnitude 4.5 that have occurred between 1932 and 1978 are shown in Figure 10. Location determinations of earthquakes in the channel prior to 1969 are imprecise because of limited coverage of the network of seismographic stations at the time. Prior to 1969, epicenter locations were probably accurate to within ± 7 miles (± 11 km). After installation of additional seismometers since 1969, location determinations were refined to ± 3 miles (± 5 km). In the Santa Barbara Channel region, six destructive earthquakes have occurred; in 1812, 1821, 1925, 1927, 1941, and at Point Mugu in 1973 (U.S. Geological Survey, 1975; Lee and others, 1979). The two largest events occurred on December 21, 1821, (est. magnitude 7 to 7.5) and November 4, 1927 (est. magnitude 7.3). The epicenters for both events are poorly known. Reports of tsunamis associated with these events indicate that they were centered somewhere in the western Santa Barbara Channel and that dipslip or landsliding occurred at the seafloor (Yerkes, written commun., 1979). Previously the maximum credible earthquake predicted for the area is one of Richter magnitude 6 with a recurrence interval of approximately 20 years (U.S. Geological Survey, 1975), however, if the estimated magnitudes of the 1821 and 1927 events are correct, this estimate is probably to low. The study by Lee, Yerkes, and Simirenko (1979) shows that epicenters are distributed along the east-trending reverse faults with clusters of relatively high seismicity in the central and northeast parts of the channel. Locally, well-located earthquakes and well-constrained fault plane solutions can be associated geometrically with specific east-trending reverse faults such as the mid-channel, Pitas Point-Ventura, Red Mountain and Anacapa faults.

Although the Santa Barbara Channel lies in a seismically active region and the physiography is such that inundation by run-up is possible, especially in the Oxnard Plain area, few tsunamis are documented. Prior to 1967, only five locally generated tsunamis had been recorded in the channel region; these were reported in Santa Barbara in 1812, 1821, 1854, 1896?, and 1927 (Iida and others, 1967; Yerkes, written commun., 1979). No extensive property damage or loss of lives were reported.

Natural hydrocarbon seeps are reported offshore from Coal Oil Point and Point Conception in the Santa Barbara Channel (U.S. Geological Survey, 1975). More than 900 individual seeps have been mapped in a 7 mi (18 km^2) area off Coal Oil Point (Fischer and Stevenson, 1973), and additional seeps occur on the northern shelf of the northern Channel Islands (Wilkinson, 1971).

Quaternary sediments apparently are being actively eroded along the mainland shelf off Carpinteria, Coal Oil Point near Gaviota, and Point

Conception (U.S. Geological Survey, 1975). Erosion and transport of Holocene sediments seems to be taking place along the sill that separates the Santa Barbara Basin from the Santa Monica Basin (Greene and others, 1978; Edwards and Gorsline, 1978).

Borderland, inner basins and banks--In the Mugu-Santa Monica and San Pedro shelf areas, detailed geophysical investigations of geology, structure, and geologic hazards have been made, and the findings are reported by Wagner and Junger (1977), Greene and others (1975), Field and others (1977). Geological environmental studies are underway for the Newport-San Diego shelf.

Two major fault zones transect the inner basins and banks area; they are the Palos Verdes Hills-Coronado Bank and Newport-Inglewood-Rose Canyon fault zones (Fig. 14). Based on offsets in the seafloor and young (Holocene) sediments, many faults associated with these zones may be active (Ziony and others, 1974; Jennings, 1975; Greene and others, 1979). Most of the active faults in the Mugu-Santa Monica shelf area are short and discontinuous. The Malibu Coast fault in the northern part of the area probably is the longest and most likely to generate major earthquakes. In the San Pedro shelf area, active faults seem to be a major geologic hazard. Probably the most important is the offshore extension of the Palos Verdes Hills-Coronado Bank fault zone, branches of which extend for 110 miles (177 km) across the Palos Verdes peninsula, San Pedro shelf and Gulf of Santa Catalina, and locally offset the seafloor. Earthquake epicenters along this zone verify its continuing activity. Many other faults that extend upward to the seafloor must be considered environmentally hazardous, as they cut beds of Holocene age (Wagner and Junger, 1977; Greene and others, 1975, plate 13; Greene and others, 1979; Fig. 1).

Areas known to be prone to submarine sliding occur in the submarine canyons and mainland slope of the entire coast from Pt. Mugu to San Diego. Large zones of mass movement have been documented on the slopes of the Hueneme-Mugu shelf (Greene and others, 1978), Santa Monica Bay (Haner and Gorsline, 1978), off Point Fermin (Greene and others, 1975) and off Dana Point. (Field and Edwards, in preparation). Unconsolidated Quaternary deposits are as much as 600 feet (183 m) thick in the vicinity of Santa Monica Bay, and most of the San Pedro shelf is covered with similar flat-lying sediments.

The inner basin and banks area is moderately active seismically (Fig. 14), and seismicity is most prominent in the offshore area between Point Mugu and Point Dume, in the vicinity of the Malibu Coast fault, along the offshore parts of the Palos Verdes Hills-Coronado fault zone, and in areas adjoining the Newport-Inglewood-Rose Canyon fault zone (Greene and others, 1975, plates 10, 13). Predictions of maximum credible earthquakes and their recurrence intervals have not been made for the inner basins and banks. Only a few locally generated tsunamis have been recorded along the coast between Point Mugu and the Mexican border and none of these caused major damage; one was noted in 1879 at Santa Monica, and two others were reported in 1925 (uncertain) and 1933 at Long Beach (Iida and others, 1967). The 1933 seismic seawave resulted from the March 10, 1933 Long Beach earthquake. Because the area is seismically active, inundation of the coastal lowlands possibly could result from tsunamis generated locally or distantly.

Oil and gas seeps have been reported in the northen part of Santa Monica Bay, along the probable extension of the Malibu Coast fault, in southern Santa Monica Bay along the probable extension of the Palos Verdes fault, and offshore between Point Vicente and Point Fermin (Greene and others, 1975, plates 10, 13). Wilkinson (1971) shows two oil seeps and one gas seep in the San Pedro shelf area.

Borderland, outer basins and banks--Few reports have been published on geological environmental problems on the outer part of the borderland and the area south of 32°N, which is included in a proposed lease sale for the first time, is largely unsurveyed. Geological hazards on the northern part of the Santa Rosa-Cortes Ridge and Tanner-Cortes Banks are described by Greene and others (1975), Field and Clarke (1979), Field and Richmond (in press), and Nardin and others (1979); a detailed analysis of the central part of Santa Rosa-Cortes Ridge and San Nicolas platform is in preparation.

The longest Quaternary fault mapped in the outer basins and banks area is the San Clemente fault; the northwestern segment is 50 miles (80 km) long and the southeastern segment, more than 15 miles (24 km) long (Jennings, 1975). Recent submersible dives in the vicinity of this fault, off the southern end of San Clemente Island provided data on recent seafloor breaks that may be associated with movement on the San Clemente fault. Many other smaller faults cut the area, and some apparently are active (Fig. 10). The Santa Rosa-Cortes Ridge in particular seems to be tectonically unstable. Faults are common along the ridge crest where relatively small apparent vertical separations are characteristic (Greene and others, 1975, plate 5; Field and Richmond, in press). Beneath the flanks of the ridge, faults are less numerous but are longer and have greater apparent vertical separations than those on the crest. Seafloor offsets above displaced seismic reflectors suggest that some faults are active. In the Tanner-Cortes Banks area, faults are concentrated along the northern flank of Cortes Bank and along the southern edge of the ridges and troughs between the two banks (Greene and others, 1975, plate 2). Many of these faults displace either Holocene sediments or the sea floor.

Numerous submarine slumps and sediment slides have occurred along the flanks of the Santa Rosa-Cortes Ridge from Santa Rosa Island to Tanner-Cortes Banks. Recurrent slumping is likely because slopes are relatively steep (4°-7°), and unconsolidated Holocene sediments are locally thick. The failure zones vary in size from large slumps measuring several km^2 (Field and Richmond, in press) to small features measuring hundreds of m^2 (Field and Clarke, 1979). The bank and ridge tops are characterized by exposures and subcrops of pre-Quaternary bedrock locally overlain by a thin veneer or small pockets of unconsolidated Holocene sediments, and sediments in these areas are generally stable.

The Santa Rosa-Cortes Ridge area is moderately active seismically. Most of the earthquake epicenters in this area are randomly scattered, but there is some clustering south of South Point on Santa Rosa Island (Hileman and others, 1973; Greene and others, 1975, Plate 5). Most of the earthquakes in this region have been estimated to be between 2.5 and 4.5 Richter magnitude. During a four-year period betwen 1970 and 1973, the USGS seismic network recorded 11 earthquakes beneath the northern ridge ranging from less than 2.5 to greater than 3.5 Richter magnitude (Greene and others, 1975). Several earthquakes have been reported in the vicinity of the San Clemente fault. In 1941, a Richter magnitude 5.9 to 6.0 earthquake was recorded from an area near the southeastern extension of this San Clemente fault (Lamar and others, 1973). Significant earthquakes also have been reported from the vicinity of San Nicolas Island. Because Tanner and Cortes Banks lie beyond the limits of the seismographic network there are no reliable epicenter data and thus no estimates of maximum credible earthquakes and recurrence intervals. Tsunamis have not been reported in the outer basins and banks region of the borderland. However, some of the ridges, banks, and island platforms lie in shallow water, and the generation of seismic seawaves in this region could pose a hazard to engineering structures or coastal facilities.

Although no oil and gas seeps have been reported on the Santa Rosa-Cortes Ridge and Tanner-Cortes Banks areas, the combined presence of hydrocarbons in the sediments and a large number of faults suggest that surface seeps and subsurface gas-charged sediments may be present. Proprietary data tend to confirm this possibility.

Distribution of sediment types on the northern part of the Santa Rosa-Cortes Ridge (clastic sands on the edges, foraminiferal sands in the center) suggests that bottom currents may be strong on the perimeter and weaker in the center. Both the sparse sediment cover on the ridge top, due to the isolation from sediment sources, and the abundance of rocky outcrops devoid of sediment along the axis of the ridge suggest the influence of strong current activity (Greene and others, 1975, plates 8, 9; Field and Richmond, in press). On Tanner and Cortes Banks, strong current activity is suggested by areas of exposed bedrock and by the thinness of the sediment cover over much of the nearby area (Greene and others, 1975, plates 1, 2, 4). The low silt and clay content, relatively good sorting, and coarseness of bank-top sediments also suggest current action, although the coarseness is partly a reflection of the abundant supply of coarse biogenic debris.

Secondary effects, such as seafloor subsidence resulting from fluid withdrawal should be investigated before oil field development, but are beyond the scope of this report.

REFERENCES CITED IN CHAPTER A

Adams, M. V., John, C. B., Kelley, R. F., LaPointe, A. E., and Meuer, R. W., 1975, Mineral resource management on the Outer Continental Shelf: U.S. Geol. Survey Circ. 720, 32 p.

American Petroleum Institute, 1975, Reserves of crude oil, natural gas liquids, and natural ga in the United States and Canada and the United States productive capacity as of December 31, 1974: Am. Petroleum Inst., v. 29, May 1975, 254 p.

Beyer, L. A., 1980, Offshore southern California in Oliver, H. W., ed., Interpretation of the preliminary gravity map of California and its continental margin: California Division of Mines Bulletin (in press).

Bureau of Land Management, 1975, Final environmental statement, proposed 1975 Outer Continental Shelf oil and gas general lease sale, offshore southern California: 5 vols.

Campbell, R. H., Wolf, S. C., Hunter, R. E., Lee, W. H. K., Ellsworth, W. L., Wagner, H. C., Vedder, J. G., and Junger, Arne, 1975, The Santa Barbara Channel region, a review (abs.): Geol. Soc. America, Abstracts with Programs, v. 7, no. 3, p. 301-302.

Cook, H. E., ed., 1979, Geologic studies of the Pt. Conception Deep Stratigraphic Test Well OCS-CAL 78-164 No. 1, Outer Continental Shelf, Southern California: U.S.G.S. Open-File Report 79-1218, 148 p.

Crouch, J. K., 1978, Neogene tectonic evolution of the California Continental Borderland and western Transverse Ranges: U.S.G.S. Open-File Report 78-606, 23 p.

Crouch, J. K., Holmes, M. L., McCulloh, T. H., Long, A. T., and Brune, R. H., 1978, Multichannel seismic reflection and sonobuoy data in the outer Southern California Borderland: U.S.G.S. Open-File Report 78-706, 24 p.

Curran, J. F., Hall, K. B., and Herron, R. F., 1971, Geology, oil fields, and future petroleum potential of Santa Barbara Channel area, California, in Cram, I. H., ed., Future petroleum provinces of the United States--their geology and potential: Am. Assoc. of Petroleum Geologists Mem. 15, v. 1, p. 192-211.

Dames and Moore, 1974, Resumption of drilling operations in the South Ellwood offshore oil field from Platform Holly, final environmental impact report: California State Lands Comm., 3 vols., 1561 p.

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

_____, 1966, Geology of the central Santa Ynez Mountains, Santa Barbara County, California: California Div. Mines and Geology Bull. 186, 99 p.

Edwards, B. D. and Gorsline, D. S., 1978, New Evidence of current winnowing activity on Hueneme Sill, California Continental Borderland (abs.): 1978 Annual meeting AAPG-SEPM program, 9-12 April, Oklahoma City, p. 62.

Ellsworth, W. L., and others, 1973, Point Mugu, California, earthquake of 21 February 1973 and its aftershocks: Science, v. 182, no. 41127, p. 1127-1129.

Field, M. E., Clarke, S. H., Jr., and Greene, H. G., 1977, Evaluation of geological hazards in OCS Petroleum lease areas, southern California Continental Borderland: Proceedings of Offshore Technology Conference, Houston, Texas, 11 p.

Field, M. E. and Clarke, S. H., Jr., 1979, Small-scale slumps and slides and their significance for basin slope processes, southern California borderland, in Doyle, L. J. and Pilkey, O. H., eds., Geology of continental slopes: SEPM Spec. Publ., No. 27.

Field, M. E. and Richmond, W. A., in press, Sedimentary and structural patterns on the northern Santa Rosa-Cortes Ridge, southern California Marine Geology.

Fischer, P. J., and Stevenson, A. J., 1973, Natural hydrocarbon seeps along the northern shelf of the Santa Barbara Basin, California: Am. Assoc. Petroleum Geologists, Soc. Econ. Paleontologists and Mineralogists, and Soc. Explor. Geophysicists, Pacific Secs., Guidebook, Joint Ann. Meeting p. 17-28, Fifth Annual Offshore Technology Conf., Houston, Texas, Paper No. OTC-1738.

Greene, H. G., 1976, Late Cenozoic geology of the Ventura basin, California, in Howell D. G., ed., Aspects of the geologic history of the California Continental Borderland: Am. Assoc. Petroleum Geologists, Pacific Section, Misc. Pub. 24, p. 499-523.

Greene, H. G., Bailey, K. A., Clarke, S. H., Jr., Ziony, J. I., and Kennedy, M. P., 1979, Implications of fault patterns of the inner California Continental Borderland between San Pedro and San Diego, Field trip guidebook, geologic hazards in San Diego: Geol. Soc. America, 1979, Ann. meeting, San Diego, California.

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 southern California borderland: U.S. Geol. Survey Open-File Report 75-596, 70 p., 16 plates.

Haq, B., Yeats, R. S. and others, 1979, Eastern Pacific boundary currents: Geotimes, v. 24, No. 4, p. 30.

Hileman, J. A., Allen, C. R., and Nordquist, J. M., 1973, Seismicity of the southern California region: California Institute of Technology, Division of Geology and Planetary Sciences, Contr. No. 2385, 487 p.

Howell, D. G., 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: Am. Assoc. Petroleum Geologists Misc. Pub. 24, p. 392-416.

Howell, D. G. and Vedder, J. G., in press, Structural implications of stratigraphic discontinuities across the souther California borderland, in W. G. Ernst, ed., The Geotectonic development of California, Rubey Vol. No. 1.

Iida, Kumizi, Cox, C. Doak, and Pararas-Carayannis, George, 1967, Preliminary catalog of tsunamis occurring in the Pacific Ocean: Data Rept. No. 5, HIG-67-10, Hawaii Institute of Geophysics, Univ. Hawaii.

Jennings, C. W., 1975, Fault map of California, Geologic data map series, Map No. 1: California Div. Mines and Geology, scale 1:750,000.

Junger, Arne, 1976, Tectonics of the southern California borderland, in Howell, D. G., ed., Aspects of the geologic history of the California Continental Borderland: Am. Assoc. Petroleum Geologists Pacific Section, Misc. Pub. 24, p. 486-529.

_____, 1979, Maps and seismic profiles showing geologic structure of the northern Channel Islands Platform, California Continental Borderland: U.S.G.S. Misc. File-991.

Junger, Arne, and Wagner, H. C., 1977, Geology of the Santa Monica and San Pedro Basins, California Continental Borderland: U.S. Geol. Survey Misc. Field Studies Maps MF-820.

Lamar, D. L., Merifield, P. M., and Proctor, R. J., 1973, Earthquake recurrence interval on major faults in southern California; in Moran, D. E., Slosson, J. E. Stone, R. O., and Yelverton, C. A., eds., Geology, seismicity and environmental impact: Assoc. Engineering Geologists Spc. Publ., Oct. 1973, p. 265-276.

Lee, W.H.K., and Vedder, J. G., 1973, Recent earthquake activity in the Santa Barbara Channel region (California): Seismol. Soc. America Bull., v. 63, no. 5, pg. 1757-1773.

Lee, W.H.K., Johnson, C. E., Henyey, T. L., and Yerkes, R. F., 1978, A preliminary study of the Santa Barbara, California, earthquake of August 13, 1978, and its major aftershocks: U.S. Geol. Survey Circular 797, 11 p.

Lee, W.H.K., Yerkes, R. F., and Simirenko, M., 1979, Earthquake activity and Quaternary deformation of the western Transverse Ranges, California: U.S. Geol. Survey Circular 799-A, 26 p.

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: Am. Assoc. Petroleum Geologists, Pacific Sections, Misc. Pub. 24, p. 241-253.

Menard, H. W., 1978, Stratigraphic test well yields oil and gas "show" offshore California: U.S. Geol. Survey News Release, November 1, 1978, 2 p.

Nardin, T. R., Edwards, B. D., and Gorsline, D. S., 1979, Santa Cruz Basin, California: Dominance of slope processes in basin sedimentation, in Doyle, L. J., and Pilkey, O. H., eds., Geology of continental slopes: SEPM Spec. Paper No. 27.

Paul, R. G., and others, 1976, Geological and operational summary, southern California deep stratigraphic test OCS-CAL 75-70 No. 1, Cortes Bank area offshore southern California: U.S. Geol. Survey Open-File Report 76-232, 65 p.

Smith, Glynn D., 1979, Drill ship sets two world records: Offshore Vol. 39, No. 6 pp. 39-40.

Stillwell, J., and Lange, D., 1979, 24 Firm's Profits Hit Record $13.4 Billion: Oil and Gas Journal, Vol. 77, No. 9, p. 42.

Taylor, J. C., 1976, Geologic appraisal of the petroleum potential of offshore southern California: The borderland compared to onshore coastal basins: U.S. Geol. Survey Circ. 730, 43 p.

U.S. Department of the Interior, 1976, Leasing and management energy resources on the Outer Continental Shelf: Bureau of Land Management/Geological Survey, USGS: INF-74-33.

U.S. Geological Survey, Department of the Interior, 1975, Oil and gas development in the Santa Barbara Channel, Outer Continental Shelf, California: U.S. Geol. Survey, Dept. of the Interior Final Environmental Statement, 3 vols.

Vedder, J. G., Beyer, L. A., Durham, D. L., Junger, Arne, McCulloh, T. H., Roberts, A. E., Taylor, J. C., and Wagner, H. C., 1974a, Geological inferences and mineral resource potential of the California Continental Borderland north of Mexico-U.S. boundary: Special Admin. Report to Director, Bureau of Land Mangement, January , 1974, 68 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. Geol. Survey Misc. Field Studies Map MF-624, 34 p., 9 sheets.

Vedder, J. G., Wagner, H. C., and Schoellhamer, J. E., 1969, Geological framework of the Santa Barbara Channel region, in geology, petroleum development, and seismicity of the Santa Barbara Channel region, California: U.S. Geol. Survey Prof. Paper 679-A, 11 p.

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

Vedder, J. G., Taylor, J. C., Arnal, R. E., and Bukry, David, 1976b, Maps showing locations of selected pre-Quaternary rock samples from the California Continental Borderland: U.S. Geol. Survey Misc. Field Studies Map MF-737, 3 sheets.

Vedder, J. G., Greene, H. G., Scott, E. W., Taylor, J. C., and others, 1976c, A summary report of the regional geology, petroleum potential, environmental geology and technology for exploration and development in the area of proposed Lease Sale 48, California Continental Borderland: U.S.G.S. OPen-File Report 76-787.

Vedder, J. G., Crouch, J. K., Arnal, R. E., Bukry, David, Barron, J. A., and Lee-Wong, F., 1977, Descriptions of pre-Quaternary samples, R/V Ellen B. Scripps, September, 1976, Patton Ridge to Blake Knolls, California Continental Borderland: U.S. Geol. Survey Open-File Report, 77-474, 19 p.

Vedder, J. G., Arnal, R. E., Bukry, David, Barron, J. A., and Lee-Wong, F., 1979, Descriptions of dart core samples, R/V Samuel P. Lee cruise L2-78-SC, May 1978, California Continental Borderland: U.S. Geol. Survey, Open-File Report 79-936, 46 p.

Vedder, J. G., Crouch, J. K., Scott, E. W., Greene, H. G., Cranmer, D., Ibrahim, M., Tudor, R. B., and Vinning, G., 1980, A Summary report on the regional geology, petroleum potential, environmental geology, and operational considerations in the area of proposed Lease Sale No. 68, offshore southern California: U.S. Geolog. Survey Open-File Report 80-198, 62 p.

Weaver, D. W., 1969, Geology of the Channel Islands: Am. Assoc. Petroleum Geologists and Soc. Econ. Paleontologists and Mineralogists, Pacific Section, Spec. Pub., 200 p.

Weaver, D. W., Doerner, D. P., and Nolf, B., 1969, Geology of the northern Channel Islands: Am. Assoc. Petroleum Geologists, and Soc. Econ. Paleontologists and Mineralogists, Pacific Section, Spec. Pub., 200 p.

Wilkinson, E. R., 1971, California offshore oil and gas seeps: California Div. Oil and Gas, California Oil Fields--Summ. Report, 11 p. 1972.

Yerkes, R. F., and Lee, W. H. K., 1979a, Maps showing faults and fault activity, and epicenters, focal depths and focal mechanisms for 1970-1975 earthquakes, western Transverse Ranges, California: U.S. Geol. Survey Misc. Field Studies Map MF 1032.

_____, 1979b, Late Quaternary deformation in the western Transverse Ranges, California, in Earthquake Activity and Quaternary Deformation of the Western Transverse Ranges, Calif: U.S.G.S. Circ. 799-B.

Ziony, J. I., Wentworth, C. M., Buchanan, J. M., and Wagner, H. C., 1974, Preliminary map showing recency of faulting in coastal southern California: U.S. Geol. Survey Misc. Geol. Inv. Map, 585.

CHAPTER B

REGIONAL GEOLOGY, PETROLEUM POTENTIAL, AND ENVIRONMENTAL GEOLOGY IN THE NORTHERN PART OF PROPOSED LEASE SALE 73, OFFSHORE CENTRAL AND NORTHERN CALIFORNIA

By

D. S. McCulloch, S. H. Clarke, Jr., M. E. Field,

and P. A. Utter

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REGIONAL GEOLOGY, PETROLEUM POTENTIAL, AND ENVIRONMENTAL GEOLOGY IN THE NORTHERN PART OF PROPOSED LEASE SALE 73, OFFSHORE CENTRAL AND NORTHERN CALIFORNIA

INTRODUCTION

This chapter summarizes the regional geologic framework, petroleum potential, and environmental geology that will affect exploration and development in the northern part of proposed area OCS Lease Sale 73. Coverage ranges from detailed, closely spaced geophysical surveys along parts of the coast line, to widely spaced reconnaissance of areas further offshore (Appendix). In areas where no survey data are available, the summary is drawn entirely from the literature.

The part of proposed OCS Lease Sale 73 described in this chapter encompasses the entire continental shelf of central and northern California, north of Point Conception. It is bounded on the northeast by the State of California OCS three-mile limit, on the southeast by latitude 34.50° north, on the southwest by the 2500 meter isobath, and on the northwest by latitude 42.50° north (Fig. 1).

The geology and environmental hazards in Eel River basin were written by S. H. Clarke, Jr., and M. E. Field respectively. Figures were prepared by P. A. Utter, and the balance of the report was prepared by D. S. McCulloch.

REGIONAL GEOLOGIC FRAMEWORK

General Setting

The central and northern California part of proposed OCS lease sale 73 contains five basins that lie on the shelf or partially on the adjacent continental slope (Fig. 1). In late Cretaceous time, before the basins existed, the Farallon lithospheric plate, which lay between the obliquely

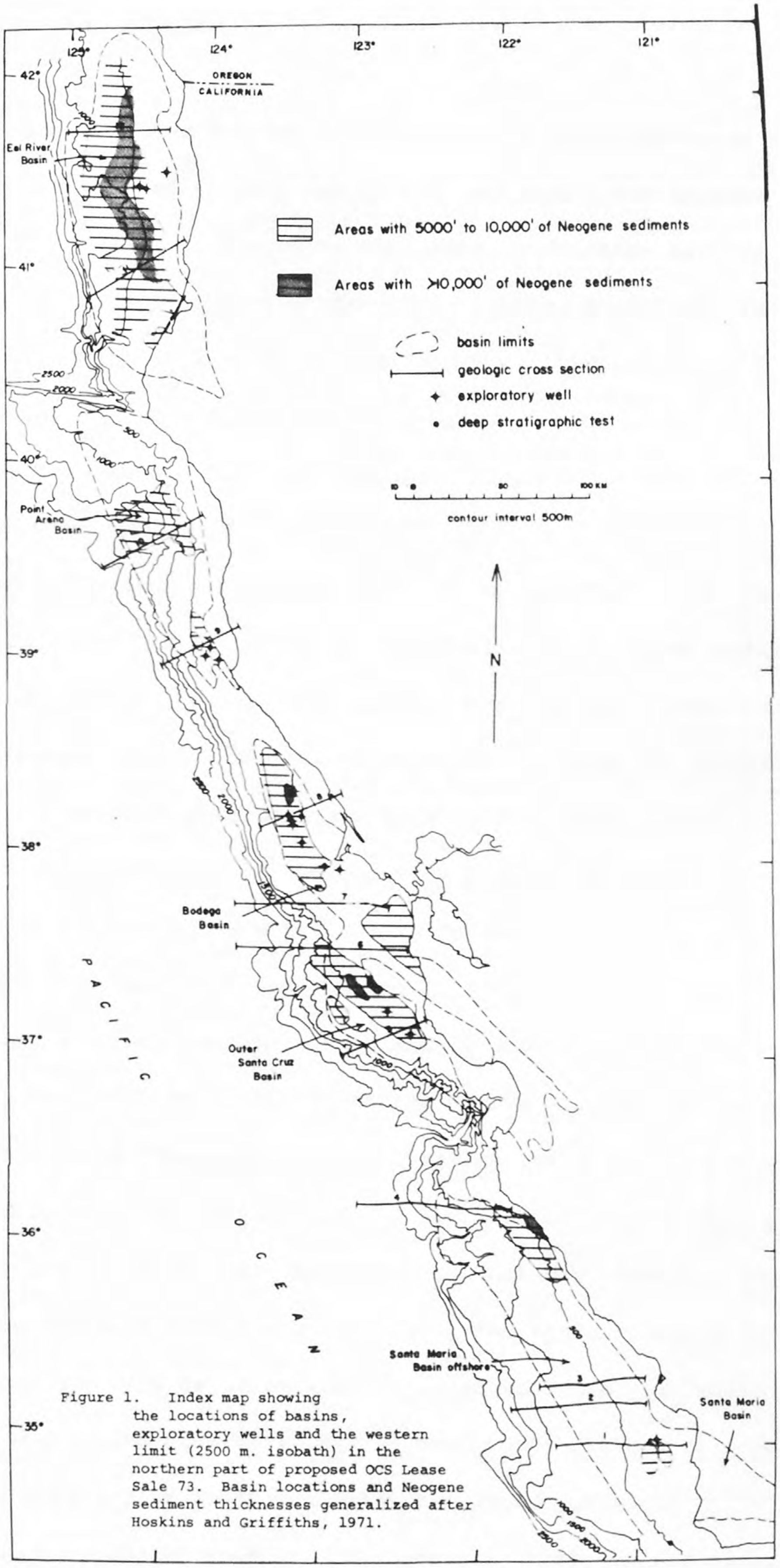


Figure 1. Index map showing the locations of basins, exploratory wells and the western limit (2500 m. isobath) in the northern part of proposed OCS Lease Sale 73. Basin locations and Neogene sediment thicknesses generalized after Hoskins and Griffiths, 1971.

converging North American and Pacific plates, was being subducted along the western margin of the North American Plate. Following the contact of the North American and Pacific plates to the south, subduction was replaced from south to north by right-lateral strike-slip faulting resulting from the differences in motion of the two plates (Atwater, 1970; Morgan, 1968). Strike slip faulting along the San Andreas and associated faults persists as far north as Cape Mendocino. North of the cape, the small Gorda-Juan de Fuca Plate is now being subducted.

Granitic and gneissic basement rocks of the Salinian block (Reed, 1933, Page, 1970) underlie the northwest-trending Salinian provence onshore, and extend offshore to form the basement beneath the central third of the central-northern California shelf. This block is separated from the cordilleran on the east by the San Andreas fault, and from the Nacimiento block on the west by the Sur-Nacimiento fault. As Ross (1978) pointed out, the Salinian block is an allocthon surrounded, and probably underlain by, Franciscan rocks (Ross and McCulloch, 1979) and contrary to generally accepted models its source probably is not the cordilleran to the east from which it differs significantly but it, like rocks in central Alaska, (Jones and others, 1976) may have been carried thousands of kilometers to the north by pre-Neogene strike slip displacement. Preliminary paleomagnetic work (Champion and others, in press) suggests that the Salinian block may have lain as much as 2500 km to the south in late Cretaceous time, and study of upper Cretaceous sedimentary rocks on the Salinian and the adjacent Nacimiento block has suggested to Howell and others (in press) that these blocks, originally juxtaposed by strike slip faulting, were then moved northward together, and arrived at the latitude of southern California by early Eocene time.

Caught between the two major plates, the Salinian block is not only bounded by major faults, but right lateral shear forces exerted on the block have produced considerable internal strike-slip faulting (e.g., Johnson and Normark, 1974; Ross, 1973; Ross and Brabb, 1973; Kistler and Peterman, 1973).

North and south of the Salinian block the shelf is generally thought to be underlain by Jurassic, Cretaceous and early Tertiary(?) marine metasediments considered to belong to the Franciscan assemblage. High seismic velocities in the metasediments, their degree of deformation, their metamorphic grade and a widespread angular unconformity that separates them from younger rocks indicate that they were once more deeply buried, and that a considerable part of their erosional history occurred in late Cretaceous or early Tertiary time (Hoskins and Griffiths, 1971). Following erosion marine sedimentation proceeded through early Tertiary time (Eocene and Oligocene?), but renewed deformation and erosion that preceeded a shelf-wide mid-Tertiary marine transgression left only remnants of lower Tertiary deposits. These transgressive deposits (lower and middle Miocene) covered most of the present continental shelf, and in places, part of the adjacent slope.

Deformation through the mid Tertiary was related to subduction, however, in upper mid-Miocene time, a change in tectonic forces initiated the formation of both the shelf as we now know it and the present shelf basins. Basement ridges were uplifted generally along the outer margin of the shelf (Curray, 1966) to form the seaward margins of the geologically young, shallow-shelf basins that are the present targets of petroleum exploration. Blake and others (1978) suggested that the shallow shelf basins may have been produced by a change in relative plate motion that resulted in extension of the plate boundary. Recalculation of relative plate motion using more recent poles does not demand extension (Eli Silver, oral comm., 1980) and Howell and others (1980), citing the evidence for strike slip and compression during basin formation, have attributed basin origin to an interval of wrench tectonics. The shelf basins acted as depocenters for marine sedimentation more-or-less continuously until late Pliocene time. Most basins contain down-to-basement normal or high angle reverse faults along their eastern margins consistent with right-lateral shear, and most exhibit late Tertiary or Quaternary compressional folding. Deposition prior to mid-Miocene may have been similarly limited by shelf-edge structures, but the location and character of these features are not known.

Santa Maria Basin Offshore.--The southernmost basin in the area of proposed OCS Lease Sale 73 measures approximately 40 km x 230 km and is elongate parallel to the coast (Fig. 2). It is bounded on the northeast by Franciscan basement rocks that have been elevated along major coastal faults, and on the southwest by the shallow Santa Lucia Bank formed by the Santa Lucia High, a structural block that is bounded on the east by the Santa Lucia Bank Fault. The northwest end of the basin continues onto the continental slope. The basin shallows to the south as it approaches the western end of the Transverse Range, but it continues south and east, and joins the western end of the Santa Barbara basin on the south side of the Transverse Range. The basin structure effectively truncates the western end of the Transverse Range. Geophysical evidence also suggests such a termination. A gravitational low associated with the Santa Barbara basin has been mapped as continuing to the northwest around Points Conception and Arguello into the southern end of the offshore Santa Maria basin (Larry Beyer, oral comm., 1979) and northwest-trending aeromagnetic anomalies that parallel Transverse Range structures in the Point Sal area are truncated along a magnetic anomaly associated with the Hosgri Fault (McCulloch and Chapman, 1977).

Basement rocks exposed along the shore are Franciscan-Knoxville rocks of

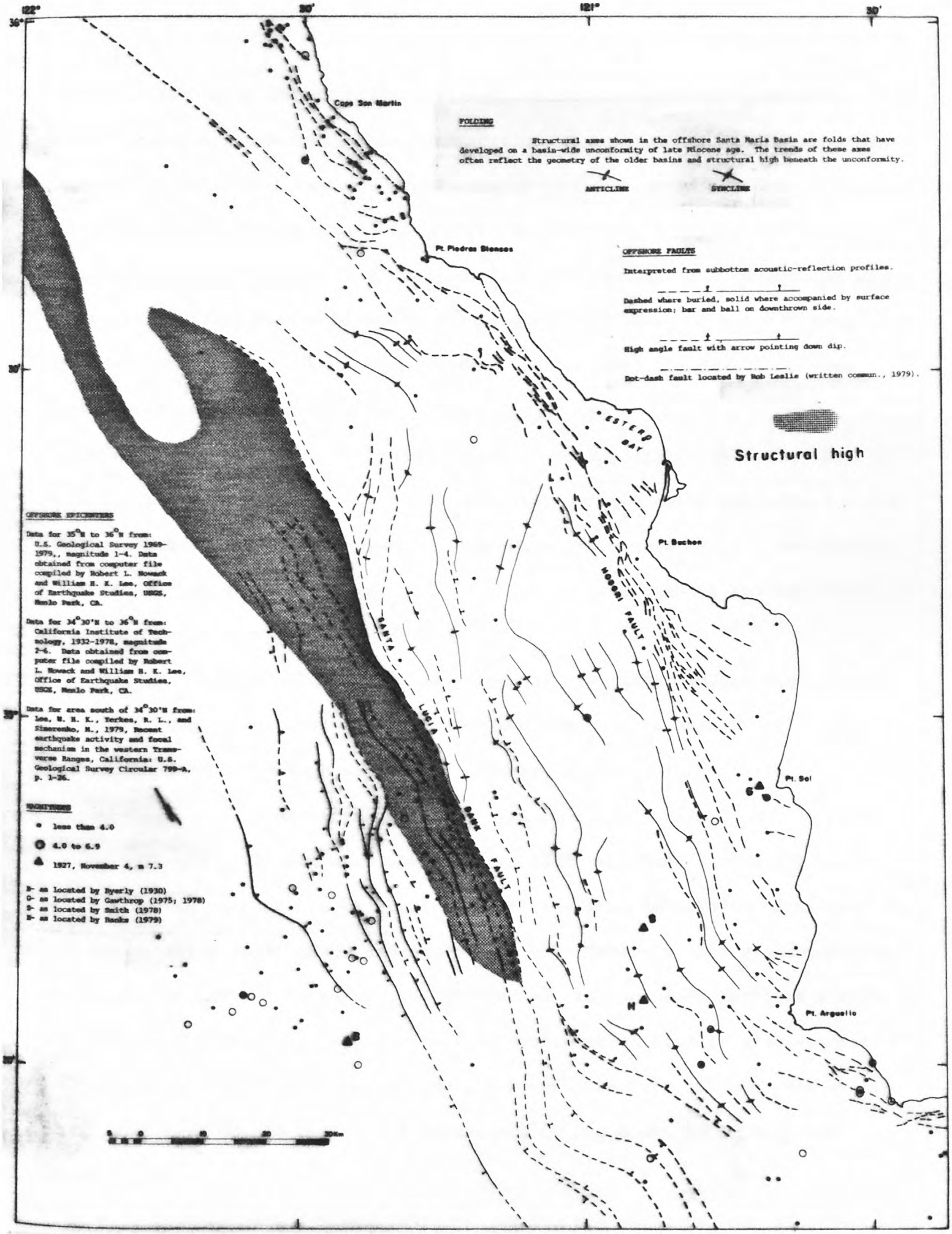


Figure 2. Faults, Post-Late Miocene Folds and Epicenters in the Offshore Santa Maria-Point Arguello area, California.

Jurassic-Cretaceous-early Tertiary(?) age. Similar rocks (metasediments, altered basic igneous rocks) have been dredged from acoustic basement on the Santa Lucia High, and from the upper edge of the continental shelf. The structural style of the basin and granite derived coarse clastics of upper Cretaceous and Eocene age from the Santa Lucia High suggested to Hoskins and Griffiths (1971) that the basement may be granitic. Granite cobbles have been dredged from the Santa Lucia High, however, it is possible that they were transported, for other exotic rocks occur in dredge hauls on the shelf. If the basement is granitic, it would necessitate considerable revision of existing tectonic reconstructions of this plate margin which now consider the offshore basement to be Franciscan, (e.g. Page and others, 1979), and confine the granite basement to the Salinian block which lies onshore and separated from this basin by Franciscan terrane.

The shallow Santa Lucia Bank is formed by the fault bounded Santa Lucia structural high. Vertical separation on the Santa Lucia Bank fault on the eastern margin of the high was accompanied by considerable strike-slip displacement. The magnetic signature of the rocks differs across the fault; to the west the total magnetic intensity is flat, at about a constant value, whereas to the east of the fault, irregularities with amplitudes of as much as 200 gammas are present (Page and others, 1979). There is also a considerable difference in the thickness of the Miocene and Pliocene aged sections across the fault. Northwestward transport of this structural high is also suggested by the similarity of the physiography and gross structure of this part of the shelf with that of the California Borderland to the south (McCulloch and others, 1980).

Only limited data are available concerning the character and distribution of post-Cretaceous rocks in the basin. A generalized stratigraphic column for

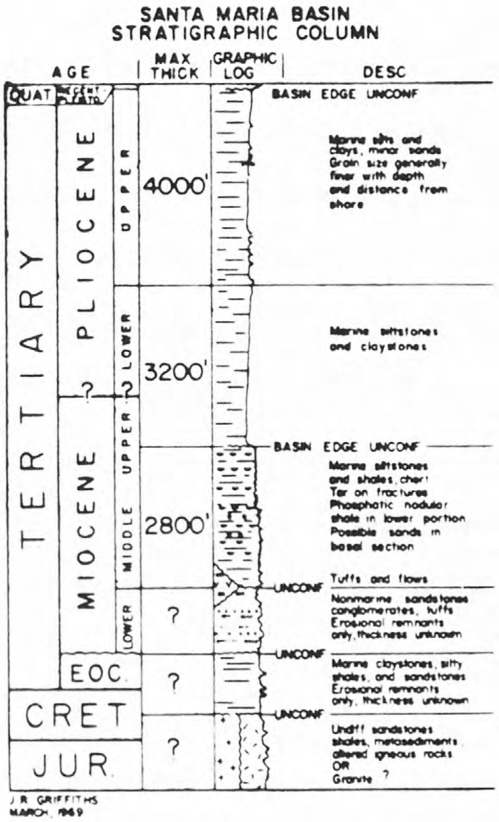


Figure 3.

Stratigraphic column (Hoskins and Griffiths, 1971) showing lithology, age and estimated maximum thickness of rocks in the Santa Maria Basin offshore. Additional work by H. C. Wagner and D. S. McCulloch (unpub. interpretations of seismic reflection profiles) indicates that the middle Miocene unconformity is basin-wide, and that there is an onlap unconformity between rocks thought to be of early and late Pliocene age.

the entire basin is shown on Figure 3. Note that in this and succeeding columns the thicknesses shown are the interval maximum for the entire basin. Paleogene rocks (marine mudstone, silty shale, sandstone) are present on the Santa Lucia High. These strata are truncated by an early Tertiary unconformity, and their distribution in the basin is thought to be limited to erosional remnants.

Geologic interpretations of four acoustic profiles across the basin are shown on Figure 4. Lithologies and ages are inferred from two test wells in the basin, Humble P-060-1 and OCS-CAL 78-164 No. 1 (McCulloch and others, 1979; Fig. 1). Basement rocks (TKJ_1, TKJ_2) are thought to be equivalent to rocks of the Franciscan complex, but to differ in origin, TKJ_1 rocks are possibly older in part than TKJ_2 rocks, and are an extension of similar rocks found exposed along the eastern edge of the basin, TKJ_2 basement rocks west of the Santa Lucia Bank fault may have originated as a subduction zone complex. Both TKJ_1 and TKJ_2 rocks and superjacent early Tertiary sedimentary rocks of possible Eocene and Oligocene age were deformed and eroded leaving only small erosion remnants of the early Tertiary deposits in topographic depressions. In late Oligocene and early Miocene time (represented by the lower part of unit Tmo) volcaniclastic rocks were deposited on this erosion surface. These rocks, that are probably equivelent to the Lospe and Obispo Formations onshore, thin northward and are missing from the northernmost profile on Figure 4. In middle and early late Miocene time well-bedded silicious marine shales and cherts (upper part of unit Tmo) were deposited in relatively deep marine water over the shelf. These rocks are referred to the Monterey Formation onshore. Unit Tmo was deformed sometime in the late Miocene by folding and numerous east dipping and moderately steep faults. Some faults offset the basement rocks more than unit Tmo, which suggests reactivation of older faults. The late Miocene folding and faulting probably resulted from compression related to subduction of the adjacent oceanic plate along the foot of what is now the Santa Lucia Escarpment (Page and others, 1979). Erosion removed some of the tops of the folded Tmo rocks before the following deposition of marine silt and clay (unit Tpm) which are referred to the late Miocene and early Pliocene Sisquoc and Pico formations onshore. Folding occurred once more but this time without the faulting that accompanied the earlier deformation. Sedimentation followed the folding, and in middle to late Pliocene time marine sediment (unit Tp, referred to the Foxen Mudstone onshore) covered the basin floor. The final episode of deposition recognized on the section (unit Q) is represented by the well bedded sediment of Quaternary (Pleistocene and

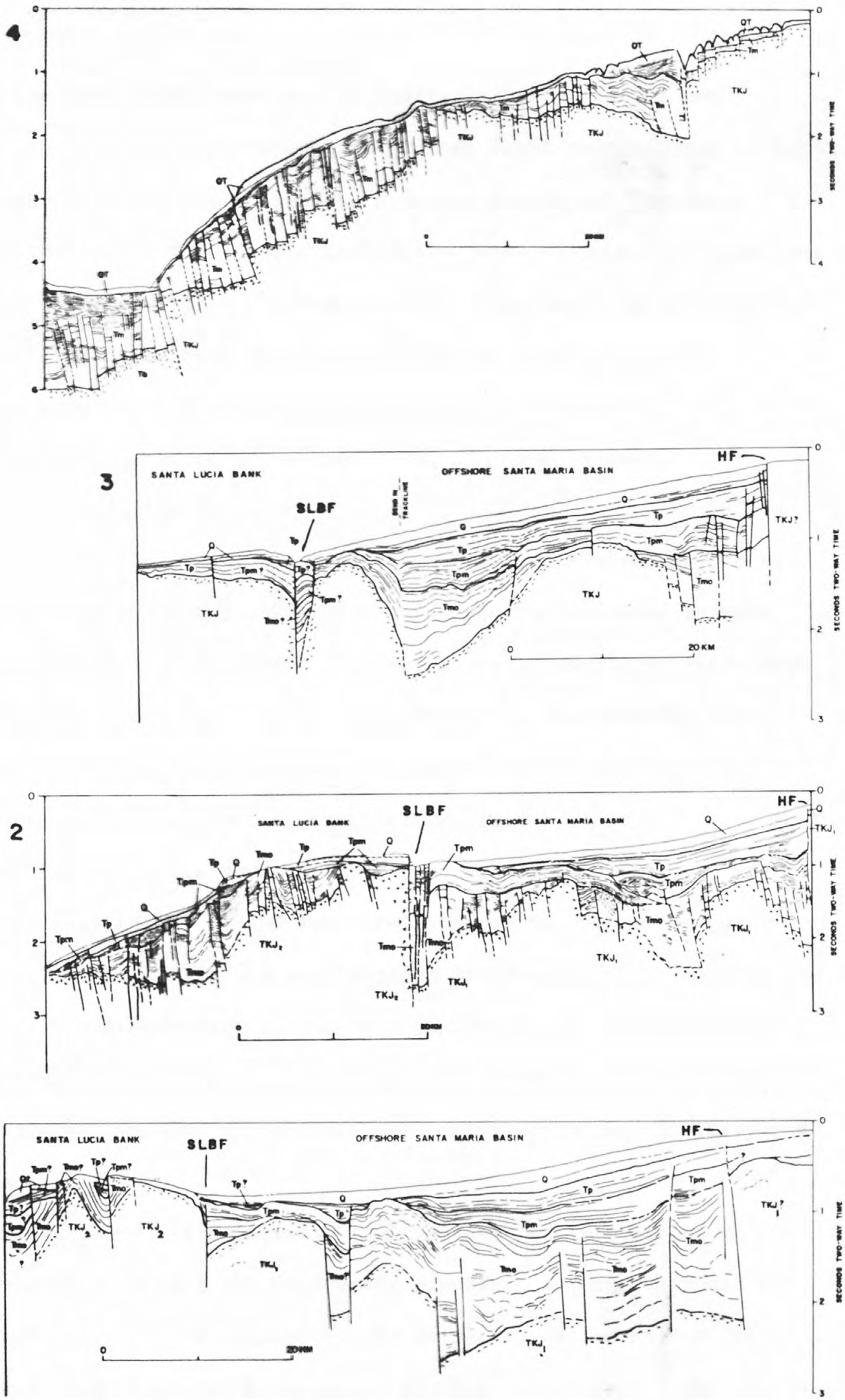


Figure 4. Geologic interpretations of acoustic profiles across Offshore Santa Maria Basin. SLBF = Santa Lucia Bank Fault; HF = Hosgri Fault. Vertical exaggeration approximately 10 to 1. Profiles located on Figure 1; geologic units described in text.

represented by the well bedded sediment of Quaternary (Pleistocene and Holocene) age. An acoustically transparent surface layer recognizable as high resolution records is thought to represent Holocene deposits. The large vertical separation on the Santa Lucia Bank fault (Fig. 4) makes it impossible to trace seismic reflectors from the basin to the Santa Lucia bank. Therefore rock ages west of the fault have been inferred by the similarities of character of the acoustic reflectors, by the degree of deformation, and by the sequence of the depositional, deformational, and erosional events (unconformities) seen in the basin.

Structural trends (fold axes and faults) in the northern two-thirds of the basin parallel the shoreline. The structures generally appear to have been initiated by at least early Tertiary time, and most persisted into late Miocene, but the associated faulting and deformation is considerably less above the early Tertiary unconformity. Just south of Point Sur there is evidence for present day compression and thrusting in the basin sediments that lie adjacent to the high angle reverse fault that bounds the northeast edge of the basin. Structural trends in the southern third of the basin are north-south, oblique to the shoreline and the bounding Santa Lucia High (Hoskins and Griffiths, 1971). Considerable evidence for compression is also present in this area. Low-angle thrusting, with a vergenz to the west started by at least early Tertiary time, and appears to have continued through Tertiary and Quaternary time.

Outer Santa Cruz Basin.--This relatively shallow late Tertiary basin, which measures approximately 25 km x 100 km, trends northwest across the shelf and extends onto the slope. It is bounded on the northeast by the Pigeon Point High, a structural high that is the probable southern extension of the quartz diorite cored Farallon High, and on the west by the Santa Cruz High (Fig.

granitic rocks on the basis of unstated geophysical data and the proximity of granitic rocks to the east. Two exploratory wells in the basin (Fig. 1, Shell Oil Co. wells P-035-1ET, P-036-1ET) bottomed in upper Cretaceous marine sediments at depths of 2892 and 2358 meters. Silver and others (1971) state that the Outer Santa Cruz High is composed of Franciscan rocks or an early Tertiary equivalent. A dredge haul and dart core recovered undated mafic volcanics from the western flank of this high (unpub. U.S. Geological Survey data). McCulloch(1973) and Graham (1976) suggested that right-lateral strike-slip displacement along the San Gregorio-Palo Colorado fault (Hoskins and Griffiths, 1971, Greene and others, 1973) may have displaced the southern edge of the offshore Salinian block northwestward approximately 80 km. If so, the Farallon-Pigeon Point High represents the southwest boundary of the Salinian block, and the basement beneath the Outer Santa Cruz basin should be Franciscan or Franciscan equivalent rocks, rather than granitic.

Cretaceous and early Tertiary (Oligocene?) marine sandstone are present locally beneath the basin (Fig. 6) but their general distribution is not known (Hoskins and Griffiths,1971). Both the Cretaceous and Oligocene(?) periods of deposition were followed by deformation and erosion. The overlying Neogene units suggest repeated periods of erosion followed by marine sedimentation that reflect the transition from shallow sandy to deep finer-grained deposition. Volcanics (interbeded in marine shales) are limited to the lower Neogene as in the Santa Maria basin offshore. Cherty shales (Monterey Formation?) dominated the deposition until the early late Miocene period of deformation and erosion that accompanied the uplift of the structural highs, and the initiation of the present basin. Relatively fine-grained sediment, primarily silt and clay with a minor amount of sand, accumulated in the basin in upper Miocene and Pliocene time.

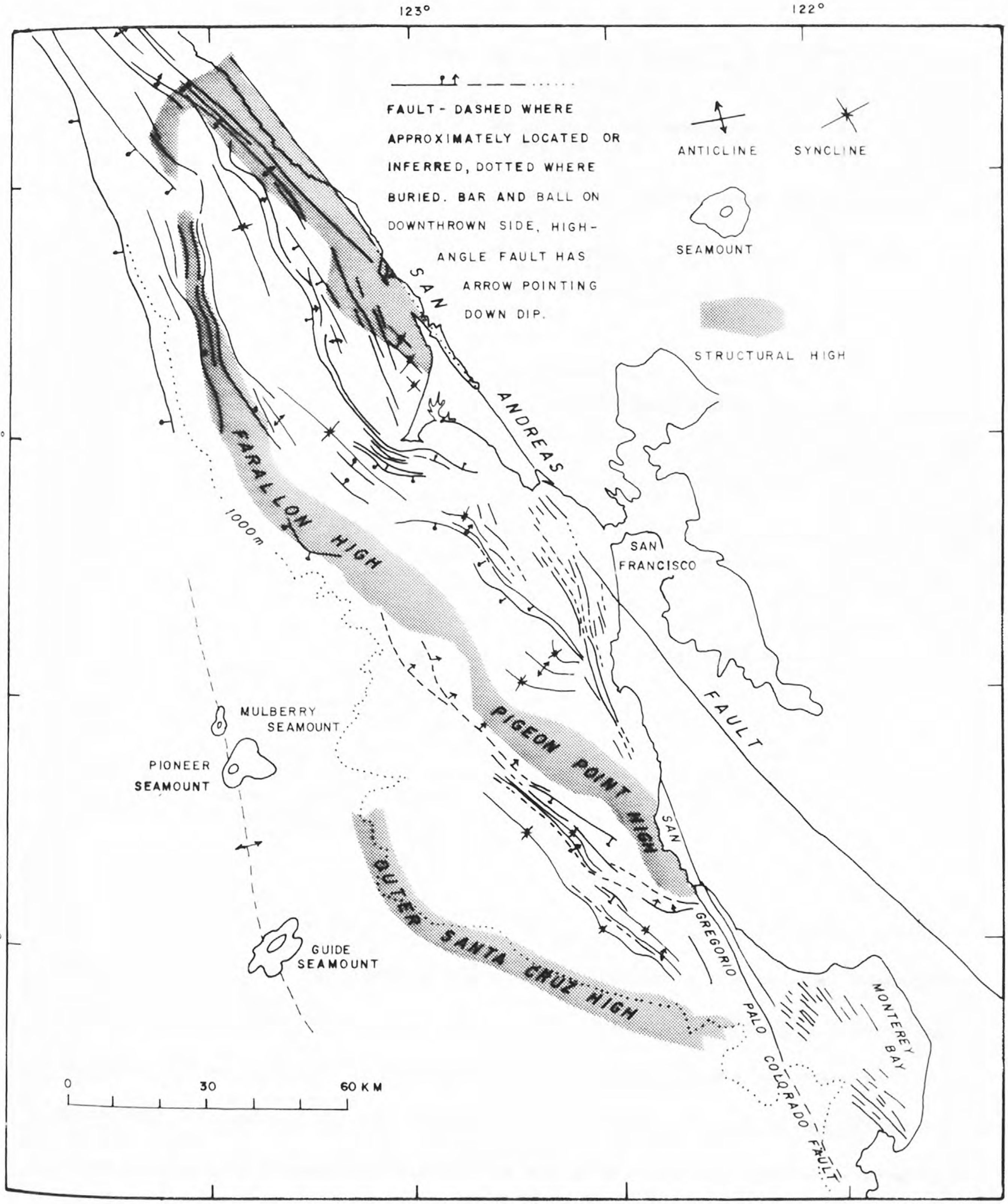


Figure 5. Generalized map of geologic structure and faults in Outer Santa Cruz and Bodega basins. Mapping in Monterey Bay after Greene and others, 1973, Mapping from Monterey Bay to Point Reyes by D.S. McCulloch, and north of Point Reyes, modified after Rubin, in McCulloch and others, 1980).

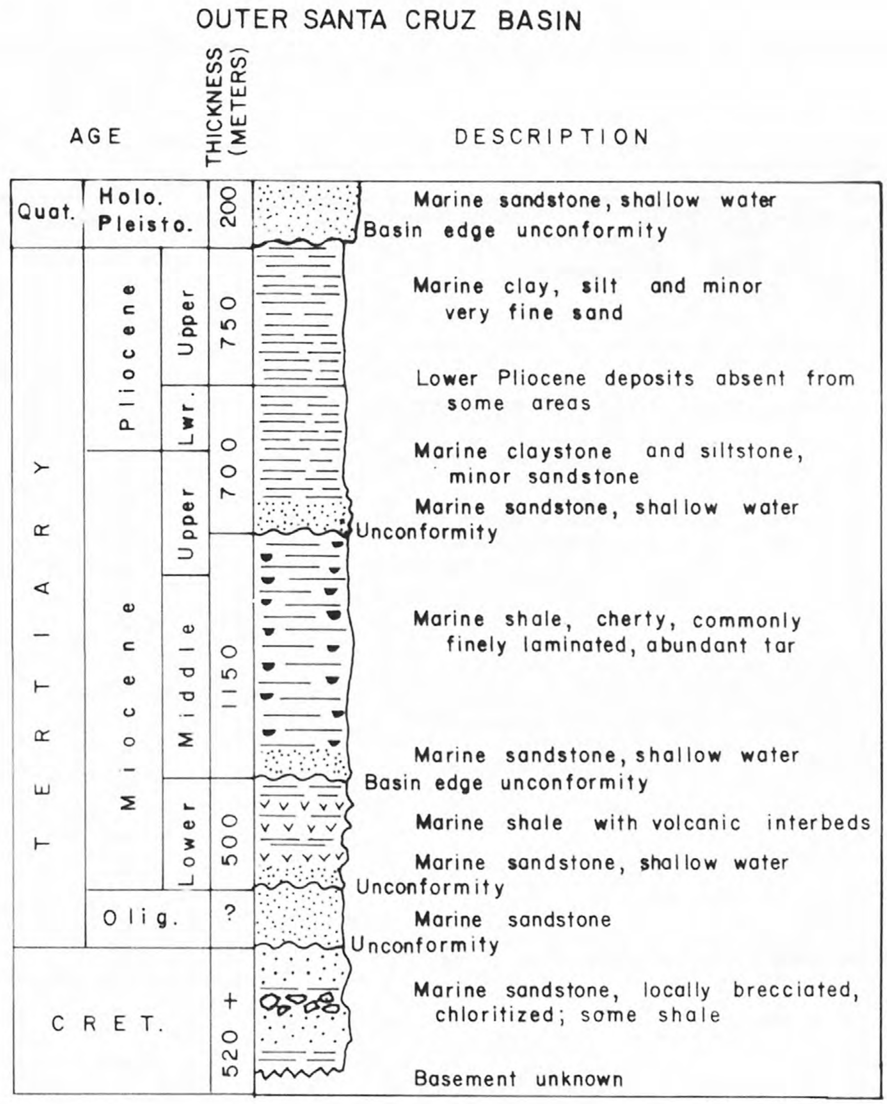


Figure 6. Generalized stratigraphic column for Outer Santa Cruz Basin, central California (After Hoskins and Griffiths, 1971).

The structural axis of the basin and the Outer Santa Cruz High plunge to the northwest, over the edge of the shelf. The sediments thicken down the slope, and appear to be limited along the toe of the slope by a discontinuous volcanic ridge along which the Mulberry, Guide and Pioneer Seamounts form prominent topographic highs. Beneath the Early upper Miocene unconformity the rocks are gently folded and the faults are generally high-angle reverse with a vergenz to the west. The southwestern basin margin does not appear to be fault controlled, for the early Tertiary sediments are upturned along the flank of the Santa Cruz High. The northestern margin is controlled by a down-

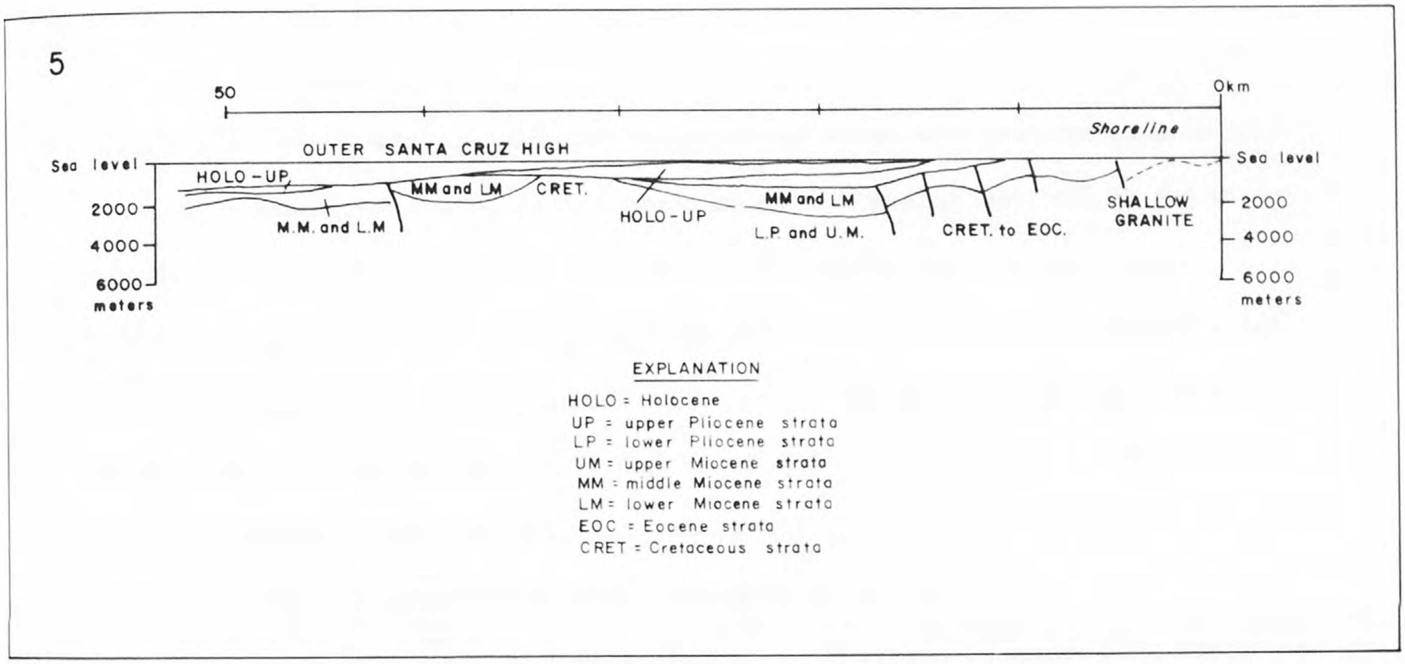


Figure 7. Geologic cross section of Outer Santa Cruz Basin (Hoskins and Griffiths, 1971). Section located on Figure 1.

to-basin fault that displaces rocks up to at least the upper Miocene unconformity.

Bodega Basin.--"Bodega Basin" as used in this report (Fig. 5) encompasses both the Santa Cruz and Bodega basins of Hoskins and Griffiths (1971). This basin lies northeast of the Farallon-Pigeon Point High. It is bounded on the east by the San Andreas fault and down-to-basin faults along which granite basement has been elevated, and to the southwest in the Gulf of the Farallones by a structural high of deformed Neogene sediments. This basin is approximately 180 km long and has an average width of approximately 25 km. The following summary of the geology of this basin is drawn from Hoskins and Griffiths (1971), Cooper (1971), and the interpretation of single channel seismic reflection records (McCulloch, 1976).

The Bodega Basin overlies the Salinian basement block. Cretaceous granitic rocks have been recovered from Cordell Bank west of Point Reyes and from Farallon Island along the Farallon High to the southwest (Hanna, 1952;

Uchupi and Emery, 1941). Similar rocks occur along the eastern side of the basin at Montara Mountain, on the west shore of Tomales Bay and at Point Reyes, but are limited to the southwest side of the San Andreas fault. Granitic rocks have been recovered from the bottom of two exploratory wells in the basin just south and southwest of Point Reyes (Fig. 1, Standard Oil Co. wells P-041-1ET and P-039-1ET at depths of 1423 m and 1707 m). Interpretations of magnetic and gravity data across the Gulf of the Farallones are also consistent with a presumed granitic basement (Griscom, 1966; Cooper, 1971).

Cretaceous rocks are probably limited to scattered remnants in the southern part of the basin, and are thought to be absent to the north. These deposits are primarily marine sandstones with minor amounts of fine-grained sediment, and contain basic volcanics and sills (Fig. 8). Lower Eocene deposits are thin and scattered, and are composed of marine shale and deep marine sandstones. Lower Eocene sediments are absent near Point Reyes but they increase in thickness to the north where lower Eocene rocks lie in sedimentary contact on the granitic basement. Middle Eocene sedimentary rocks may occur locally in the northern part of the basin, but are not known in the south. As in the adjacent Outer Santa Cruz basins, Neogene strata record repeated periods of uplift and erosion followed by periods of marine sedimentation. Lower Miocene rocks rest upon an erosional unconformity, and grade vertically from shallow-marine basal sandstones to deeper-marine shales and sandstones. The middle-Miocene sequence is similar, with shallow-marine basal sandstone resting on an erosional unconformity, and grading upward to finer grained rocks containing cherty shale. As previously noted, uplift and erosion of the Farallon-Pigeon Point High occurred in early late Miocene time. Subsidence of the Bodega basin to the northeast was followed by

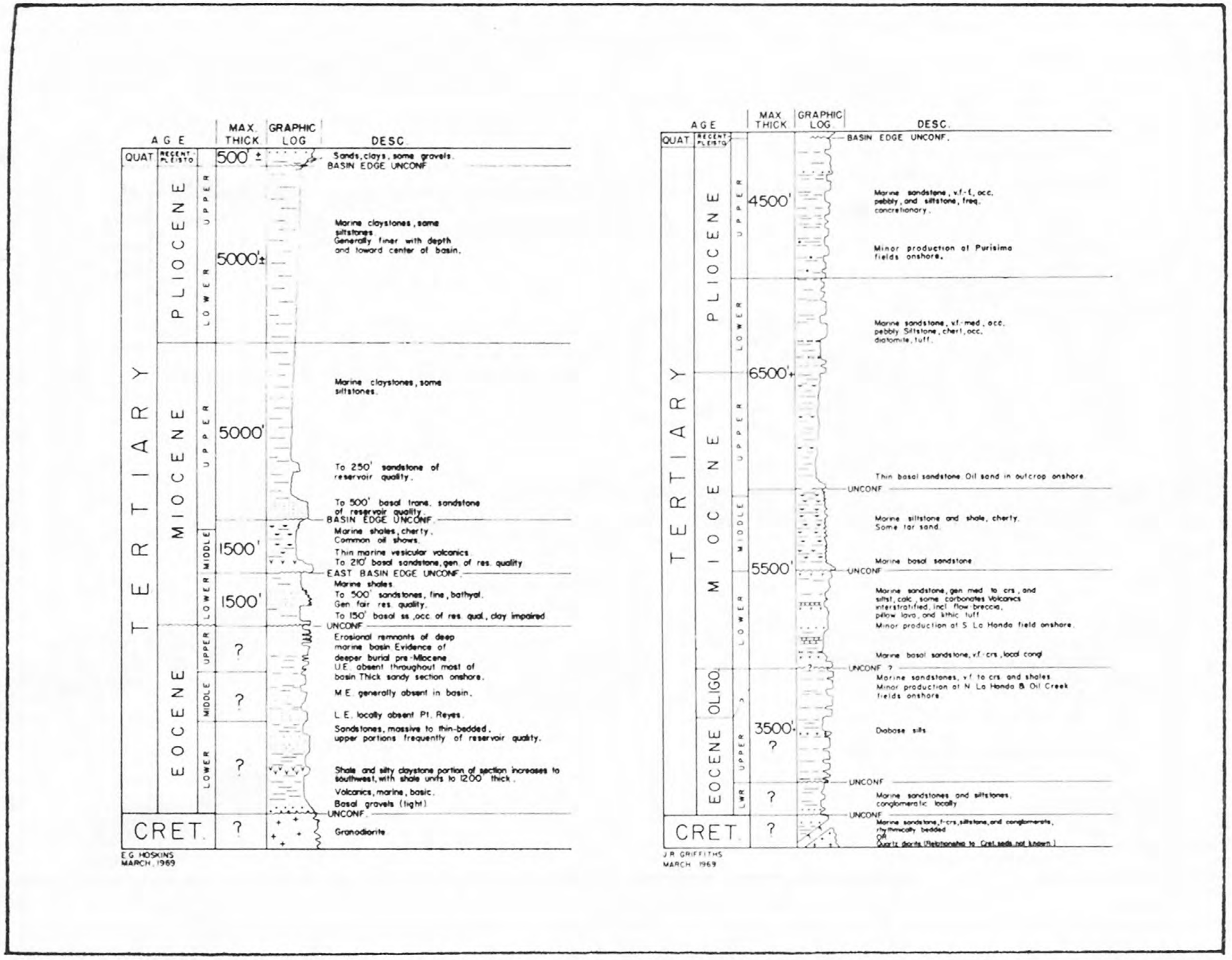


Figure 8. Generalized stratigraphic columns for northern (left) and southern (right) Bodega Basin (Hoskins and Griffiths, 1971).

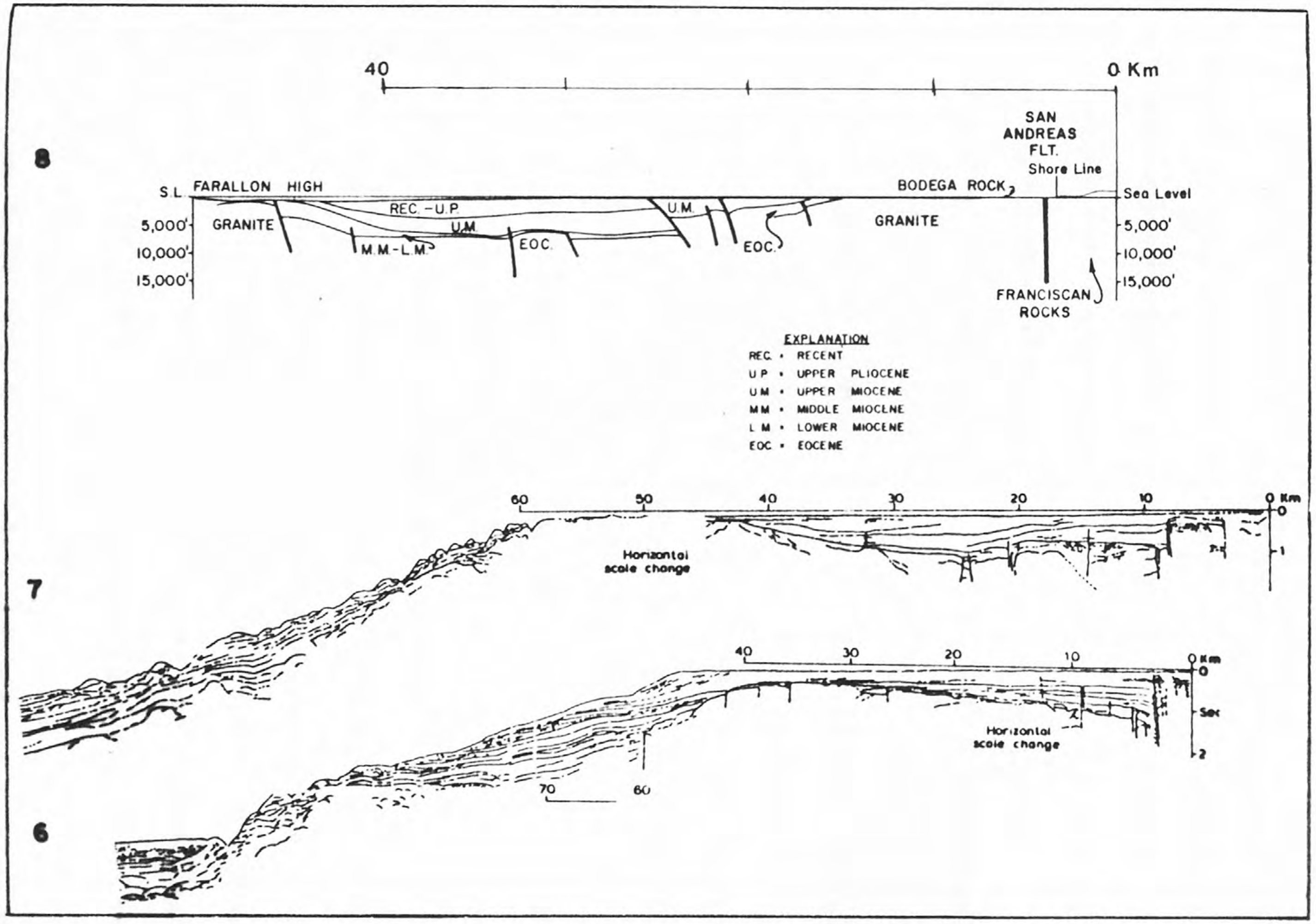


Figure 9. Geologic cross section of northern Bodega Basin (Hoskins and Griffiths, 1971), and line drawings of seismic profiles in central Bodega Basin (McCulloch, unpublished U.S. Geological Survey data). Cross section and profiles located on figure 1.

deposition of as much as 3000 m of Neogene marine clays and silts and some sands of late Miocene and Pliocene age.

The tectonic history of this part of the shelf and the Bodega basin is similar to that of the adjacent shelf areas. Episodes of pre-middle Miocene deformation are recorded in the structure and erosional unconformities in Cretaceous and Paleogene rocks. Pre-Neogene structures are complex and may follow a different structural grain than those developed in the younger overlying strata (Hoskins and Griffiths, 1971). Subduction-related tectonics probably came to a close in late Miocene time with the uplift of the Farallon-Pigeon Point High. At about this time lower Neogene sediments began to be compressed into an elongate ridge, nearly parallel to, and just seaward of the San Andreas fault in the Gulf of the Farallones. At the same time, mid-Tertiary strata were deformed within the basin. The end of this deformation within the basin is recorded by an unconformity between the middle and upper Miocene units. Right-lateral shear and regional compression accompanied the transition to strike-slip faulting. Folds developed parallel to the long axis of the basin, and the northeastern-bounding structural high of compressed Neogene sediment underwent additional compression. Compression was accompanied by the development of high angle reverse faults, like those that displace granitic rocks at Point Reyes (Fig. 9) and at the same time a large displacement fault formed along the eastern basin margin west of Montara Mountain. This latest episode of deformation, which began in late Pliocene, continues today.

Point Arena Basin.--The eastern and northern margins of the Point Arena basin are well defined by the San Andreas fault as it runs northwestward from Point Arena and swings westward along the Mendocino Escarpment (Curray and Nason, 1967). The basin has a length of approximately 140 km. The average width of the basin to the 1000 m isobath is about 20 km, however the western edge of the basin lies well offshore of the 1000 m isobath, and is formed by a partially buried structural high mapped by Curray (1966). The high trends northwestward away from the coast, giving the basin a width of 30 km at the south and about 55 km to the north (Fig. 10). A Deep Sea Drilling Project core hole (DSDP Leg 18, Site 173, Kulm and others, 1973) drilled on the western bounding ridge penetrated 138 m of lower continental slope deposits consisting of Pleistocene, Pliocene and Miocene grayish green mud, 147 m of upper to lower most Miocene diatomites and 35 m of gray nannoplankton ooze, and bottomed in andesitic basement. Silver (written commun., 1976) dredged graywacke of middle-Eocene to Oligocene age from this ridge about 50 km west of Fort Bragg. Thus the ridge appears to be geologically complex. The basin is reported to be underlain partly by pre-Cretaceous (Jurassic?) metasediments (Hoskins and Griffiths, 1971; Fig. 11). Thick sections of Cretaceous shallow water marine shale, siltstone and fine-grained sandstones crop out onshore to the south, but they thin abruptly to the north in the basin, probably as the result of pre-Eocene erosion. Eocene sediments also thin abruptly to the north in the basin, and are also truncated by an erosional unconformity below lower Miocene strata. Onshore to the south there is a thick section of lower to upper Eocene sandstone and shale, suggesting that if a comparable section existed on the shelf, it was largely removed by the late Paleogene-early Neogene erosion. Lower Miocene deep water marine shales containing a thick but discontinuous basal sandstone rest on the unconformity, recording a transgression and subsequent deep marine deposition. As in the basins to the south, the following middle Miocene is represented by cherty shale. A lower upper Miocene basal marine sandstone rests unconformably on older sediments

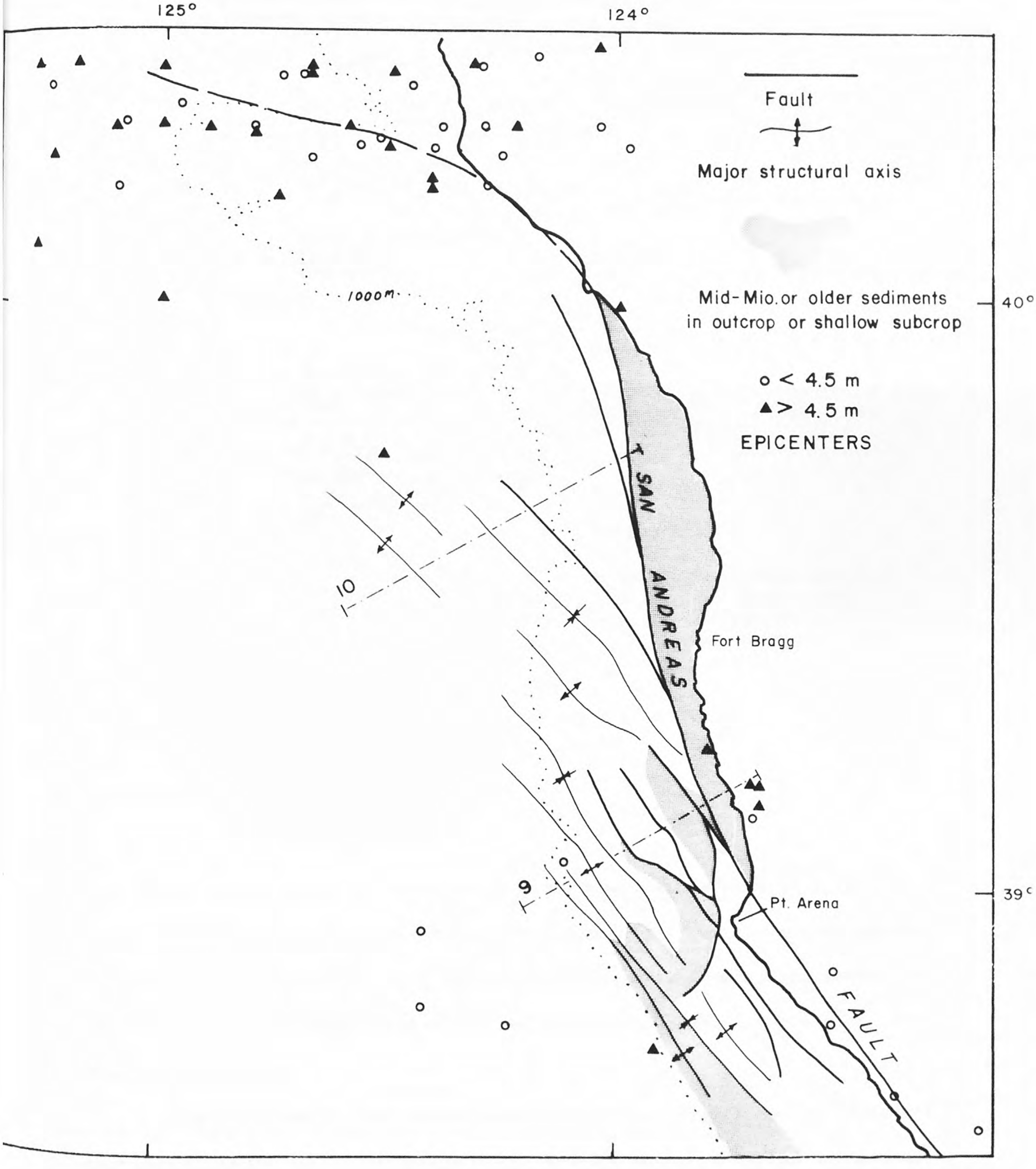


Figure 10. Generalized map of geologic structure and faults in Point Arena Basin (from Hoskins and Griffiths, 1971). Geologic sections in figure 12.

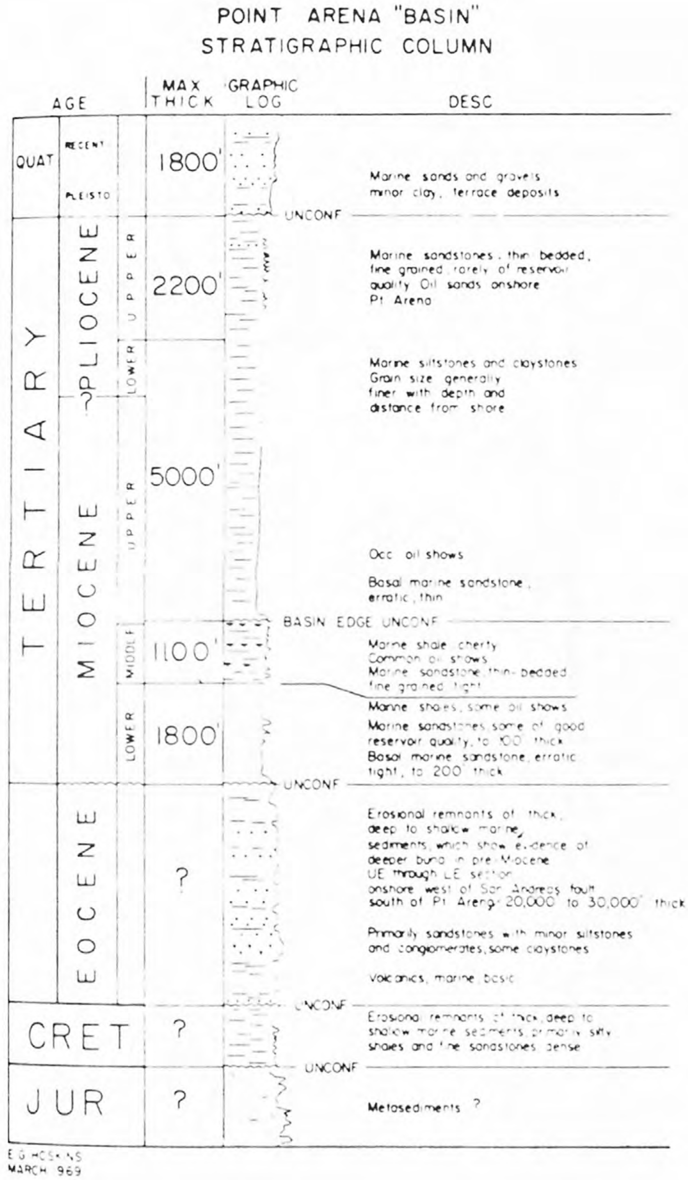


Figure 11.

Generalized stratigraphic column for Point Arena Basin (Hoskins and Griffiths, 1971).

near Point Arena, but over most of the basin there appears to have been no break between middle and upper Miocene sedimentation. Upper Miocene marine siltstones and claystones grade upward into upper Pliocene marine sandstones, which in turn are truncated by an unconformity at the base of the coarser Pleistocene section.

Little is known of the pre-Neogene tectonic history of the basin except that several episodes of deformation and erosion occurred during Cretaceous and Paleogene time. Judging from the degree of induration of early Eocene sediments, a considerable thickness of overlying rocks may have been

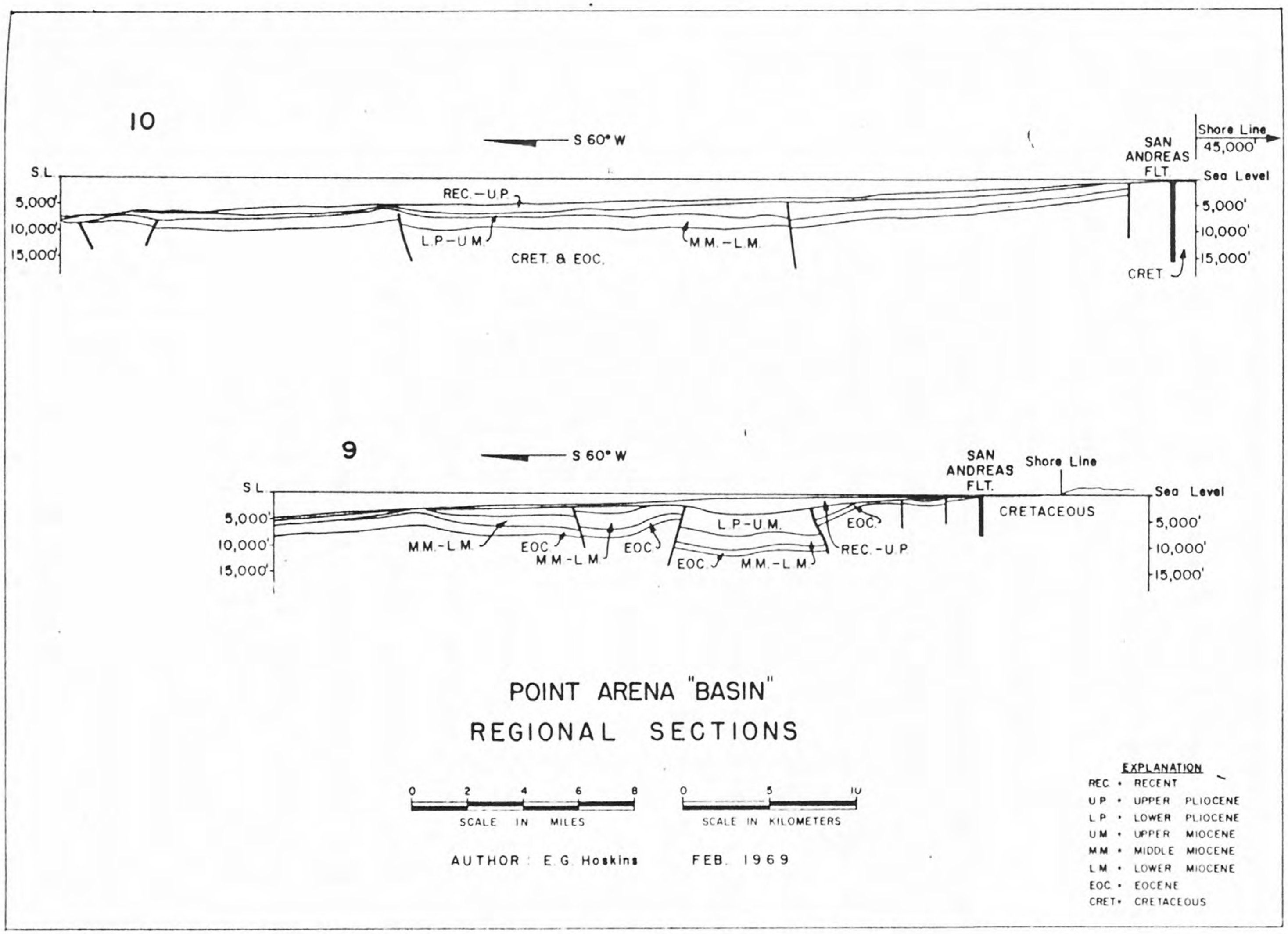


Figure 12. Geologic cross sections in Point Arena Basin (Hoskins and Griffiths, 1971). Sections located on figures 1 and 10.

removed. Likewise little is known of the history of the western boundary ridge. Seismic reflection profiles (Silver, 1971; Kulm and von Huene, 1973) across the ridge and age determinations from the DSDP core hole suggest that Miocene and younger strata are little deformed. Neogene structure is complex at the south end of the basin, but is relatively simple to the north (Fig. 12). Deformation of the south end of the basin may have started with the uplift that produced the early late Miocene unconformity in the Point Arena area. However, the major high-angle reverse faults, some with vertical displacements of about 2000 m and the fold axes that lie parallel to the elongate basin were largely formed in upper Pliocene time. These faults and folds trend northwest, and diverge northward from the San Andreas fault.

Eel River Basin.--The basin extends from Cape Mendocino (40°30'N) on the northern California coast northward for 200 km to Cape Sebastian (42°20'N) in southern Oregon, and from the coastline seaward to the continental slope, an average distance of about 70 km (Fig. 13). The south end of the basin extends inland for about 50 km in the lower Eel River-Arcata Bay area. The geology of the on-land portion of the basin has been described by Ogle (1953), and that of the surrounding region by Irwin (1960), and Bailey, Irwin and Jones (1964). The geology of the offshore basin is described generally by Hoskins and Griffiths (1971) and Field and others (1980), and the regional structure is discussed by Silver (1969, 1971a, 1971b).

The onshore Eel River basin is a syncline that trends nearly west and is bounded on the north and east by anticlinal folds and steeply dipping faults. The basin contains a thick sequence of upper Miocene and younger rocks that unconformably overlie and are in fault contact with Eocene and older units (Fig. 14). Basement rocks along the eastern margin of the basin are assigned to the central belt of the Franciscan Complex, a late Jurassic-

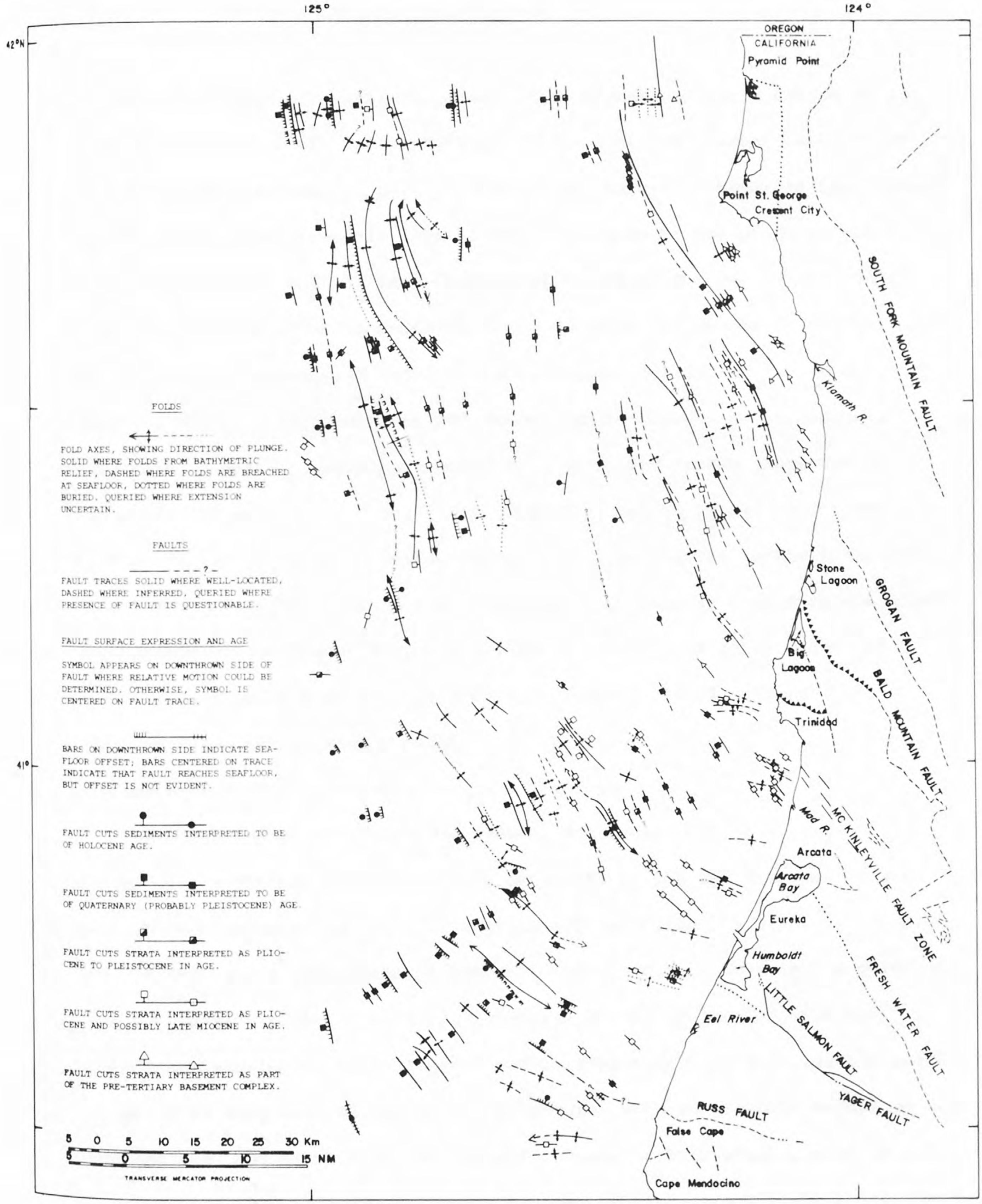


Figure 13. Generalized map of geologic structure and faults in Eel River Basin, from Field and others, 1980.

Cretaceous melange of graywacke, chert, basalt-greenstone and schist in a sheared matrix of shale and sandstone. Elsewhere, the coastal belt of the Franciscan Complex and the partly coeval Yager Formation underlie the onshore Eel River basin and probably form basement for most of the offshore basin as well. The coastal belt is Late Cretaceous to latest Eocene in age, and consists principally of interbedded fine to coarse grained clastic rocks that are slightly metamorphosed (zeolite facies) and, locally, of volcanic rocks of spilitic composition, limestone and chert. It is thought to represent a subduction complex comprising accretionary prism and trench slope basin deposits (Bachman, 1978). The Yager Formation, Eocene in age (Evitt and Pierce, 1975), is in fault contact with central belt rocks in the lower Eel River area, but lies in depositional contact with coastal belt strata a short distance to the southwest (Ogle, 1953; Irwin, 1960). It is at least 765 m (2500 ft) and perhaps as much as 3060 m (10,000 ft) thick, and consists of well indurated marine shale, mudstone and siltstone, with lesser graywacke and conglomerate containing locally-derived Franciscan detritus (Ogle, 1953).

Regional deformation occurred between Eocene and middle Miocene time and strata of the Wildcat Group overlie older rocks in the Eel River basin with angular unconformity (Ogle, 1953; Hoskins and Griffiths, 1971). The Wildcat Group comprises an essentially conformable sequence more than 3600 m thick of fine to coarsely clastic, principally marine strata of late Miocene to Pleistocene age (Ogle, 1953; Ingle, 1976). Predominant lithologies are weakly consolidated mudstone, siltstone and claystone, with subordinate sandstone and conglomerate, and minor lignite and tuff. Units of this group appear to record an eastward transgression over basement during late Miocene and early

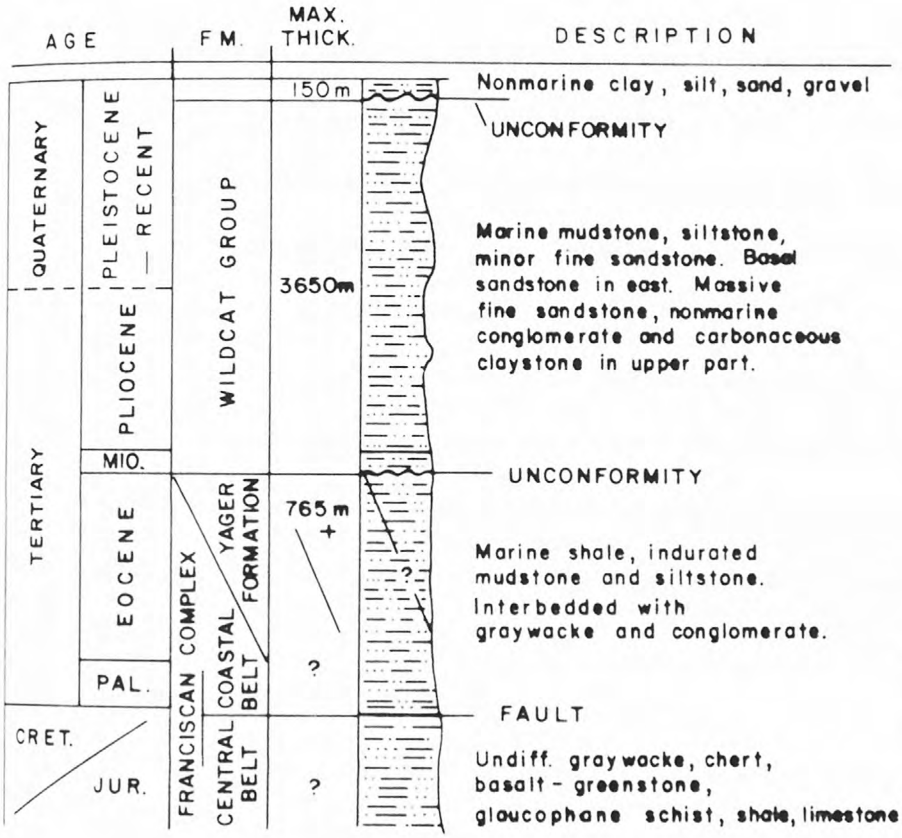


Figure 14.

Stratigraphic column, Eel River Basin (modified after Ogle, 1953; Hoskins and Griffiths, 1971).

Pliocene, deepening of the basin to bathyal-abyssal depths with basin plain, submarine fan and basin slope deposition during Pliocene and early Pleistocene, followed by shoaling to shelf depths and ultimately by emergence and marginal marine and non-marine depositon in Pleistocene time (Ogle, 1953; Ingle, 1976; Piper and others, 1976). The section coarsens upward, reflecting Pleistocene regression, and eastward, reflecting the presence of a landmass. Similar, predominantly shallow-marine, strata are preserved in a graben located about 16 km (10 mi) to the north (Manning and Ogle, 1950), and in the Crescent City area (Back, 1957).

Wildcat deposition closed with basin margin warping and uplift, culminating in basin-wide deformation that followed established structural trends (Ogle, 1953). Pleistocene and Holocene clays, sands, silts and gravels unconformably overlie Wildcat strata in onshore parts of the basin. These deposits have an aggregate thickness of about 150 m (500 ft) and represent shallow marine and coastal plain environments. As in the Wildcat Group, the marine section becomes finer grained northwestward, suggesting that the basin deepened in that direction.

The axis of the Eel River basin trends N80°W onshore (Ogle, 1953), but swings to a near northerly orientation offshore. Folds onshore parallel the basin margin and associated faults are thrusts and high-angle reverse faults, apparently reflecting northeast-southwest to north-south compression of the basin (Ogle, 1953). Pleistocene strata are gently folded along older structural axes of the Wildcat Group.

Major structures offshore also parallel the trend of the basin axis. Folds involving Pliocene and younger strata on the marginal plateaus and adjacent continental slope are expressed in the sea floor and are cut by high-angle reverse faults having dip separations that are predominantly west-side down (Fig. 15). The folds are characteristically broadly symmetrical or asymmetrical with east dipping axial planes, reflecting a principal compressive stress from the west. This east to northeast directed compression presumably results from Quaternary underthrusting of the Gorda plate. This margin segment has been interpreted as a forearc basin-ridge-slope accretionary prism with dominantly landward dipping thrusts, and the uplifted marginal plateaus forming the western margin of the offshore Eel River basin as stacked, imbricated wedges of Gorda basin sediment. Numerous unconformities in the sedimentary fill of the restricted basins on the marginal plateaus attest to an episodic history of deformation throughout deposition of the Neogene section. Some folds of the marginal plateaus appear to be associated with shale flowage and diaprism, and some of the marginal

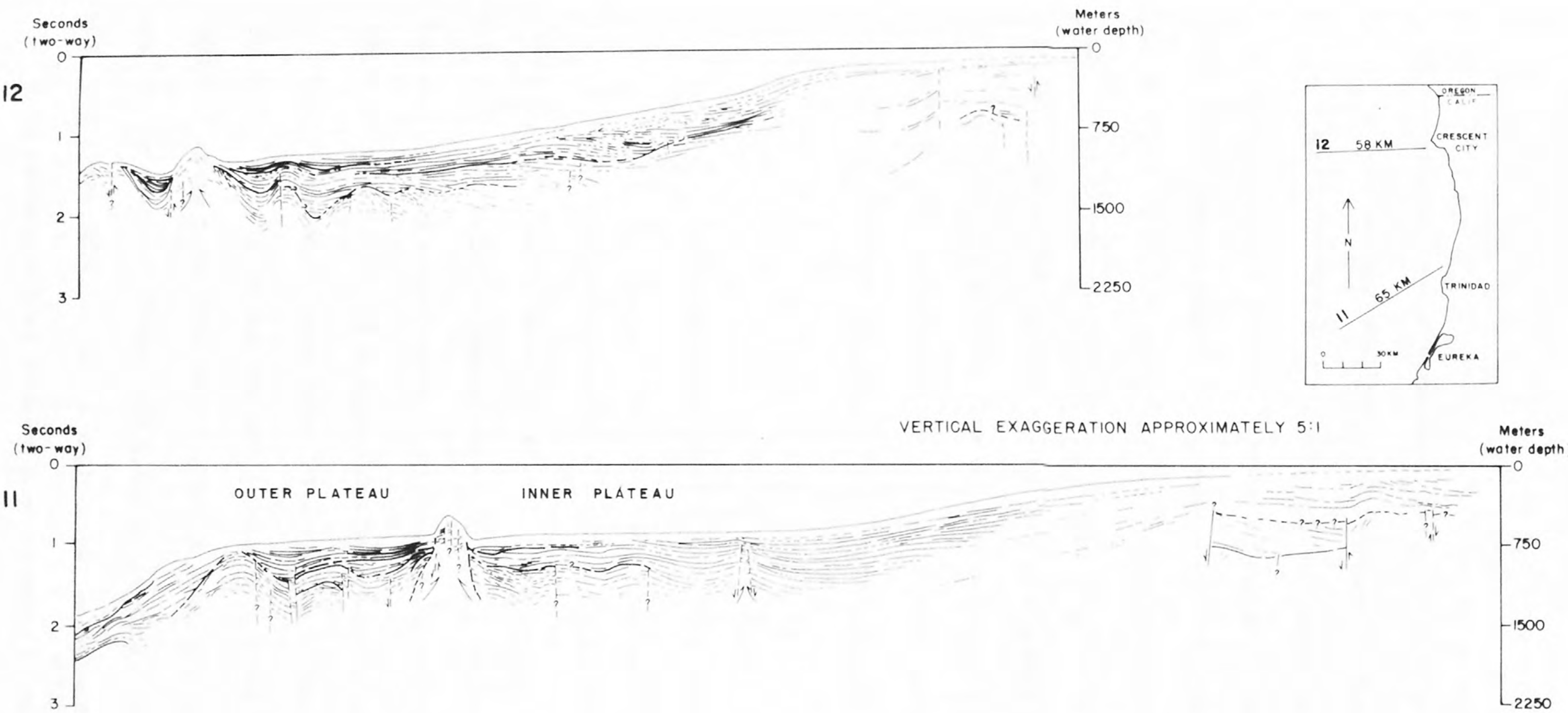


Figure 15. Line drawings of acoustic profiles across Eel River Basin. Sections located on figure 1.

ridges are piercement structures (Fig. 15). The deep structural depression landward of the uplifted marginal plateaus is filled by a thick section of upper Tertiary and Quaternary hemipelagic sediment and turbidites. Several northwest trending roughly en-echelon faults, some showing evidence of Quaternary displacement, cut basement and the overlying Cenozoic sedimentary section on the inner shelf south and west of Crescent City. Associated with these faults are en-echelon folds that are stepped to the right (Silver, 1971a). Fault plane solutions by Bolt and others (1968) from three shallow-focus earthquakes in this area during 1961-1965 are consistent with right-lateral motion, interpreted by Silver (1971a) as the result of shear interaction between the Pacific and North American lithospheric plates.

PETROLEUM GEOLOGY

Previous Petroleum Exploration in Northern Part of Proposed OCS Lease Sale 73

Exploration of the northern part of proposed OCS Lease Sale 73 has been underway by the Petroleum industry and geophysical companies during at least the last two decades. For example, Hoskins and Griffiths (1971) indicate that the Shell Oil Company shot an extensive network of shallow and deep penetration seismic reflection profiles over the entire shelf, and collected sea floor samples by dart core and shallow borings. Some industry exploration was done in anticipation of, and following the May 14, 1963 lease sale that included these shelf basins and some in anticipation of OCS Lease Sale 53. A partial tabulation of the 1963 leasing events is given in Table 1. Following the 1963 lease sale, nineteen exploratory wells were drilled from ships (Table 2). Most targets appear to have been structural rather than stratigraphic traps. With the exception of the Santa Maria basin onshore, production from the adjacent onshore basins is almost entirely from structural traps. No significant hydrocarbons were encountered in the offshore drilling, and all wells were abandoned.

Petroleum in Adjacent Developed Areas

The offshore area in the northern part of proposed OCS Lease Sale 73 lies adjacent to three onshore basins (Fig. 1). Santa Maria basin onshore and basins in the adjacent Salinian province may be quasi-equivalents of the Santa Maria offshore and Bodega basins, however, the onshore basins are thought by some to be separated from the offshore basins by major faults that may have had considerable late Neogene strike-slip displacment (Graham, 1976; Hall, 1975). Eel River basin, lying north of the region of Neogene strike-slip faulting clearly extends ashore as in the Humboldt basin. Petroleum production from all of these onshore basins has been relatively small. Humboldt basin has had no significant oil production, and cumulatively, as of Jan. 1973, the others had produced a total of approximately 0.8 billion barrels, which constituted approximately 6% of California's onshore oil production.

In the Santa Maria basin onshore nearly 75 percent of the oil (0.5 billion bbls) is produced from fractured shale reservoirs of middle Miocene and Pliocene age. Many fields in this basin have reservoir characteristics that pose difficult economic and technical problems, however, as McCulloh has noted (1979), changing economics and evolving technologies both may convert marginal or submarginal resources of immature, shallow, viscous and dense asphaltic crude oil into productive reservoirs. Per well recoveries in the

TABLE 1. PARTIAL OCS LEASING HISTORY--CENTRAL AND NORTHERN CALIFORNIA, 1963

Basin	# leases offered	# leased	Total of winning bonuses	# of subsequent wells drilled (see Table)	Status
Eel River		17		4	quit claimed
Point Arena	21	5	$557,843	3	" "
Bodega (and Santa Cruz)	41	27	$6,585,981	9	" "
Outer Santa Cruz	13	2	$162,432	2	" "
Santa Maria		6	$1,307,231	1	" "
Total		40		19	

Santa Maria fields vary greatly. Average recoveries range from about 10,000 to 50,000 barrels per acre but have been achieved only by dense well spacing and a long production history. Declines typically are rapid in the first few years, but field life is long with resulting high operating costs. Some of the fields produce low gravity oil only after extensive steam injection. Variable oil gravities and extensive tar sands create development problems both from technical and environmental standpoints. In general, higher gravity oil is found in the deeper reservoirs.

Production from fields in the onshore Salinian province adjacent to the Bodega Basin has been quite low. The principal onshore fields (La Honda, Halfmoon Bay, Oil Creek) produced a total of only 1.3 million barrels of oil, and 300 million cubic feet of gas by December 1975. Most production is from Miocene and Pliocene strata. The nearest significant production is from the San Ardo Field, nearly 250 km southeast of Halfmoon Bay, where oil and gas are recovered from a coarse sandstone at the base and in the middle of the Miocene Monterey Formation. Cumulative production from San Ardo through December 1975 was 0.29 billion barrels of oil and 71 billion cubic feet of gas (California

TABLE 2. EXPLORATORY WELLS DRILLED ON OCS LANDS

(after 1963 Federal OCS Lease Sale)

Company and Well Name		Basin	Total Depth		Spudded	Abandoned
			Meters	Feet		
Humble	P-012-1	Eel River	9034	2964	7-30-64	8-19-64
Humble	P-007-1	Eel River	273	897	7-01-64	7-27-64
Shell	P-019-1ET	Eel River	1981	6500	7-11-65	7-30-65
Shell	P-014-1ET	Eel River	2249	7377	6-17-65	7-7-65
Shell	P-032-1ET	Point Arena	2106	6909	11-26-66	1-13-67
Shell	P-033-1ET	Point Arena	1438	4719	10-24-66	11-11-66
Shell	P-030-1ET	Point Arena	3242	10,636	3-10-65	6-10-65
Shell	P-027-1ET	Bodega	986	3234	11-17-64	11-29-64
Shell	P-058-1ET	Bodega	2402	7882	1-18-67	2-07-67
Shell	P-053-1ET	Bodega	2456	8059	12-2-64	12-26-64
Shell	P-055-1ET	Bodega	2279	7477	10-12-64	11-6-64
Shell	P-055-2ET	Bodega	2213	7261	1-3-65	1-23-65
Shell	P-055-2AET	Bodega	2224	7297	1-25-65	2-15-65
Shell	P-051-2ET	Bodega	3190	10,466	8-2-64	10-3-64
Shell	P-041-1ET	Bodega	1433	4700	9-20-63	12-13-63
Shell	P-039-1ET	Bodega	1717	5632	2-16-65	3-3-65
Shell	P-036-1ET	Outer Santa Cruz	2283	7490	2-10-67	3-17-67
Shell	P-035-1ET	Outer Santa Cruz	2357	7736	9-01-67	9-28-67
Humble	P-060-1	Santa Maria	2444	8020	9-29-64	1-08-65

Division of Oil and Gas, 1975; California Division of Oil and Gas, 1960). Humboldt basin (the onshore Eel River basin) has had no significant oil production. The small, now abandoned, field at Petrolia produced only 350 barrels from a stratigraphic trap in Lower Cretaceous (Lower Capetown) sandstone and shale. Principal production has been gas, but again, the total has been small. Through December 1975, Tompkins Hill (Eureka) produced 63 billion cubic feet, and Table Bluff, now abandoned, produced 0.1 billion cubic feet. Production in both gas fields was from thin, lenticular, very-fine sands of the Pliocene Rio Del Formation in anticlinal traps (California Division of Oil and Gas, 1976, California Division of Oil and Gas, 1961).

Santa Maria Basin.--Miocene source rocks similar to those on shore should be present within the offshore Santa Maria Basin. Seismic data indicate that the offshore upper Tertiary section is thin. The total volume of Miocene or younger rocks in the basin is approximately 7500 cubic km. As shown on Figure 1, there are only two relatively small areas where burial is as great as 3050 meters (10,000 feet), a depth usually believed necessary for a thermal regime sufficiently high to generate hydrocarbons. However, Claypool (in Taylor, 1976) has presented evidence that petroleum generation can occur at lower than normal temperatures in rocks similar to those in this Miocene section. In addition, a higher than normal temperature gradient exists onshore and an exceptionally high geothermal gradient was encountered in the deep stratigraphic test well (OCS-CAL 78-164 No. 1) drilled in 1978 at the extreme south end of the offshore basin (McCulloh and Beyer, 1979; Fig. 1). If a similar high geothermal gradient extends to the entire offshore basin it may significantly increase the possibility for the generation of hydrocarbons. Unfortunately there has been essentially no measurement of the heat flow that occurs on the central and northern California shelves that could be used as a basis for examining this possibility.

Reservoir beds are not known to be present offshore, but it is anticipated that fractured shale in the middle Miocene Monterey Formation will be a primary objective. This presupposes that the onshore and offshore lithologies and diagenetic history of the Monterey Formation are similar. Pliocene sandstone reservoirs onshore are limited to the northeast part of the basin and are not expected to extend far offshore. Potential reservoirs within the offshore Santa Maria basin are unknown but may be present as transgressive deposits laid down before the middle Miocene marine transgression. There appear to be local continental deposits of possible Oligocene age beneath the Miocene rocks, but in general the Miocene section rests on probable Franciscan basement. The 1965 test well (Humble P-060-1) in the OCS area penetrated approximately 2150 meters of Pliocene and Miocene strata and 300 meters of volcanic rocks of probable Miocene age before bottoming in Franciscan basement. Areas around the margins of the offshore basin, where Miocene fractured shale reservoirs may be present, possibly contain low gravity oil.

There is some evidence for source rocks in the basin as shown by McCulloh's (1979) analysis of the 1978 stratigraphic test well. He says,

"The shallowest "show" recorded on the mud log occurred at a depth of about 2900 ft. The show was of gas without indications of crude oil or heavier hydrocarbons and originated from a clayey interval. The shallowest indication of migratory hydrocarbons heavier than methane occurred at about 3355 ft. These hydrocarbons consisted of chromatographically analyzed ethane, propane and butane accompanied by traces of petroliferous sands in the drill cuttings. Shows of both gas and more-or-less tarry oil are abundant to general from 3410 ft to about 5850 ft. Minor indications of tarry oil and heavy paraffin homologs were recorded throughout the deeper Miocene strata to a depth of about 9400 ft.

"Compositional details about the oil shows are lacking. No production tests were conducted and samples were not collected for analysis. Many of the shows of both gas and oil were from siltstone, mudstone, or calcareous shale as determined from induction electric log, the mud-log lithologic notes, and sample lithologies. The hydrocarbons which occur in such fine-grained strata are either indigenous products or have migrated from deeper sources. These fine-grained sediments would be regarded by most petroleum geologists as lacking the permeability to serve as petroleum reservoirs.

"In any event, the shows of oil and gas that occurred during drilling of this well attest eloquently to the presence of effective petroleum source rocks at or near the well site."

A more recent well (Mobile PO-321-1) drilled in Lease area 68 near the stratigraphic test well reached a depth of approximately 3500 m. This newer well must have penetrated essentially the same Neogene rocks, and its target may have been an unconformity on the top of a late Cretaceous or eary Jurassic bedded sequence (Espada equivalent?) also found in the vicinity of the stratigraphic test well (McCulloch and others, 1979). This well was not announced as a discovery, and was abandoned; however, there is no information available as to whether or not it encountered producible hydrocarbons.

Outer Santa Cruz Basin.--The most probable source beds are tar-impregnated mid-Miocene cherty shales that are found throughout the basin. Cretaceous rocks below the lower Miocene erosional unconformity are highly deformed and dense, and are considered to have little hydrocarbon potential. Pre-Miocene reservoir beds are not known, but Hoskins and Griffiths (1971) say that the data are insufficient to conclude that such reservoir rocks are totally missing. Minor oil shows are present in upper Miocene and Pliocene rocks, but these rocks generally are fine-grained and of poor reservoir quality. If production from fracture porosity is contemplated, it may necessitate a considerable and long term effort comparable to the development from fracture porosity in the Santa Maria basin onshore.

Bodega Basin.--There are reservoir quality sands of Eocene age in the basin but they are dense, having been deeply buried before being exhumed by the nearly shelf-wide erosion in Oligocene time. Although the Eocene section might be considered a prospective target, Eocene structures are difficult to define by seismic profiling and commonly do not coincide with younger overlying structures (Hoskins and Griffiths, 1971). In addition, onshore production, although largely from Eocene sands, has been trivial.

Reservoir quality sands are also present in Miocene basal and deep water marine units and at the base of the Pliocene. Tar and oil shows are common in the middle Miocene cherty shales, and some occur in the basal Pliocene sands. The major structures in upper Miocene and younger rocks are simple, large, closed anticlines. Although these structures and associated reservoir quality sands might be presumed to be attactive prospects, Hoskins and Griffiths (1971) say that "prior to drilling, Bodega basin appeared to have good potential... Such is not the present case, insofar as the Miocene and younger basin is concerned, as tests (8 dry holes) have been drilled on all major structures."

Point Arena Basin.--The most likely prospective section is composed of early Miocene and Pliocene sediments. There may be reservoir quality deep water marine sands in the basin, but their distribution is probably erratic. Oil shows are common in the middle and upper Miocene shales and cherty shales. Major structures associated with these potential source beds are elongate northwest-trending anticlines. In the southeast part of the basin the folds parallel, and are often bounded by high-angle reverse faults with large vertical components of displacement. Although these structures appeared to be the most likely prospects, three wells located on these structures in the southeastern end of the basin were dry.

Reservoir quality sands may also be present in the underlying Eocene rocks; however, as in the basins to the south, these rocks are dense. Eocene rocks are present at the south end of the basin, but thin rapidly toward the northwest. Furthermore, target structures in the Eocene may be difficult to define for as Hoskins and Griffiths (1971) note "....exploration below Miocene cherty shales is imprecise with present technology, to say the least."

Eel River Basin.--The onshore extension of the basin, which constitutes approximately 10% of the area of the entire basin, has produced only a moderate amount of gas from Pliocene sandstone, and an insignificant amount of oil from late Cretaceous sandstone and shale. If the onshore is representative of the basin as a whole, offshore prospects may be for gas. The prospective section is probably the upper Miocene-lower Pliocene Wildcat Group (maximum thickness of 3670 m), composed mostly of marine siltstone and claystone. A 1.6 m-long core taken recently from Quaternary sediment ponded near the crest of a piercement structure on the marginal plateaus west of Eureka contained gasoline-range hydrocarbons and gas in the methane to butane range (Field and others, 1979). These hydrocarbons are thought to have formed within Tertiary strata and migrated upward along fractures into the overlying unconsolidated sediment. Otherwise, hydrocarbon shows offshore are limited (Hoskins and Griffiths, 1971) and Miocene cherty shales, the probable source beds in basins to the south, are not reported here. Reservoir quality marine sandstone, within the Wildcat Group onshore, are fine-grained and lenticular, and their distribution is sporadic. Structures associated with the Mio-Pliocene section offshore are generally north-northwest trending gentle folds, some of which are bounded by parallel faults. Four wells drilled on these structures in the east central part of the basin were dry. There is evidence of shale flowage and diapirism in the basin (Hoskins and Griffiths, 1971), with the possibility of related structural traps.

The underlying Eocene section is composed of well indurated, fine-grained marine sediments with minor graywacke and conglomerate. Hoskins and Griffiths (1971) indicate that Eocene strata are present only in scattered erosional remnants on the Franciscan basement. Thus, Eocene rocks appear to have little potential, either as source beds or reservoirs.

ENVIRONMENTAL HAZARDS

Geologic hazards in parts of the central and northern California shelf basins that were previously included as prospective lease blocks in sale 53 have been described by McCulloch and others (1980) and Field and others (1980). Although these hazard studies were of limited areas they help to describe the kinds of hazards that may occur elsewhere in Lease Sale 73. However, geologic hazards in the remaining areas of Lease Sale 73 that may become prospective lease blocks cannot be adequately defined without additional fieldwork.

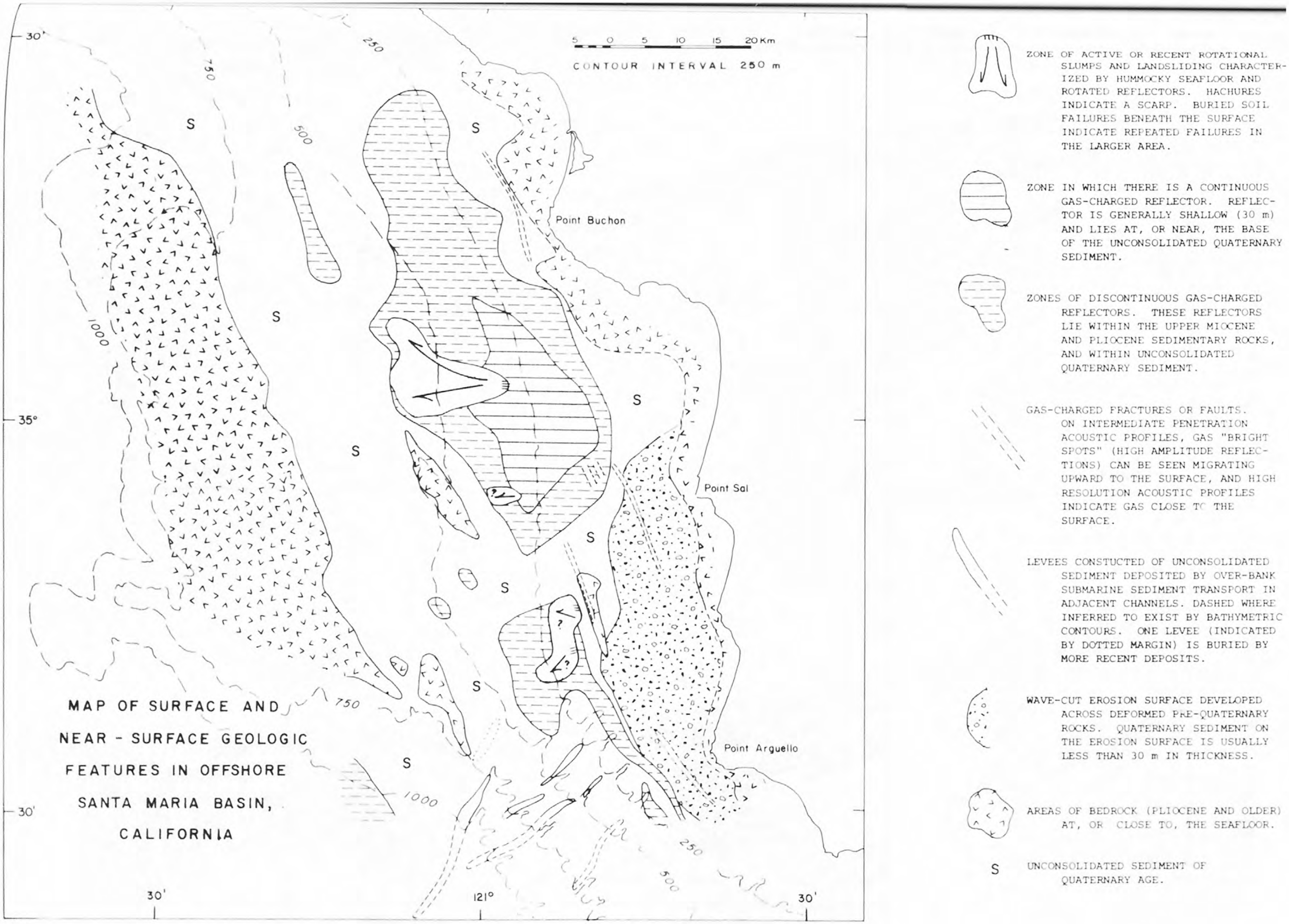
Instability of the sea floor, whether from seismic activity or sedimentary processes, is recognized as the principal hazard to emplacement of platforms and pipelines in the marine environment. Hazards related directly to seismic activity include ground shaking, fault rupture, generation of tsunamis, and earthquake-induced ground failures such as liquefaction and slumping. Faults showing displacement of either the sea floor or young (<11,000 years) sediments as well as those associated with historical earthquakes are considered active and therefore potentially hazardous to development. Instability of the sea floor can also result from dynamic (e.g. wave surge) and static (e.g. gravity) forces acting independently of seismic activity. Some areas of the sea floor are prone to mass movement (e.g. slumps, slides) or other forms of sediment transport (flows, creep, or current scour). Oil and gas seeps, while not inherently hazardous, may provide clues to the location of fractured reservoir rocks and shallow over-pressured gas pockets that can pose a danger to drilling operations.

The occurrence of gas increases chances for blowouts, which are considered to be the most costly and feared operational hazards related to oil and gas operations (Danenberger, 1980). Gas also decreases soil strength, and careful consideration must be given to gas content when designing foundations for seabed structures. As shown in the following discussion of the shelf basins in central and northern California, all lie adjacent to one or more long seismically active faults, and they can be expected to experience seismically induced ground motion. Slumps and slides have been mapped in the Point Arena and offshore Santa Maria basins, and evidence for shallow gas exists in, or adjacent to, all the basins.

Santa Maria Basin.--Geological hazards in offshore Santa Maria basin are of several kinds, gas charged sediment, shallow soil failures, deep-seated lateral displacement landslides, potential fault offset of the sea floor, and relatively strong seismic shaking (Fig. 16)

High amplitude seismic reflections ("bright spots") indicate that there may be accumulations of gas in the tops of anticlines in the Neogene rocks beneath the basin (Figures 17, 18). The gas appears to be moving upward from these structures, and migrating up dip toward the shore throughout the late Tertiary and Quaternary strata. This gas may be thermogenic in part (McCulloch and others, 1980).

Shallow soil failures (the largest has an area of 125 sq. km.) that involve the upper several tens of meters of unconsolidated sediment have occurred as gentle slopes (less than 2°) at water depths greater than 300 m. The gentle slopes on which the failures occur indicates that gravitational contribution to initial slide movement was minimal, and the water depths are sufficiently great to isolate the slides from cyclical storm-wave loading. When coupled with evidence for several episodes of sliding at the same sites,



MAP OF SURFACE AND NEAR - SURFACE GEOLOGIC FEATURES IN OFFSHORE SANTA MARIA BASIN, CALIFORNIA
CONTOUR INTERVAL 250 m
5 0 5 10 15 20 Km
Point Buchon
Point Sal
Point Arguello
30'
35°
30'
30'
121°
30'
250
500
750
1000
S
ZONE OF ACTIVE OR RECENT ROTATIONAL SLUMPS AND LANDSLIDING CHARACTERIZED BY HUMMOCKY SEAFLOOR AND ROTATED REFLECTORS. HACHURES INDICATE A SCARP. BURIED SOIL FAILURES BENEATH THE SURFACE INDICATE REPEATED FAILURES IN THE LARGER AREA.
ZONE IN WHICH THERE IS A CONTINUOUS GAS-CHARGED REFLECTOR. REFLECTOR IS GENERALLY SHALLOW (30 m) AND LIES AT, OR NEAR, THE BASE OF THE UNCONSOLIDATED QUATERNARY SEDIMENT.
ZONES OF DISCONTINUOUS GAS-CHARGED REFLECTORS. THESE REFLECTORS LIE WITHIN THE UPPER MIOCENE AND PLIOCENE SEDIMENTARY ROCKS, AND WITHIN UNCONSOLIDATED QUATERNARY SEDIMENT.
GAS-CHARGED FRACTURES OR FAULTS. ON INTERMEDIATE PENETRATION ACOUSTIC PROFILES, GAS "BRIGHT SPOTS" (HIGH AMPLITUDE REFLECTIONS) CAN BE SEEN MIGRATING UPWARD TO THE SURFACE, AND HIGH RESOLUTION ACOUSTIC PROFILES INDICATE GAS CLOSE TO THE SURFACE.
LEVEES CONSTUCTED OF UNCONSOLIDATED SEDIMENT DEPOSITED BY OVER-BANK SUBMARINE SEDIMENT TRANSPORT IN ADJACENT CHANNELS. DASHED WHERE INFERRED TO EXIST BY BATHYMETRIC CONTOURS. ONE LEVEE (INDICATED BY DOTTED MARGIN) IS BURIED BY MORE RECENT DEPOSITS.
WAVE-CUT EROSION SURFACE DEVELOPED ACROSS DEFORMED PRE-QUATERNARY ROCKS. QUATERNARY SEDIMENT ON THE EROSION SURFACE IS USUALLY LESS THAN 30 m IN THICKNESS.
AREAS OF BEDROCK (PLIOCENE AND OLDER) AT, OR CLOSE TO, THE SEAFLOOR.
S UNCONSOLIDATED SEDIMENT OF QUATERNARY AGE.

Figure 16.

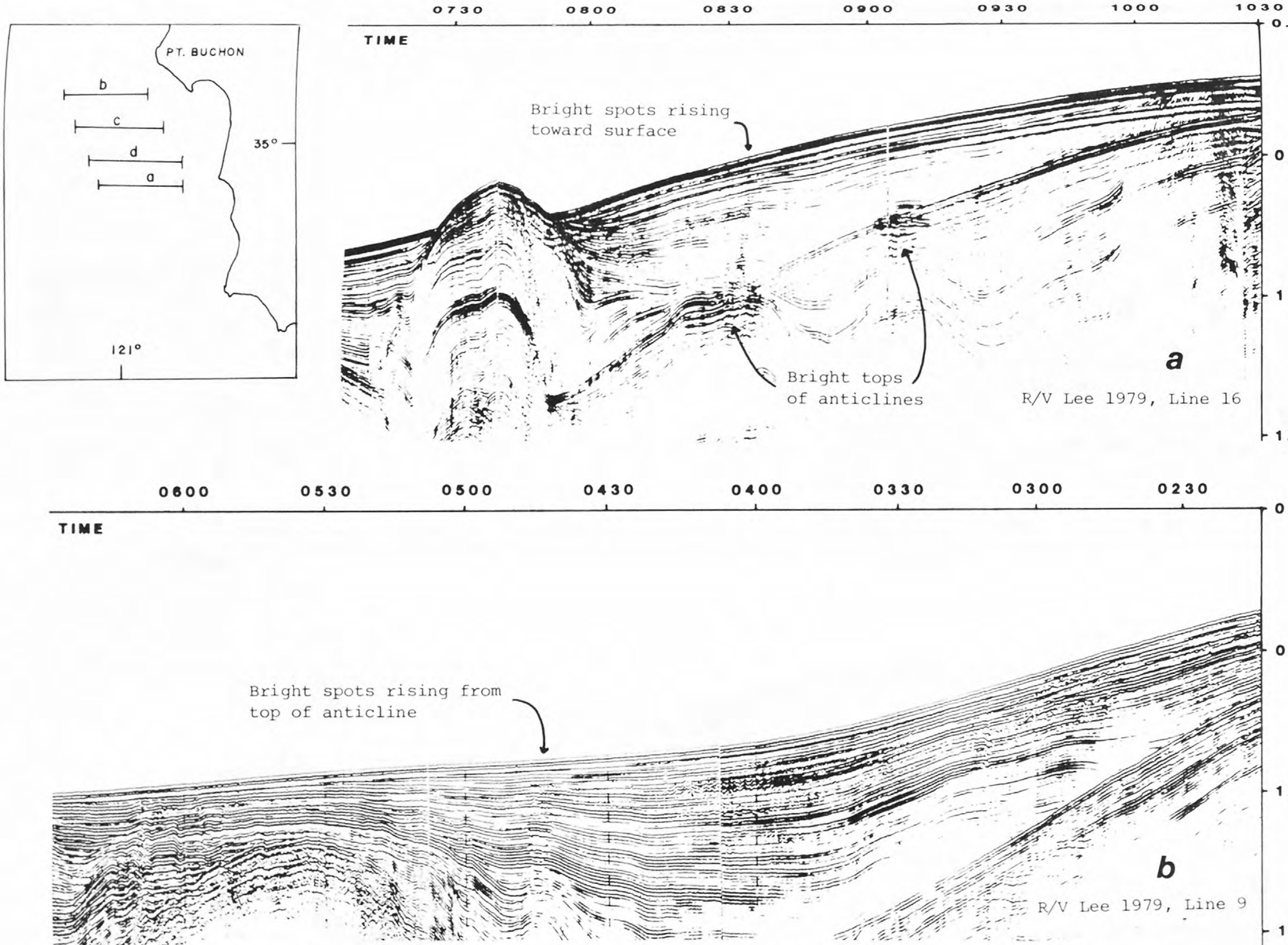


Figure 17. High amplitude "bright spot" reflectors and diffractions associated with subsurface gas in Outer Santa Maria Basin.

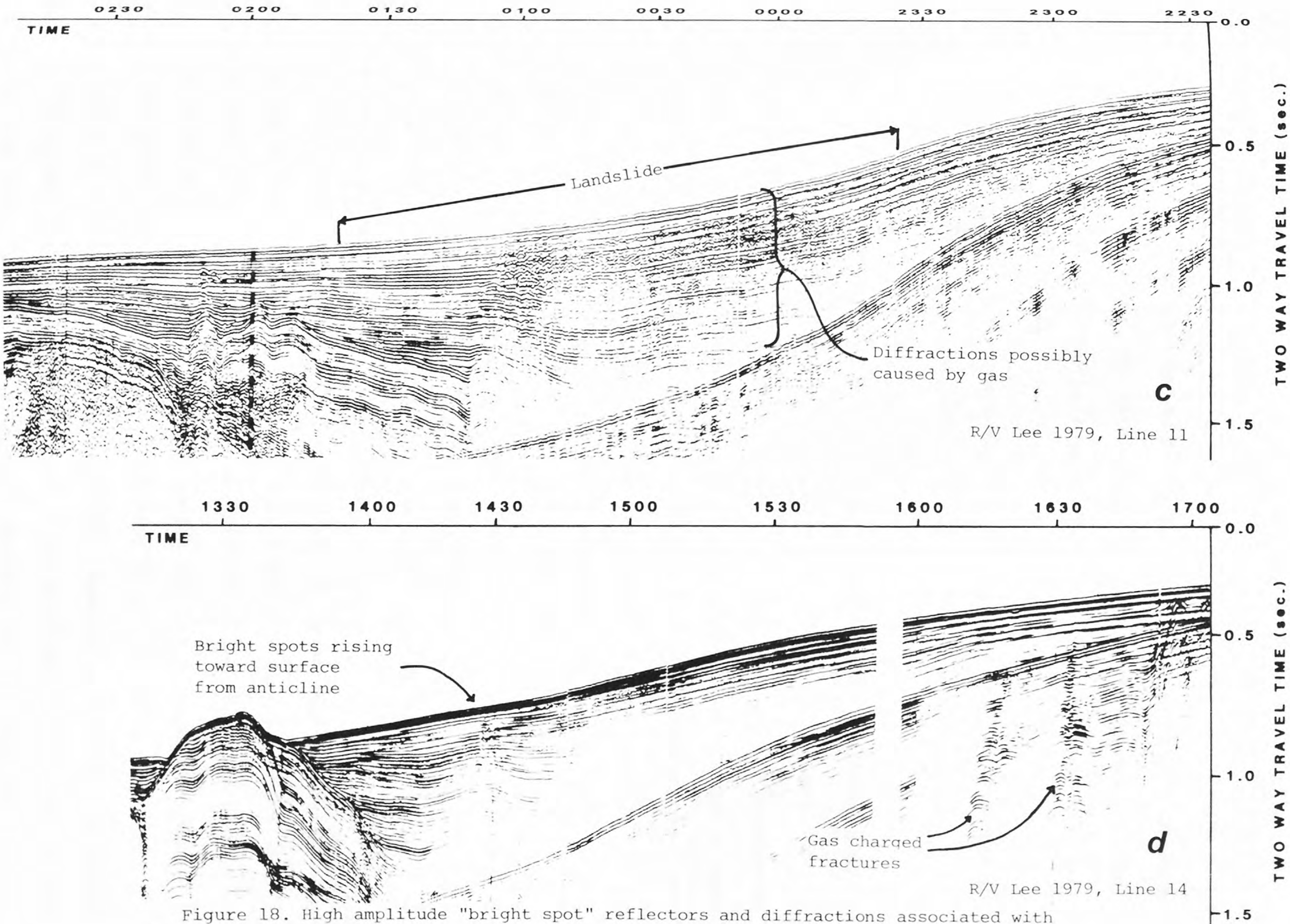


Figure 18. High amplitude "bright spot" reflectors and diffractions associated with subsurface gas in Outer Santa Maria Basin.

it is suggested that sliding may have resulted from a loss of soil strength due to seismic shaking. The slides occur in areas of gas charged sediment, and the presence of gas may have contributed to failure by decreasing soil strength (Fig. 16 and 18).

Deep-seated lateral displacements of rock masses and shallow slumps and slides occur in the northeastern end of the basin. The slides occur approximately 10-40 km south of Point Sur at the narrowest part of the continental shelf, as it is possible that sliding may have contributed to narrowing the shelf. The large slide blocks of Neogene rocks (uppermost Miocene, Pliocene and Quaternary) are found as discrete blocks of relatively coherent seismic reflectors that are underlain and laterally bounded by zones of contorted bedding. Shallow slumps are superimposed on these blocks. The sea floor in the area is highly disrupted by chaotic slump topography, in contrast to its normal smooth surface. Unmodified slump toes on the sea floor and the absence of ponded young sediment in the topographic depressions indicate that these failures are active. The shallow failures are probably gravity-driven but seismic profiles suggest that the deep seated failures may be caused by seaward thrusting associated with high-angle reverse faulting along the northeastern edge of the basin.

The basin is bounded on the east and west by relatively long seismically active faults (Fig. 2). Profiles across the 3-5 km wide Hosgri Fault zone (Wagner, 1974) on the east show considerable east-side-up verticle seperation on steep easterly dipping faults along which presumed Franciscan basement rocks have been elevated to near the surface (Fig. 4). The displacement history of this fault zone is controversial. Some (e.g. Graham and Dickinson, 1978) suggest that it has acted as part of the major coastal fault system that continues north, eventually joining or approaching the San Andreas fault in the Gulf of the Farallones and that it has undergone right-lateral strike slip displacement of as much as 115 km. Others (e.g. Hamilton and Willingham, 1977) prefer less than 20 km strike slip, and argue for no direct connection with a coastal fault system. Recent mapping (Leslie, in press) has demonstrated a possible offshore connection between an eastern strand of the Hosgri fault zone and the San Simeon fault to the northwest, and this mapping supports the possibility of a through-going fault system.

Earthquake epicenters indicate that the fault is seismically active, and first motion studies show that it is undergoing right lateral displacement with some north-south compression (Fig. 19). Although the fault has produced no unequivocal sea floor offsets in Holocene deposits, Wagner (1974) and Leslie (in press) show displacement of the base of the unconsolidated surface sediment of Quaternary and probable Holocene age. Thus, this seismically active fault must be considered as having the potential for producing surface displacement.

The Hosgri Fault has been mapped to about 10 km south of the latitude of Point Sal, (Buchanan-Banks and others, 1978) and at the south end of the basin faulting steps seaward and changes in strike from NNW to NW. To the west the faults turn and parallel the northwest trend of the faults associated with the Santa Lucia Bank. The Santa Lucia Bank fault comprises two or more strands that approach but do not break the surface. The large topographic expression of the fault (as much as 40 m) appears to be largely a fault line scarp, rather than a fault scarp. As shown by the offset of unit Tp along the fault (Fig. 4) there has been considerable relatively young displacement on the fault, and within the basin, sediment of probable Pleistocene age has been folded against the edge of the block, indicating young relative displacement between the Santa Lucia high and the basin. West of the Santa Lucia Bank fault there are numerous steeply dipping faults, most of which show vertical separation, and some of which have displaced the sea floor to lengths of 30 to 40 km. Adjustment to the motion between the North American and Pacific plates appears to be taking place across this basin. In this part of California movement between the plates is thought to be approximately 5.5 cm/yr (Atwater, 1970) and only about 2.5 cm/yr is occurring on the San Andreas. Thus, more than half the displacement may be involved in deformation and faulting west of the San Andreas fault (Gawthrop, 1975).

Earthquake history prior to instrumentally located epicenters that date from the late 1920's must be drawn from historic accounts (Townley and Allen, 1939). During this pre-instrumental period of 124 years more than 116 earthquakes were reported, most since 1900 (Fig. 6, in McCulloch and others, 1980). The post-1900 increase appears to have been greater than the demographic change (Donley and others, 1979) and probably represents a real increase in seismic activity. Rossi-Forel shaking intensities assigned to 57 of these 116 earthquakes have the following distribution:

Rossi-Forel Intensity	Number of Earthquakes
X	3
VIII-IX	8
VII-VIII	5
VI-VII	4
V-VI	12
IV-V	8
III-IV	11
II-III	6

The most severe earthquake during this time, and as yet the most severe in this area, was the magnitude 7.3 Lompoc earthquake of November 4, 1927.

Byerly (1930) located the epicenter 75 km west of Point Arguello. Reanalysis of seismographic data by Smith (1978), Hanks (1979), Gawthrop and Engdahl (1975) and Gawthrop (1975, 1978a) moved the epicenter progressively eastward (Fig. 2), and the Gawthrop location places it very nearly on the Hosgri Fault. Evernden (oral commun., 1980) modeled the observed onshore distribution of shaking intensity (Fig. 19) concluded that the epicenter was close to the mapped location of the Hosgri fault. The earthquake generated a tsunami that locally reached a height of 6 feet. The tsunami was also recorded on tide gauges at San Francisco and San Diego, and was sufficiently large to cross the Pacific and to be recorded at Hawaii and Japan. Because of its possible location on the Hosgri fault, that passes several kilometers west of the Diablo Canyon nuclear reactor at Point Buchon, this earthquake has received considerable scrutiny. It is the basis for the maximum credible earthquake that the reactor must be designed to withstand.

Strong seismic shaking can be expected in the eastern part of the basin in the event of a repeat of a 1927 earthquake on the Hosgri fault zone. Design spectra for maximum ground motion of the Diablo Canyon reactor facility at Point Buchon (Newmark, 1976) specify:

Acceleration (g)	Velocity (inches/sec.)	Displacement (inches)
0.75	24	8

Although this ground motion is strong, it is presently under review, in part because unexpectedly high vertical accelerations recorded during the m 6.7 Imperial Valley earthquake of October 15, 1974 (Porcella and Matthesen, 1979) suggest the possibility for still stronger ground motion.

Strong ground motion could also be expected in the western part of the basin as the result of faulting on Santa Lucia Bank. The largest events on the Santa Lucia Bank are m 5.4 and 5.6, and, as relocated by Gawthrop (1975)

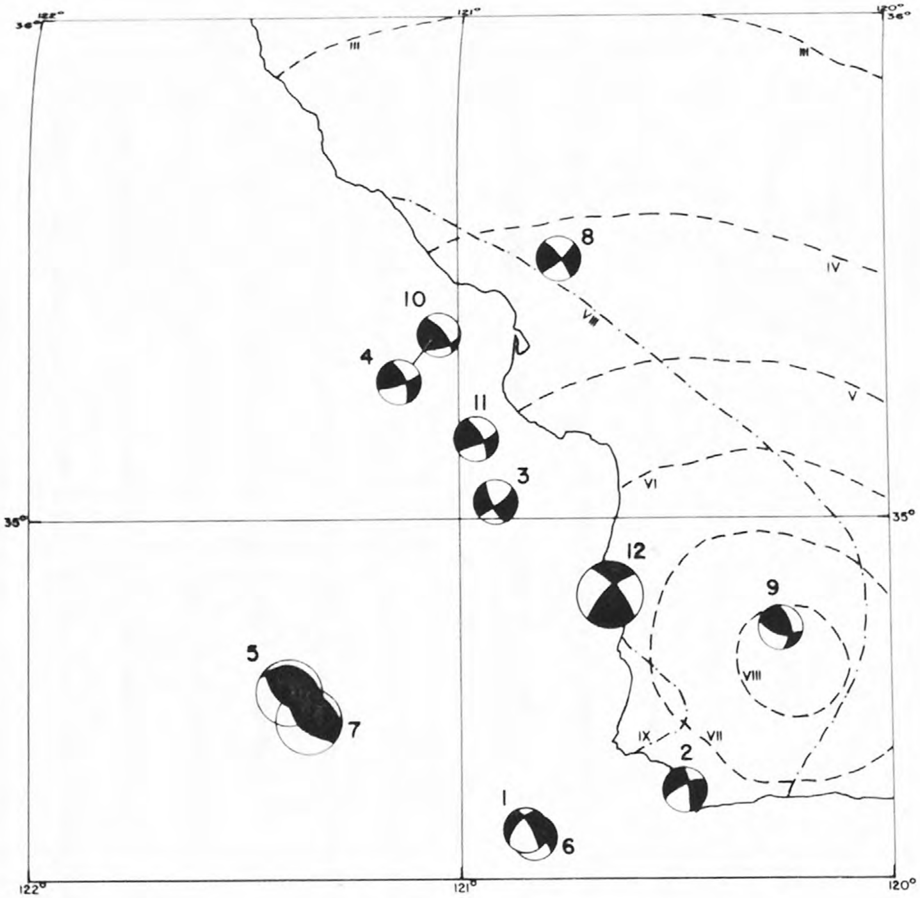


Figure 19. First motions and Rossi-Forel shaking intensities in the Santa Maria Basin area. The first motion diagrams are lower hemisphere plots, the white indicating dilation, the black, compression. Large diagrams indicate well-constrained events.

– – – – – – – – 1915 Los Alamos earthquake
–·–·–·–·–·– 1927 Lompoc earthquake

	DATE	MAGNITUDE
1	49/06/27	4.5
2	59/10/01	4.5
3	62/02/01	3.7
4	69/09/01	3.7
5	69/10/22	5.4
6	69/10/30	3.7
7	69/11/05	5.6
8	71/01/26	3.1
9	72/09/23	3.0
10	74/06/19	2.8
11	74/09/24	3.0
12	80/05/28	4.8

References

-all focal mechanisms except events 1, 6, and 12 from Gawthrop, W. H., 1978, Seismicity and tectonics of the central California coastal zone: California Division Mines and Geology, Special Report 137, p. 45-56.

-events 1 and 6 from Gawthrop, W. H., 1975, Seismicity of the central California coastal region: U.S. Geological Survey Open-File Report 75-134, 90p.

-event 12 from Robert S. Cockerham (written commun., 1980).

-1915 Los Alamos isoseismals from Beal, C. H., 1915, The earthquake of Los Alamos, Santa Barbara, California, Jan. 11, 1915: Seismological Society of America Bulletin, v. 5, p. 14-25.

-1927 Lompoc isoseismals from Byerly, P., 1930, The California earthquake of November 4, 1927: Seismological Society of America Bulletin, v. 20, p. 53-66.

they lie in the area where faults break the sea floor. However, if one of the several approximately 40 km long sea floor fault offsets on the bank resulted from a single displacement event, the associated earthquake would have had a magnitude of approximately 7 as estimated from comparisons of observed fault rupture length vs. earthquake magnitude (e.g. Tocher, 1958; Iida, 1965; Albee and Smith, 1967; Bonilla, 1967, 1970).

Outer Santa Cruz and Bodega Basins.--Active faulting in Bodega Basin is largely limited to its eastern margin (Fig. 5). In Monterey Bay, at the south end of the basin, seismically active faults displace Holocene deposits and the modern sea floor (Greene and others, 1973). These faults strike northwest obliquely toward, and terminate against, the seismically active San Gregorio-Palo Colorado fault. First motions indicate that the faults in the bay and the San Gregorio - Palo Colorado fault are moving with right lateral strike slip displacement. To the north, in the Gulf of the Farallones just west of San Francisco, young faults displace Holocene deposits at the sea floor, but the redistribution of sea floor sediment is so rapid that displacement of the sea floor is minimal. These faults occur in a wide zone between the San Andreas and the possible northwestern extension of the San Gregorio - Palo Colorado fault. There are a few epicenters further offshore that lie along the margins of the outer Santa Cruz High and the Farallon - Pigeon Point High, but their relation to possible faulting is not known. Strong seismic shaking could occur in outer Santa Cruz basin in the event of a large earthquake on the San Gregoio-Palo Colorado fault. Based on the assumption that this fault is part of a coastal fault system that extends at least from the south shore of Monterey Bay northward to the Golden Gate, it has been suggested that this fault may have the potential of producing a magnitude 7.5 earthquake (Greene and others, 1973). Strong seismic shaking could also occur in Bodega basin from such an event, or be caused by a large earthquake on the San Andreas fault.

Shallow gas, herein called shelf-edge gas, has been mapped along the upper edge of the continental slope of the outer Santa Cruz basin. The gas appears to be migrating up the slope and accumulating along bedding surfaces in a prograded sediment wedge that forms the edge of the continental shelf (McCulloch and others, 1980). Associated with this shelf edge gas is irregular bottom topography that suggests downslope movement of unconsolidated surface sediment on the continental slope. In the northern part of Bodega basin (Fig. 20) much of the continental slope west of the 250 m isobath is in landslide. Landslides may extend further south then the latitude of Point Reyes, but there are insufficient data to define this distribution.

Shallow gas a few meters to tens of meters below the sea floor has been mapped along the eastern edge of the northern Bodega basin (Fig. 20) where it occurs in a band as much as 12 km wide and 90 km long. A small accumulation of shallow gas on the edge of the shelf approximately 50 km northwest of Point Reyes has surface pits thought to be craters eroded by escaping gas.

Tsunamis have been reported in this area, but they are generally associated with water level changes of less than about 1 meter. The greatest change in water elevation reported in Iida and others (1967) for the period from the first observation of a tsunami in San Francisco in 1812 to 1967 was 4.6 meters reported at Half Moon Bay in 1859. Iida and others (1967) give the location of the probable epicenter as San Francisco (Oct. 18, 1859). A magnitude 7.4 earthquake (April 11, 1946) in the easter Aleutian Islands produced tsunamis of 3.5 meters in Santa Cruz and Half Moon Bay, but the amplitudes were considerably smaller where measured along adjacent parts of the coast. The Great Alaskan Earthquake (M8.5, March 1964) that generated the highly destructive tsunamis at Crescent City to the north had only a minor effect along the shore of Bodega basin, producing only a 1.3 meter rise in water at San Francisco (Iida and others, 1967; Wiegel, 1970).

Point Arena Basin.--There are inadequate publicly available acoustic reflection records to examine potential geologic hazards related to faulting or slumping and sliding in northern two-thirds of this basin (Appendix). In addition, the basin is not well covered by existing seismograph networks, and it is possible (as suggested by the relatively high proportion of M >4.5 earthquakes reported; Fig. 10) that smaller earthquakes that indicate not only activity but also possible location of active faults, are not detected. The potential for strong ground motion over the entire basin is great, for the San Andreas lies within 10 to 30 km of the 1000 meter isobath. In addition, several M >4.5 earthquakes have occurred along the western edge of the basin. Shallow gas accompanied by gas craters and a possible gas plume in the water column have been mapped along the shelf edge in the southern third of the basin (Fig. 20), and slides have been identified seaward of the 500 meter isobath on the adjacent continental slope. The combined potential for strong ground motion, the possible presence of shallow gas and the fine-grained muds on the basin floor (Welday and Williams, 1975) suggest that slumps and slides may exist in the northern two-thirds of the basin.

Eel River Basin.--Subduction of the Gorda lithosperic plate beneath Eel River Basin results in considerable seismic activity. Within the general area of the basin, 1182 earthquakes (detected without instruments or >m2) during the last 12 decades have had the following distribution (Couch and others, 1974; Real and others, 1978):

MAGNITUDE

DECADE	3	3.0-3.9	4.0-4.9	5.0-5.9	6.0-6.9	> 7	UNKNOWN	TOTAL
1850's							12	12
1860's							5	5
1870's							6	6
1880's							12	12
1890's							49	49
1900's							106	106
1910's					1		50	51
1920's				1	1	2	73	77
1930's			5	12	2		78	97
1940's		8	29	13	4		41	95
1950's	38	138	50	6	3		25	260
1960's	11	178	56	10	0		27	282
1970-3	4	75	42	4	0		4	129
TOTALS	53	399	182	46	11	2	488	1181

This table indicates that on the average the area should experience one >M5 earthquake per year and one >M6 earthquake per decade. Major earthquakes of M7-7.5 have also occurred, and should be expected in the future (Smith, 1975).

The shelf and plateau areas are cut by numerous faults, many of which displace the sea floor or Quaternary age sediments (Fig. 13, Field and others, 1980). First motion studies by Bolt and others (1968) have shown a right-lateral strike slip component along northwest-trending structures southwest of Crescent City. Normal and thrust faulting, as well as strike-slip faulting are also found within the basin. The large number of faults that displace the sea floor or very young sediments, coupled with the high seismicity of the area, suggests that there exists a high potential for repeated movement along

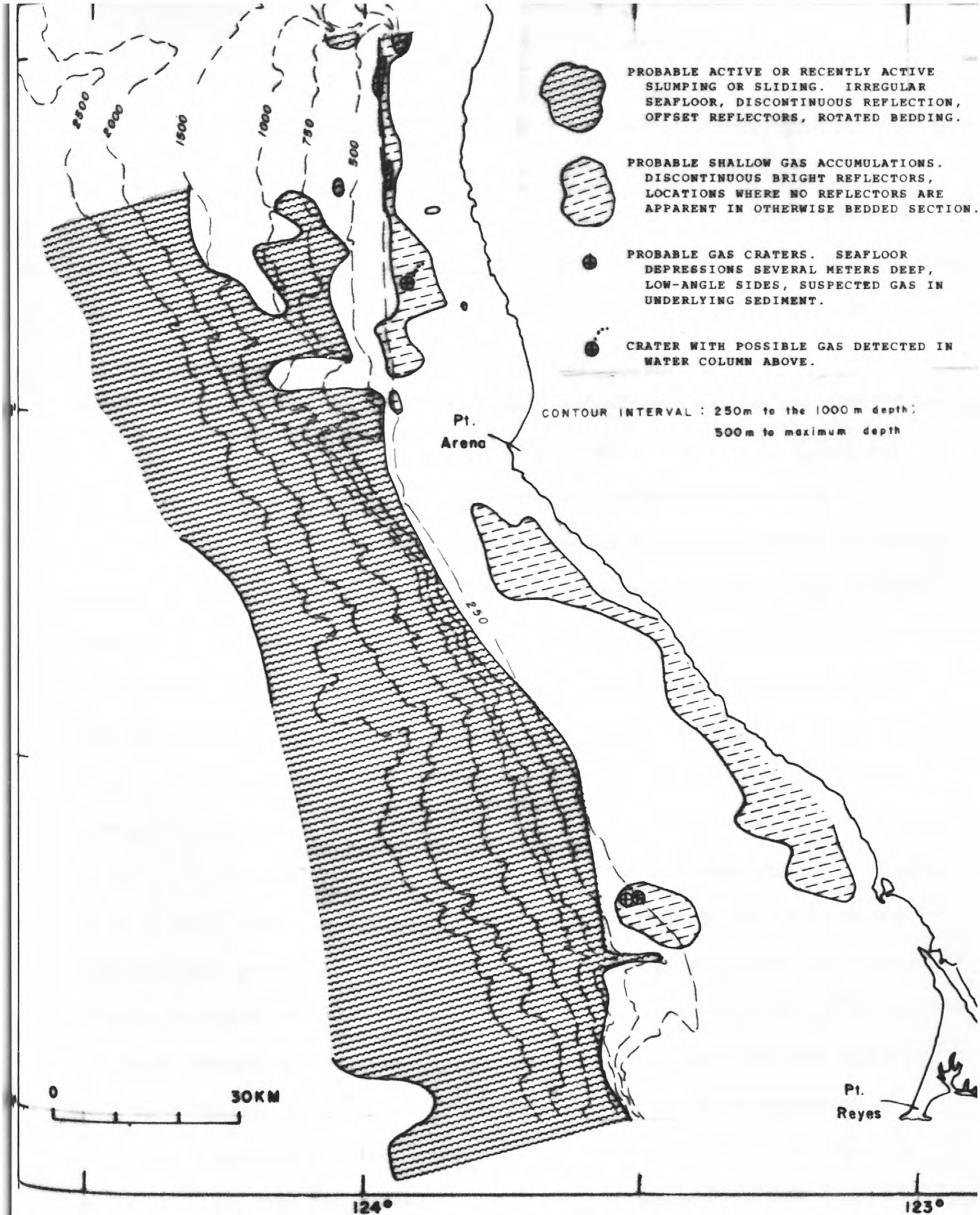


Figure 20. Surface and near surface features in Arena and Bodega basins, after Rubin, in McCulloch and others, 1980.

faults.

A series of discontinuous ridges on the central and outer plateaus are interpreted as being diapiric in origin. Ridge flanks and crests have irregular surface topography and contain little or no Quaternary sediment. Internal acoustic structure ranges from opaque to deformed, and sediment cores from the ridges contain Pliocene aged stiff clayey silt with mudstone clasts. Recent diapiric activity of these ridges is documented by large-scale slumping, upward bowing of the sea floor, and offsets in the sea floor from recent thrust faulting (Field and Gardner, 1980). The active uplift may produce concurrent ground shaking and abrupt changes in declivity.

Onto this seismically active shelf streams draining northern California discharge large loads of fine-grained organic-enriched potentially unstable sediment. Average deposition rates may be as high as 1.0 m/1000 yr throughout the area and much higher nearshore. Sediment exceeding 50 m in thickness collects in large depocenters offshore of Humboldt Bay and the Klamath River. Thick sequences of sediment are deposited on the slope and inner plateau. Associated with this young sediment are large zones, measuring 100's of km^2, of sediment slumps and slides. Many of the slumps extend to depths of 80 m or more below the sea floor and in some areas there is evidence for repeated failure at the same location. The hummocky nature of the slumps attests to their recency, and their widespread distribution demonstrates that sediment failure is the principle mechanism of downslope sediment movement in Eel River Basin. Large areas of unstable sediments, which appear to be incipient slumps, also occur throughout the area (Fig. 21). In addition, sediment cores from the plateau areas contain contorted and disturbed bedding, graded sand layers, and other indications of mass transport. On the shelf shoreward of the failure zones, large areas show acoustic characteristics that

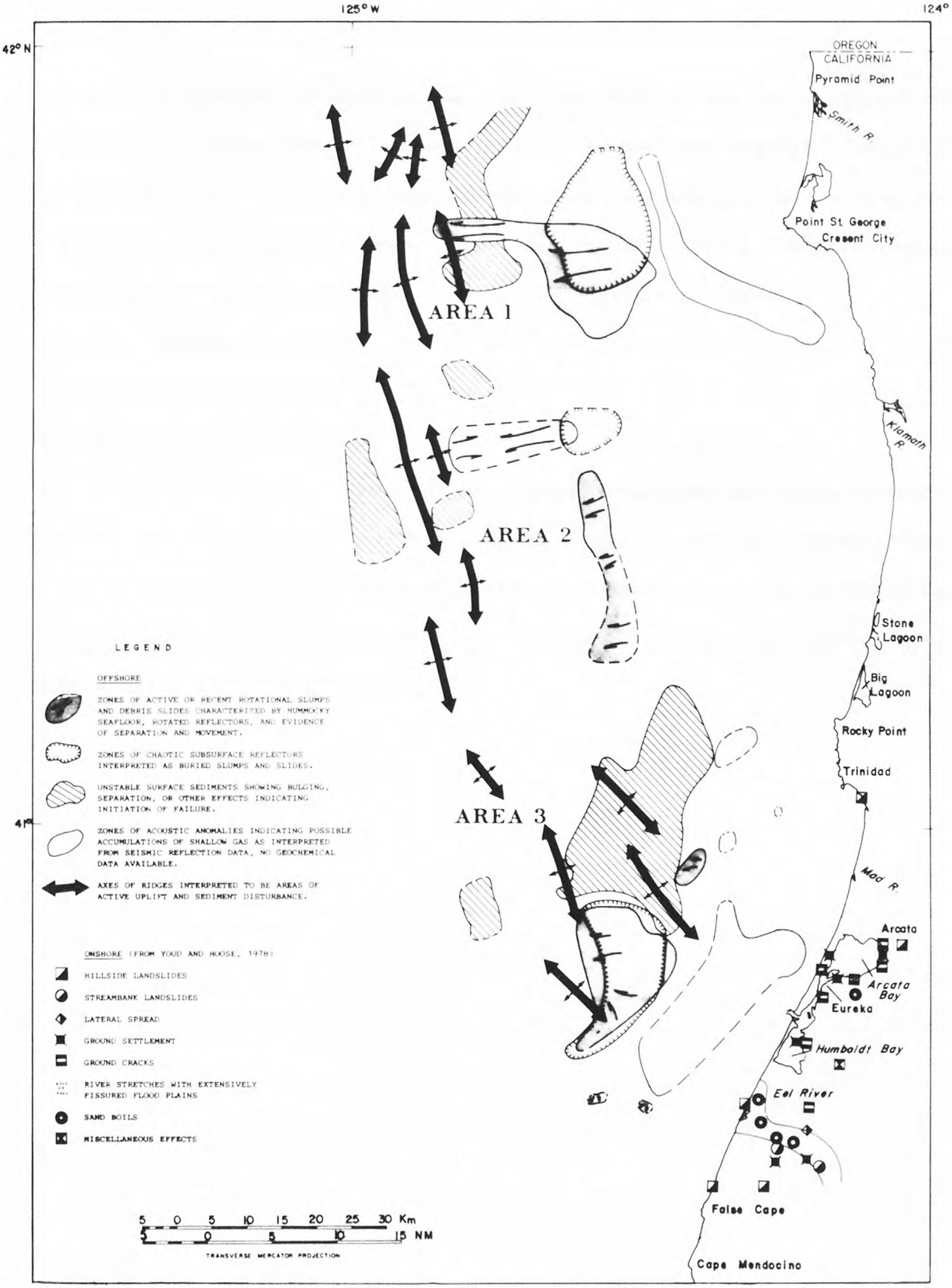


Figure 21. Surface and near surface features in Eel River Basin.

suggest the presence of shallow gas. The sea floor on the outer plateau is underlain by Bottom Simulating Reflectors (BSR) that may indicate the presence of gas hydrates. Dillon and others (1980) have suggested that hydrates may form seals that trap gas. Thus, there is a possibility for the existence of overpressured gas that may present problems during exploration.

The frequent large earthquakes generated along major structural planes (Mendocino and Blanco fracture zones, Juan de Fuca Ridge, Queen Charlotte Islands and Fairweather faults) in northwestern North America generate tsunamis that effect shallow regions of the northern California shelf and coast. For example, Crescent City has had a long history of tsunamis. The largest was generated by the 1964 Alaska earthquake which produced waves as high as 6.3 m that caused eleven deaths and about nine million dollars of damage (Iida and others, 1967).

REFERENCES CITED IN CHAPTER B

Albee, A. L., and Smith, J. L., 1967, Geologic criteria for nuclear power plant location: Society of Mining Engineers Transactions, v. 238, p. 430-434.

Atwater, Tanya, 1970, Implications of plate tectonics for the Cenozoic tectonic evolution of western North America: Geological Society of America Bulletin, v. 81, no. 12, p. 3512-3536.

Bachman, S. B., 1978, A Cretaceous and early Tertiary subduction complex, Mendocino coast, northern California, p. 419-430, in Howell, D. G. and McDougall, K. A., eds., Mesozoic Paleogeography of the Western United States-Pacific Coast Paleogeography Symposium 2: Pacific Section, Society of Economic Paleontologists and Mineralogists, Los Angeles, 573 p.

Back, William, 1957, Geology and ground-water features of the Smith River Plain, Del Norte County, California: U.S. Geological Survey Water Supply Paper 1254, 76 p.

Bailey, E. H., Irwin, W. P., and Jones, D. L., 1964, Franciscan and related rocks, and their significance in the geology of western California: California Division of Mines and Geology Bulletin 183, 177 p.

Bolt, B. A., Lomnitz, Cinna, and McEvilly, T. V., 1968, Seismological evidence on the tectonics of central and northern California and the Mendocino Escarpment: Seismological Society of America Bulletin, v. 58, no. 6, p. 1725-1767.

Bonilla, M. G., 1967, Historic surface faulting in continental United States and adjacent parts of Mexico: U.S. Geological Survey Open-File Report; also U.S. Atomic Energy Commission Report TID-24124, 36 p.

______, 1970, Surface faulting and related effects, in Wiegel, R. L., ed., Earthquake Engineering, Englewood Cliff, New Jersey, Prentice Hall, Inc., p. 47-74.

Buchanan-Banks, J. M., Pampeyan, E. H., Wagner, H. C., and McCulloch, D. S., 1978, Preliminary map showing recency of faulting in coastal south-central California: U.S. Geological Survey Miscellaneous Field Studies Map MF-910.

Byerly, Perry, 1930, The California earthquake of November 4, 1927: Seismological Society of America Bulletin, v. 20, no. 1, p. 53-66.

California Division of Oil and Gas, 1960, California oil and gas fields--Maps and data sheets, Part 1, San Joaquin-Sacramento Valleys and northern coastal regions: California Division of Oil and Gas, p. 3-493.

______, 1961, California oil and gas fields--Maps and data sheets, Part 2, Los Angeles-Ventura basins and central coastal regions: California Division of Oil and Gas, p. 496-913.

______, 1969, California oil and gas fields--Supplemental maps and data sheets: California Division of Oil and Gas, 183 p.

______, 1975, 61st annual report of the state oil and gas supervisor: California Division of Oil and Gas, Report No. PRO6, 155 p.

Champion, D. E., Gromme, C. S., and Howell, D. G., in press, Paleomagnetisim of the Cretaceous Pigeon Point Formation and the inferred northward displacement of 2500 km for the Salinian Block, California: American Geophysical Union.

Cooper, Alan, 1971, Structure of the continental shelf west of San Francisco, California: U.S. Geological Survey Open-File Report.

Couch, R. W., Victor, L., and Keeling, K., 1974, Coastal and offshore earthquakes of the Pacific northwest between 39° and 49°10'N latitude and

123° and 131°W longitude: School of Oceanography, Oregon State University, Corvallis, 67 p.

Curray, J. R., 1966, Geologic structure on the continental margin, from subbottom profiles, northern and central California: Geological Northern California, Bulletin 190, p. 337-342.

Curray, J. R., and Nason R. D., 1967, San Andreas fault north of Point Arena, California: Geological Society of America Bulletin, v. 78, no. 3, p. 413-418.

Danenberger, E. P., 1980, Outer continental shelf oil and gas blowouts: U.S. Geological Survey Open-File Report 80-101, 13 p.

Dillon, W. P., Grow, J. A., and Paull, C. K., 1980, Unconventional gas hydrate seals may trap gas off southeast U.S.: Oil and Gas Journal, January 7 issue, p. 124-130.

Evitt, W. R., and Pierce, S. T., 1975, Tertiary ages from the coastal belt of the Franciscan complex, northern California: Geology, v. 3, no. 8, p. 433-436.

Field, M. E., and Gardner, J. V., 1980, Shale diapirism on the northern California margin: Geological Society of America, abstract for Atlanta meeting.

Field, M. E., Clarke, S. H., Jr., and White, M. E., 1980, Geology and geological hazards of offshore Eel River Basin, Northern California continental margin: U.S. Geological Survey Open-File Report 80-1080.

Field, M. E., Kvenvolden, K. A., and Clarke, S. H., Jr., 1979, Location and hydrocarbon content of a gravity core from the offshore Eel River: U.S. Geological Survey Open-File Report 79-1618, 1 p.

Gawthrop, W. H., 1975, Seismicity of the central California coastal region: U.S. Geological Survey Open-File Report 75-134, 87 p.

______, 1978a, The 1927 Lompoc California earthquake: Seismological Society of America Bulletin, v. 68, p. 1705-1716.

______, 1978b, Seismicity and tectonics of the central California coastal region: California Division of Mines and Geology, Special Report 137, p. 45-56.

Gawthrop, W. H., and Engdahl, E. R., 1975, The 1927 Lompoc earthquake and the 1969 San Luis Bank earthquake sequence, a comparative study (abs.): American Geophysical Union Transactions, v. 56, no. 12, p. 1028.

Graham, S. A., 1976, Tertiary sedimentary tectonics of the central Salinian block of California: PhD. Thesis, Geological Department, Stanford University, 213 p.

Graham, S. A., and Dickinson, W. R., 1976, Evidence for 115 kilometers of right slip on the San Gregorio-Hosgri fault trend: Science, v. 199, p. 179-181.

Greene, H. G., Lee, W. H. K., McCulloch, D. S., and Brabb, E. E., 1973, Faults and earthquakes in the Monterey Bay region, California: U.S. Geological Survey Miscellaneous Field Study MF-518, 14 p.

Hall, C. A., Jr., 1975, San Simeon-Hosgri fault system, coastal California: economic and environmental implications: Science, v. 190, p. 1291-1294.

Hamilton, D. H., and Willingham, C. R., 1977, Hosgri fault zone, amount of displacment, and relationship to structures of the western Transverse Ranges: Geological Society of America Abstracts with Programs, v. 9, p. 429.

Hanks, T. C., 1979, The Lompoc, California earthquake (November 4, 1927; M-7.3) and its aftershocks: Seismological Society of America Bulletin, v. 69-2, p. 451-462.

Hanks, T. C., and others, 1975, Seismic moments of the larger earthquakes of the southern California region: Geological Society of America Bulletin, v. 86, no. 8, p. 1131-1139.

Hanna, G. D., 1952, Geology of the continental slope off central California: California Academy of Science Proceedings, 4th ser., v. 7, no. 9, p. 325-358.

Howell, D. G., McLean, Hugh, and Vedder, J. G., in press, Upper Cretaceous (Campanian) suturing and large scale translocation of the Salinian and Nacimiento blocks, California: American Geophysical Union.

Howell, D. G., Crouch, J. K., Greene, H. G., McCulloch, D. S., and Vedder, J. G., 1980, Basin development along the late Mesozoic and Cainozoic California margin: a plate tectonic margin of subduction, oblique subduction, and transform tectonics: International Association of Sedimentologists, Special Publication 4, p. 43-62.

Hoskins, E. G., and Griffiths, J. R., 1971, Hydrocarbon potential of northern and central California offshore: American Association of Petroleum Geologists, Memoir 15, v. 1, p. 212-228.

Iida, Kumizi, 1965, Earthquake magnitude, earthquake faults, and source dimensions: Nagoya University, Journal of Earth Sciencs, v. 13, no. 2, p. 115-132.

Iida, Kumizi, Cox, D. C., and Pararas-Curayannis, George, 1967, Preliminary catalog of tsunamis occurring in the Pacific Ocean: Hawaii Institute of Geophysics, University of Hawaii Data Report No. 5, HIG-67-10.

Ingle, J. C., Jr., 1976, Late Neogene paleobathymetry and paleoenvironments of Humboldt basin, northern California, p. 53-61 in Fritsche, A. E., Ter Best, Harry, Jr., and Wornardt, W. W., eds., The Neogene Symposium: Pacific Section, Society of Economic Paleotologists and Mineralogists

Annual Meeting, San Francisco, 1976, 160 p.

Irwin, W. P., 1960, Geologic reconnaissance of the northern Coast Ranges and Klamath Mountains, California, with a summary of mineral resources: California Division of Mines Bulletin 179, 80 p.

Johnson, J. D., and Normark, W. R., 1974, Neogene tectonics evolution of the Salinian Block, west-central California: Geology, v. 12, no. 1, p. 11-14.

Jones, D. L., Pessago, E. A., Csejtey, Bela, Jr., 1976, Significance of the Upper Chulitna ophiolite for the late Mesozoic evolution of southern Alaska: Geological Society of America Abstracts with Programs, v. 8, no. 3, p. 385-386.

Kistler, R. W., and Peterman, Z. E., 1973, Variations in Sr, Rb, K, Na, and Initial Sr 87/Sr 86 in Mesozoic granitic rocks and intruded wall rocks in central California: Geological Society of America Buletin, v. 84, no. 11, p. 3489-3512.

Kulm, L. D., von Huene, R., et al., 1973, Initial reports of the Deep Sea Drilling Project, v. 18: Washington (U.S. Government Printing Office), p. 31-95.

Lee, W. H. K., Yerkes, R. F., and Simirenko, M., 1979, Recent earthquake activity and focal mechanisms in the western Transverse Ranges, California: U.S. Geological Survey Circular 799-a, p. 1-26.

Leslie, R. B., (in press), Continuity and tectonic implications of the San Simeon-Hosgri fault zone, central California: U.S. Geological Survey Open-File Report, 82 p.

Manning, G. A., and Ogle, B. A., 1950, Geology of the Blue Lake quadrangle, California: California Division of Mines Bulletin 148, 36 p.

McCulloch, D. S., 1973, Paper presented at 2nd San Andreas Fault Symposium Stanford University, 1973.

______, 1976, Acoustic reflection profiles, R/V KELEZ, April 1973, Leg 1, Gulf of Farallones, central California offshore; U.S. Geological Survey Open-File Report 76-736, 50 p., 1 map.

McCulloch, D. S., and Chapman, R. H., 1977, Maps showing residual magnetic intensity along the California coast, latitude 37°30'N: U.S. Geological Survey Open-File Report 77-79.

McCulloch, D. S., Greene, H. G., Heston, K. S., and Rubin, D. M., 1980, A summary report of the geology and geologic hazards in proposed Lease Sale 53, central California outer continental shelf: U.S. Geological Survey Open-File Report 80-1095, 69 p.

McCulloch, D. S., Vedder, J. G., Wagner, H. C., and Brune, R. H., 1979, Geologic setting, in Cook, H. E., ed., Geologic Studies of the Point Conception Deep Stratigraphic Test Well OCS-CAL 78-164 No. 1, Outer Continental Shelf, Southern California, United States: U.S. Geological Survey Open-File Report 79-1218, p. 10-25.

McCulloh, T. H., 1979, Implications for petroleum appraisal, in Cook, H. E., ed., Geologic Studies of the Point Conception Deep Stratigraphic Test Well OCS-CAL 78-164 No. 1, Outer Continental Shelf, Southern California, United States: U.S. Geological Survey Open-File Report 79-1218, p. 26-42.

McCulloh, T. H., and Beyer, L. A., 1979, Geologic and geophysical implications of density and sonic logs, in Cook, H. E., ed., Geologic Studies of the Point Conception Deep Stratigraphic Test Well OCS-CAL 78-164 No. 1, Outer Continental Shelf, Southern California, United States: U.S. Geological Survey Open-File Report 79-1218, p. 43-48.

Morgan, W. J., 1968, Rises, trenches, great faults, and crustal blocks: Journal of Geophysical Research, v. 73, p. 1959-1982.

Newmark, N. M., 1976, Rational for design spectra for Diablo Canyon Reactor Facility, Appendix C, in Supplement No. 5 to the Safety Evaluation of the Diablo Canyon Power Station, Units 1 and 2, p. C1-C42.

Ogle, B. A., 1953, Geology of Eel River Valley area, Humboldt County, California: California Divison of Mines Bulletin 164, 128 p.

Page, B. M., 1970, Sur-Nacimiento fault zone of California: Continental Margin tectonics: Geological Society of America Bulletin, v. 81, no. 3, p. 667-690.

Page, B. M., Wagner, H. C., McCulloch, D. S., Silver, E. A., and Spotts, J. H., 1979, Geologic cross section of the continental margin off San Luis Obispo, the southern Coast Ranges, and the San Joaquin Valley, California: Geological Society of America Map and Chart Series MC-28G, 12 p.

Piper, D. J. W., Normark, W. R., and Ingle, J. C., Jr., 1976, The Rio Dell Formation: a Plio-Pleistocene basin slope deposit in northern California: Sedimentology, v. 23, p. 309-328.

Real, C. R., Toppozada, T. R., and Parke, D. L., 1978 (Preliminary) Earthquake epicenter map of California, showing events from 1900 through 1974 equal to or greater than magnitude 4.0 or intensity V: California Resources Agency, Department of Conservation, Open-file Report 78-4 SAC.

Reed, R. D., 1933, Geology of California: American Association of Petroleum Geologists, Tulsa, Oklahoma, 355 p.

Ross, D. C., 1973, Are the granitic rocks of Salinian block trondhjemitic?: U.S. Geological Survey Journal of Research, v. 1, no. 3, p. 251-254.

______, 1978, The Salinian block - A Mesozoic granitic orphan in the California Coast Range, in Howell, D. G., and McDougall, K. A., eds., Mesozoic Paleography of the Western United States: Society of Economic Paleontologists and Mineralogists, Pacific Section, Pacific Coast Paleogeography Symposium 2, p. 509-522.

Ross, D. C., and Brabb, E. E., 1973, Petrography and structural relations of granitic basement rocks in the Monterey Bay area, California: U.S. Geological Survey Journal of Research, v. 1, no. 3, p. 273-383.

Ross, D. C., and McCulloch, D. S., 1979, Cross section of the southern Coast Ranges and San Joaquin Valley from offshore Point Sur to Madera, California: Geological Society of America Map and Chart Series MC-28H, 4 p.

Silver, E. A., 1969, Structure of the continental margin off northern California, north of the Gorda Escarpment: Technical Report No. 2, U.S. Geological Survey Contract No. 14-08-0001-11457, Scripps Institute of Oceanography, San Diego, 123 p.

______, 1971a, Transitional tectonics and late Cenozoic structure of the continental margin off northernmost California: Geological Society of America Bulletin, v. 82, no. 1, p. 1-22.

______, 1971b, Tectonics of the Mendocino triple junction: Geological Society of America Bulletin, v. 82, no. 11, p. 2965-2978.

Silver, E. A., Curray, J. R., and Cooper, A. K., 1971, Tectonic development of the continental margin off central California: Geological Society of Sacramento, Annual Field Trip Guidebook, p. 1-10.

Smith, S. W., 1974, Analysis of offshore seismicity in the vicinity of the Diablo Canyon nuclear power plant. Report to Pacific Gas and Electric Company, San Francisco.

______, 1975, Ground motion analysis for the Humboldt Bay nuclear power plant: Unpublished report to Pacific Gas and Electric Company, San Francisco.

______, 1978, Seafloor expression of the 1927 Lompoc earthquake (abs.): EOS, American Geophysical Union Transactions, v. 59, no. 12, p. 1128.

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.

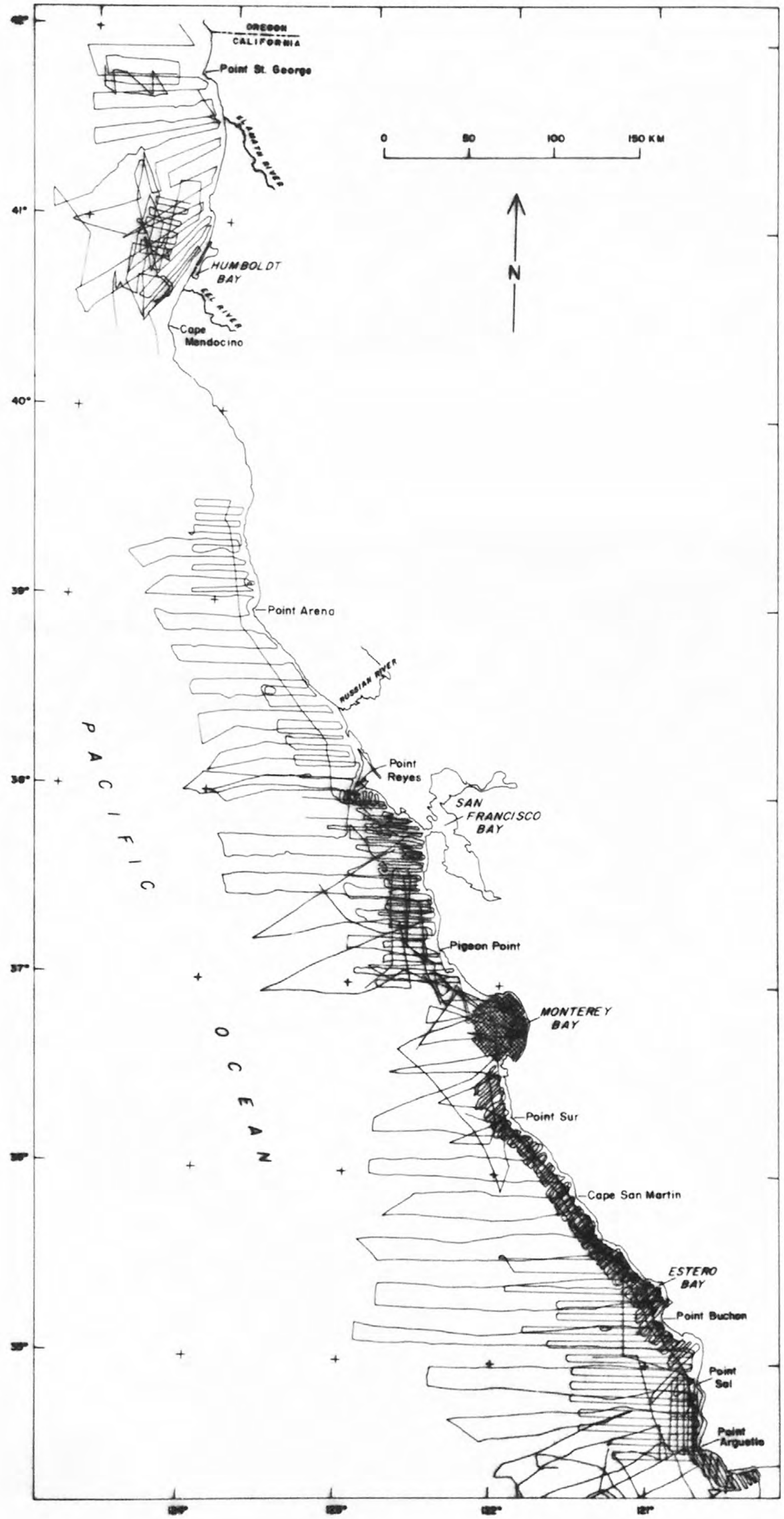
Townley, S. D., and Allen, M. W., 1939, Descriptive catalog of earthquakes of Pacific coast of the United States 1769 to 1928: Seismological Society of America Bulletin, no. 29, p. 1-297.

Uchupi, E., and Emery, K. O., 1963, The continental slope between San Francisco, California, and Cedros Is., Mexico: Deep-Sea Research, v. 10, p. 397-447.

Wagner, H. C., 1974, Marine geology between Cape San Martin and Point Sal, south-central California offshore. A preliminary report: U.S. Geological Survey Open-File Report 74-252, 17 p., 4 maps.

Welday, E. E., and Williams, J. W., 1975, Offshore surficial geology of California: California Division of Mines and Geology, Map Sheet 2.

Wiegel, R. C., 1970, Earthquake engineering: Englewood Cliff, N. J., Prentice-Hall, Inc., 518 p.



APPENDIX

U.S. Geological Survey tracklines in central and northern California Outer Continental Shelf.

CHAPTER C

PETROLEUM RESOURCE APPRAISAL OF PROPOSED LEASE SALE 73

OFFSHORE CALIFORNIA

By

E. W. Scott and G. L. Dolton

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SALE 73

RESOURCE APPRAISAL

The proposed oil and gas lease sale No. 73 offshore California area extends from the Mexican border ($32^{o}30'$ N latitude) on the south to the Oregon border (42^{o} N latitude) on the north. The area assessed for oil and gas resource potential lies within these boundaries and extends from the shoreline seaward to the 2500 meter isobath.

The assessed area involves a total of about 54,000 square miles and a sediment volume of about 45,000 cubic miles. Approximately 6% (3400 mi^2) of the total area lies within the 3 mile limit and is under the jurisdiction of the state of California.

Eight separate geologic basins or provinces are included in the total area. These provinces are, from south to north:

Southern California Borderlands

- Inner Basins
- Outer Basins and Ridges
- Santa Barbara Channel

Central and Northern California

- Santa Maria
- Santa Cruz
- Bodega
- Point Arena
- Eel River

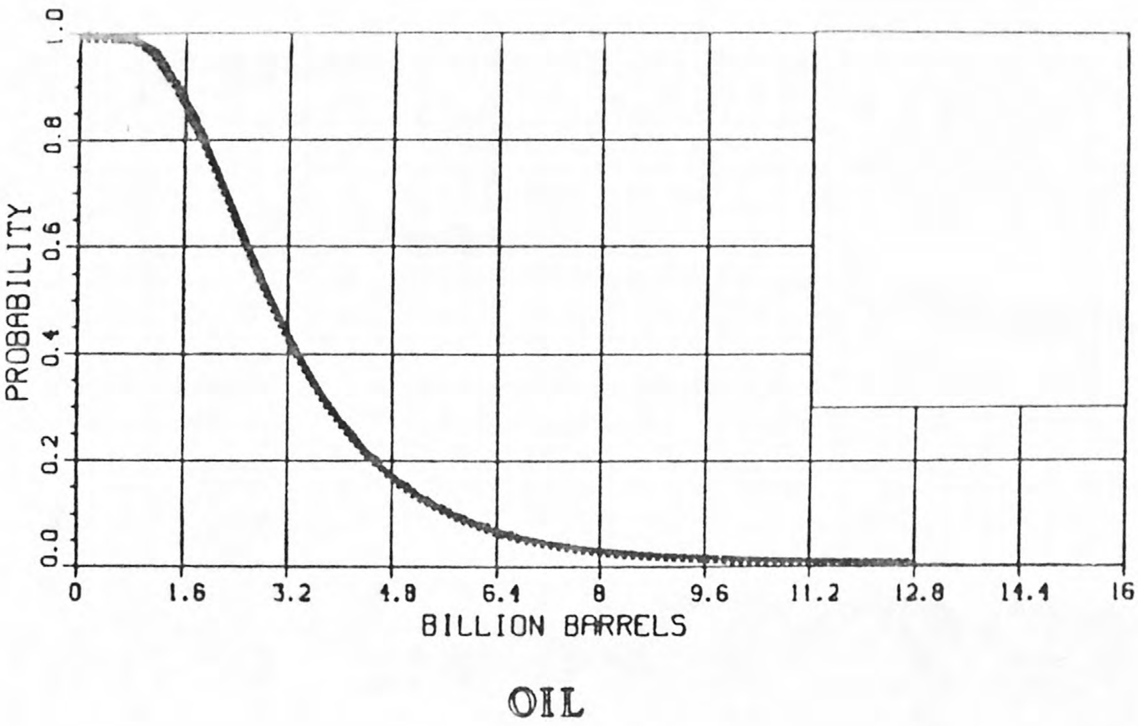
Updated assessments have been made of these basins in separate parts by water depth of 0-200 meters, and 200-2500 meters (Table). Thus, 16 separate areas were assessed for undiscovered recoverable oil and gas, and these assessments have been aggregated by Monte Carlo methods for the proposed sale #73.

Geological estimates of the amounts of undiscovered recoverable oil and gas resources for the aggregate of these provinces in this sale area are:

Unconditional Estimates of Total Undiscovered
Recoverable Oil and Gas, OCS Sale 73 (0-2500 m)

	Prob.		
	.95	.05	Mean
Oil (Billion BBLS)	1.2	6.9	3.4
Gas (TCF)	1.8	9.2	5.0

The resource estimates are based on individual basin geological analysis which includes volumetric yield and analog methods and structural analysis. It should be indicated that this aggregation represents a combination of basins from significantly different geologic settings and water depths along the Pacific margin. The above unconditional aggregate estimate incorporates each individual basin risk that is the risk of one or more of the basins not being productive within the total sale area. The complete probability distributions are shown in Figure C-1.



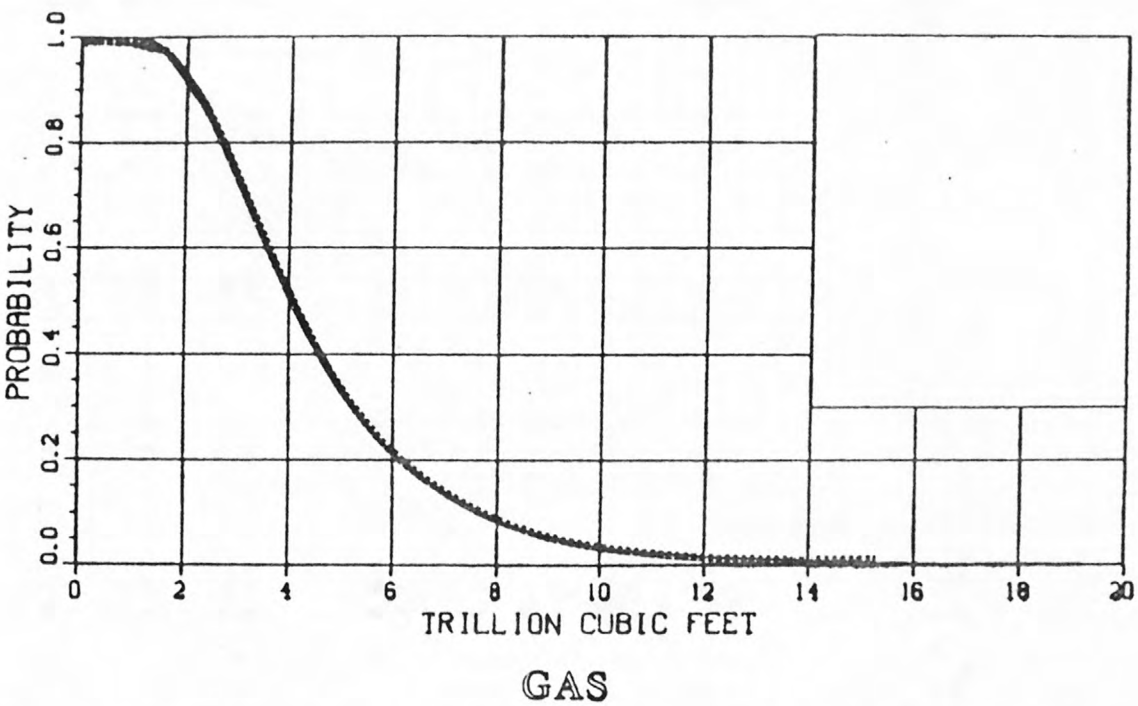


Figure C1.--Probability distribution for estimates of undiscovered recoverable oil and gas (unconditional) for OCS Sale 73, California (0-2500 m).

* CONDITIONAL ESTIMATES OF UNDISCOVERED RECOVERABLE OIL AND GAS FOR BASINS INCLUDED WITHIN OCS SALE 73.

	Oil (Bil. BBLS)				Assoc-Dis. Gas (TCF)				Non-Assoc. Gas (TCF)			
	Probability				Probability				Probability			
	.95	.05	Mean	MP	.95	.05	Mean	MP	.95	.05	Mean	MP
Southern California Borderlands												
Inner Basins												
0-200 m	0.1	0.9	0.4	1.00	< 0.1	0.5	0.2	1.00	--- None ---			
200-2500 m	0.1	1.7	0.5	.36	< 0.1	0.9	0.3	.36	--- None ---			
Outer Basins												
0-200 m	< 0.1	0.2	0.1	.12	< 0.1	0.3	0.1	.12	--- None ---			
200-2500 m	0.2	4.0	1.4	.38	0.4	5.9	2.0	.38	0.2	2.5	0.9	.14
Santa Barbara Channel												
0-200 m	0.1	1.6	0.6	1.00	0.1	1.4	0.5	1.00	0.1	1.7	0.5	1.00
200-2500 m	0.1	2.1	0.7	1.00	0.1	2.5	0.8	1.00	0.2	2.0	0.7	.93
Central & Northern California												
Santa Maria												
0-200 m	0.1	0.9	0.3	.61	0.1	0.8	0.3	.61	--- None ---			
200-2500 m	0.1	3.2	1.0	.51	0.1	2.9	0.9	.51	--- None ---			
Santa Cruz												
0-200 m	0.1	.8	0.3	.38	0.1	0.7	0.3	.38	--- None ---			
200-2500 m	< 0.1	1.1	0.3	.28	< 0.1	1.0	0.3	.28	--- None ---			
Bodega												
0-200 m	< 0.1	0.5	0.2	.26	< 0.1	0.4	0.1	.26	--- None ---			
200-2500 m	< 0.1	0.4	0.1	.18	< 0.1	0.3	0.1	.18	--- None ---			
Pt. Arena												
0-200 m	< 0.1	0.4	0.1	.27	< 0.1	0.4	0.1	.27	--- None ---			
200-2500 m	0.1	0.8	0.3	.21	0.1	0.7	0.3	.21	--- None ---			
Eel River (Calif. Portion)												
0-200 m	< 0.1	0.7	0.2	.14	< 0.1	0.5	0.2	.14	0.2	1.0	0.5	.25
200-2500 m	< 0.1	0.7	0.2	.11	0.1	1.0	0.3	.11	0.3	1.4	0.6	.26

*Conditional estimates of quantities of undiscovered hydrocarbons shown here are based in each case upon the condition that the given hydrocarbon is present; that is, if it is present, it will occur in the indicated quantity. The marginal probability (MP) states in each case the probability that the hydrocarbon is present.

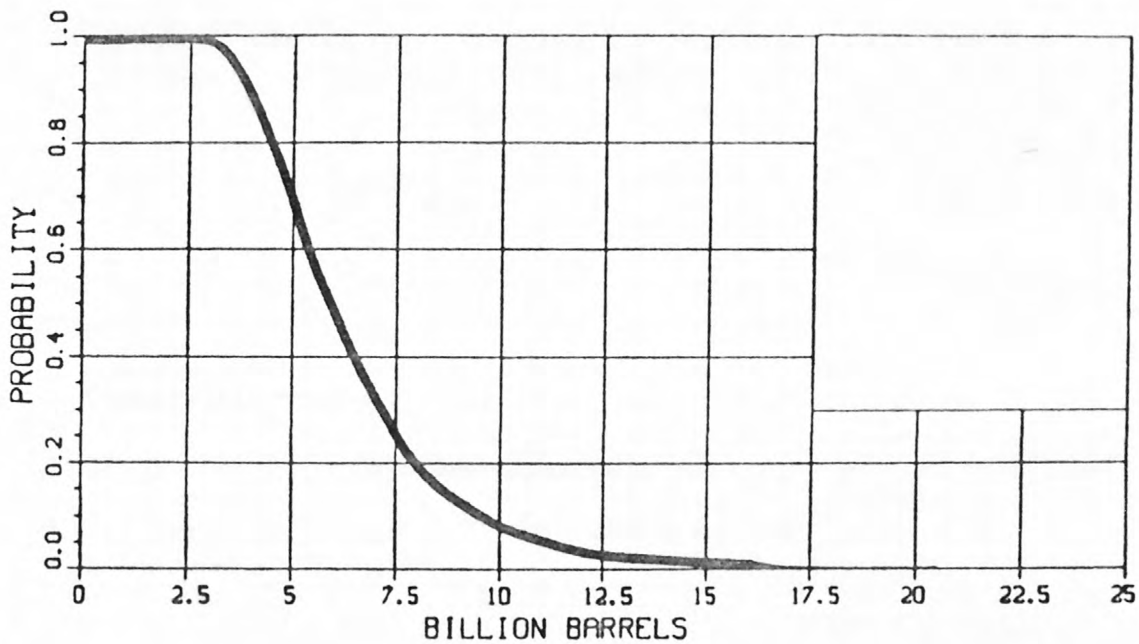
For planning purposes, conditional estimates which assume no individual province risk for the occurrence of oil or gas are sometimes employed. The conditional estimates of individual provinces which fall within this total sale area are included in Table C-1, and show the complete distribution of resources.

Conditional estimates for the aggregate sale area are derived through Monte Carlo techniques and are shown below and in Figure C-2; however, the validity of an assumption that the assessed oil and gas will collectively be present in each of the provincial elements of this large area is subject to question:

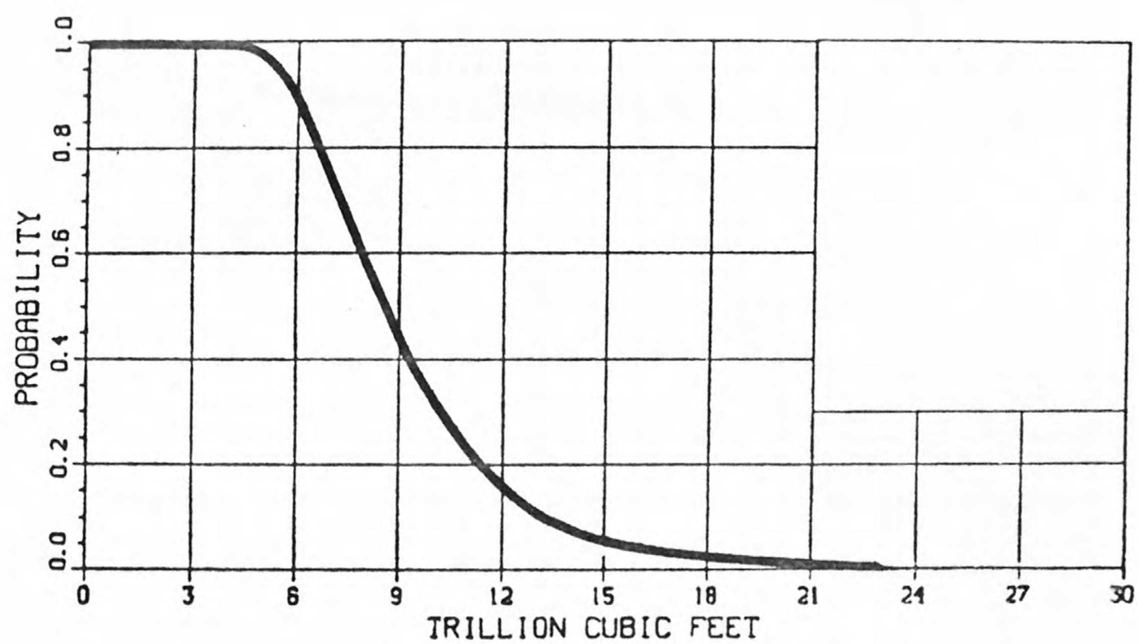
*Conditional Estimates of Total Undiscovered
Recoverable Oil and Gas, OCS Sale 73, (0-2500 m)

	Prob.			
	.95	.05	Mean	MP
Oil (Billion BBLS)	3.5	10.9	6.7	0.0 +
Gas (TCF)	5.4	15.0	10.1	0.0 +

*These estimates are a sum of the conditional estimates of the individual basins (Table C-1) and assumes that if oil (or gas) is present in all of these separate basins within the sale area in which resources were estimated, then the total indicated here would be reached. The probability of this condition being met is very slight as indicated by the marginal probability (MP) approaching zero.



OIL



GAS

Figure C2.--Probability distribution for conditional estimates of undiscovered recoverable oil and gas for OCS Sale 73, California (0-2500 m).

CHAPTER D

OPERATIONAL CONSIDERATIONS IN PROPOSED LEASE SALE 73

OFFSHORE CALIFORNIA

By

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OPERATIONAL CONSIDERATIONS

INTRODUCTION

Development of oil and gas resources on Federal lands has contributed significantly to the U.S. petroleum supply. The area under consideration for Lease Sale No. 73 extends from the Oregon border (approximately 42.0° N Latitude) south to the Mexican border (approximately 31° 05' N Latitude). The limits of the call area will be further defined at the time of the call for nominations which is scheduled for November 1980.

Review of current petroleum exploration, development and transportation technologies in OCS areas with severe operating environments indicates that hydrocarbon resources within most of the proposed area of Lease Sale No. 73 can be feasibly developed with current and imminent technologies. The technology utilized in offshore exploration, development and production relates to the economics of resource development, potential onshore and offshore impacts, and the manpower/employment requirements. Reasonable predictions on the technology that may be utilized to develop offshore California resources follows.

OFFSHORE TECHNOLOGY IN DIFFERENT OPERATING ENVIRONMENTS

Gulf of Mexico petroleum development has provided the technology base from which offshore petroleum development has progressed into diverse (and often harsher) operating environments. The first specifically designed steel structure for offshore oil production, for example, was installed in the Gulf of Mexico in 1947 (Geer, 1976).

Until the mid-1970's, offshore petroleum development in the United States had been confined to the Gulf of Mexico, Southern California and upper Cook Inlet. Recent and planned OCS lease sales have extended areas available for exploration into deeper waters and more severe operating environments thus causing offshore petroleum technology to advance at a faster pace.

Exploration drilling is now common in water depths of 305 to 457 meters (1,000 to 1,500 feet), and exploratory wells have been drilled in water depths in excess of 1,524 meters (5,000 feet) without incident. Technology is currently available to enable exploratory drilling in water depths of 2,440 meters (8,000 feet). Development drilling is currently underway in 259 meters (850 feet) water depth in southern California (Exxon's Hondo platform in the Santa Barbara Channel) and 312 meters (1,025 feet) in the Gulf of Mexico on Shell's Cognac field platform.

EXPLORATION HISTORY

Exploration has taken place on the Outer Continental Shelf off California during the last two decades. Geophysical companies have shot an extensive network of shallow and deep penetration seismic reflection surveys over the entire shelf and collected seafloor samples by dart core and shallow boring. Some industry surveys were conducted in anticipation of, and following the May 14, 1963 lease sale of OCS lands in northern and central Calfornia. The sale resulted in the issuance of 57 leases. During the term of the leases, 20 exploratory wells were drilled on 17 of the leases. While the OCS boundary off California was in dispute, the State of California permitted the drilling of approximately 250 core holes within the disputed area of offshore Southern California. Four OCS lease sales (including the 1966 drainage sale) have previously been held in the southern California portion of the proposed sale area, and a fifth sale is scheduled to be held in 1982. The 1966 drainage sale comprised only one lease, and it is productive. Seventy-one leases were issued following the February 1968 sale. To date, eleven fields have been discovered on these leases. One of these discoveries is uneconomical and is now within the Channel Islands Sanctuary. Following Sale No. 35, held in December 1975, 56 leases were issued. To date, oil has been discovered on three of these leases. Sale No. 48, held in June 1979, resulted in the issuance of 54 leases. As yet no discoveries have been made on these leases. Although development has commenced on several of the discovered fields, only three are presently producing. Production is anticipated to begin shortly from two additional fields. To date, there have been 526 exploratory and development wells drilled on Federal leases in the Pacific offshore.

EXPLORATION TECHNOLOGY

Review of exploration technology indicates trends toward drilling in deeper waters. Industry has demonstrated the ability to drill in 2,440 meters (8,000 feet) of water depth. Drilling vessel disposition in offshore California as of September 1, 1980 is as follows:

RIG NAME	TYPE	DRILLING DEPTH CAPABILITY	WATER DEPTH CAPABILITY	LOCATION
GLOMAR CORAL SEA	DRILLSHIP	25,000'	1,500'	Santa Ynez Chevron
GLOMAR PACIFIC	DRILLSHIP	25,000'	3,000'	Pitas Point Texaco
DIAMOND M. GENERAL	SEMI-SUBMERSIBLE	30,000'	1,500'	Santa Rosa Exxon

Current and future drilling vessel construction activity should have a positive impact on rig availability for exploring leases issued after Lease Sale No. 73. Since the use of jackup units is common in the Gulf of Mexico because of shallow water depth, the availability of jackup rigs will release other types of vessels such as drillships and semi-submersibles currently working in the Gulf for deepwater drilling in offshore California.

PRODUCTION TECHNOLOGY

Platforms are major components of offshore oil and gas development and production. Depending upon conditions such as reservoir characteristics, field size, water depth, distance from shore and economics, all of the drilling and production facilities may be contained on a single offshore platform or may be distributed among several platforms. In the latter case, more platforms would be required to develop and produce a field. In deep water, economic constraints favor oil field development with as few platforms as possible; thus the use of integrated drilling/production units has been the trend in OCS fields. To date, steel jacket structures with pilings have been the dominant platform type used in the Pacific OCS, but present offshore technology indicates that development of marginal fields and fields in deeper water will include increasing use of hybrid, compliant and floating platform designs and subsea completion wells. The floating and compliant platform designs include the guyed tower, articulated tower, tension leg platform and a variety of semi-submersible structures (including converted exploration rigs). The latter two designs are floating structures. Rather than rigidly resist wave forces, these platforms are designed to accommodate, to a lesser or greater extent, these forces. Floating and compliant structures require less materials (e.g., steel) to construct, and less offshore construction time. Floating systems used in conjunction with subsea completed wells can reduce field development time and speed the return on investment. Production systems not connected to pipelines will utilize offshore storage facilities, probably semi-submersible, buoyed structures, or converted vessels. For discoveries resulting from Lease Sale No. 73, floating systems would be favored in areas where soil conditions or water depths do not favor fixed platforms.

Where water depths over fields are less than 305 meters (1,000 feet) fixed steel platforms will still have a major role. The trend in design of these structures will continue to be a reduction of weight and material requirements.

Prediction of the production from fields discovered on leases issued as a result of Lease Sale No. 73 must include consideration of the following:

- o California is a petroleum refining and marketing center with easy access to different transportation systems.
- o The potential discovery sites in the proposed area of Lease Sale No. 73 could be at distances in excess of 240 kilometers (150 miles) from the California mainland and at water depths exceeding 1830 meters (6,000 feet) where transportation of hydrocarbons through pipelines to shore would not be economically feasible unless a number of fields were sufficiently close together to share pipeline and shore terminal costs.

The systems used to develop and produce fields on tracts leased in Sale No. 73 will probably be similar to systems used in other areas. These are:

- o Floating platforms with limited producing wells (subsea completions). Production capability limited by size and frequency of transporting vessels. Offshore loading with single point mooring systems. No water depth limitations.
- o Single steel jacket platforms with production capability limited by size and frequency of transporting vessels. Offshore loading with single point mooring system. Water depths limited to 305 meters (1,000 feet).

- Single steel jacket platforms with storage facilities which allow full production capacity. Water depths limited 305 meters (1,000 feet).
- Single steel jacket platforms with pipelines to shore terminals which may or may not be shared with other producing fields. Water depths limited to 305 meters (1,000 feet).
- Concrete platforms (when conditions warrant). Storage facilities allow full production capacity. Offshore loading with single point mooring system. Water depths limited to 183 meters (600 feet).
- Concrete platforms as part of a multi-platform development and production system. Pipelines to shore terminal allows full production capacity. Water depths limited to 183 meters (600 feet).
- Multiple steel jacket platforms. Pipelines to shore terminal allows full production capacity. Water depths limited to 305 meters (1,000 feet).
- Single or multiple steel platforms. Gas pipelines to shore. Water depths limited to 305 meters (1,000 feet).

The systems described above have all been used in other areas and are believed to be applicable (with suitable modifications) for use in the proposed lease sale area. While no steel jacket platform system to date has had sufficient storage capability to produce full-time at maximum rate, it has been assumed that offshore storage technology by the 1990's will provide sufficient storage capability in conjunction with production from a steel jacket platform to allow full-time or maximum production.

TRANSPORTATION TECHNOLOGY

Since California is a net importer of natural gas, all natural gas produced from offshore California will probably be used in California markets. The distribution of offshore crude oil is less certain, but it is estimated that over 80% of the present offshore production is refined and used in California. The distribution of present and future offshore production depends in part on the availability of transportation systems, but is more sensitive to market demands and government regulations. Transportation modes of hydrocarbons from the proposed lease sale area include tankers, barges, or pipelines for crude oil, and pipelines or LNG carriers for natural gas. All crude oil and natural gas presently produced offshore California is transported by pipelines to processing facilities; crude oil is then either pipelined or tankered to refineries, and natural gas is pipelined to gas companies' transmission lines. The mode of transportation of hydrocarbon production from the proposed lease sale area will depend on geographic, physiographic and economic factors pertinent to each field or group of fields. Any or all of the transportation modes described above may be used.

The cost of transporting unprocessed crude oil by tanker to processing sites is normally prohibitive due to the cost of shipment of emulsified waste water and other impurities. Where the transportation costs become too high, or onshore processing facilities are unavailable, offshore processing plants and transport of the processed crude to refineries by tankers is another alternative, and this has been proposed by offshore oil producers. However, direct pipelines between processing plants and refineries, which would eliminate the need for tankers and additional storage facilities, is preferred.

The physical properties of the crude oils do not, in general, determine the transportation mode used. Instead, they impose design or operational constraints on whichever mode the operator selects. The properties of crude oil which are significant in pipeline design are viscosity and specific gravity. Viscosity of the oil is considered in determing the pipe dimensions, which in turn affect the material and laying costs and the size and number of pumping stations. Vis cosity and specific gravity together are factors which affect the energy re quired to pump the crude oil.

The sulfur content of the oil must be considered in the design of a transporta- system. Sulfur compounds in oil are undesirable and must be reduced to acceptable levels for refinery utilization; hence the choice of destinations for a high sulfur crude may be limited by refinery desulfurization capabilities. Of more importance to the selection of a transportation mode is the amount of hydrogen sulfide gas (H2S) in crude oil. Crude oil high in sulfur is referred to as "sour" and can be corrosive when combined with water. Platform treatment can reduce H2S in oil (or natural gas) to levels acceptable for pipeline trans-shipment, but further "stripping" at a processing plant is required before shipping companies will accept sour crude for transport by tanker. Pipeline systems can be designed to transport commingled high sulfur and low sulfur oil without "batching".

Water depth is a principal limiting factor to laying offshore pipeline transportation systems. The maximum depth of pipelines currently in operation in the North Sea is 183 meters (600 feet), but the maximum water depth of the pipelines from Exxon's Hondo platform in the Santa Barbara Channel will be 260 meters (850 feet). The greatest water depth overlying any present lease off southern California is 762 meters (2,500 feet). Gathering lines between all leases and central gathering stations of leased areas would not encounter greater depths. Gathering stations in the Outer Banks areas can be located in water depths less than 260 meters (850 feet) for all OCS lease areas, and trunklines connecting these gathering stations with the mainland can be laid in water depths which do not exceed 488 meters (1,600 feet). Experimental pipelines have been installed at depths of 305 and 366 meters (1,000 and 1,200 feet), and a pipelaying barge designed to lay 61 cm. (24 inch) diameter pipe in 915 meters (3,000 feet) of water is in existence. The pipeline industry is presently considering proposals for deep water projects such as the Algeria-Spain pipeline in water depths to 1707 meters (5,600 feet). The trend of recent developments in pipelaying equipment and the goals being set by industry-sponsored research programs indicate that all leased areas off California can be serviced by on-bottom pipelines within five years.

RESOURCE ECONOMICS

Economic feasibility of developing the undiscovered hydrocarbon resources in the area of proposed Lease Sale No. 73 will be dependent on:

- The cost of engineering technology required to produce reserves in the OCS offshore California.
- Minimum field size, and productivity rate needed to justify development.
- Minimum product price to justify development in offshore California.

All these factors are very sensitive to water depth, and to the value of money. The following are essential to development in the OCS offshore California:

- The economics of developing a single field favor a single steel platform with a pipeline to a shore terminal over offshore loading if the cost of the shore terminal is shared among the operators of several fields.
- Offshore loading systems without storage capacity are much less economic than either systems with offshore storage or systems which will allow a pipeline to a shared shore terminal.
- Economics may not be very sensitive to the distance to shore that a pipeline must travel, if the pipeline cost is shared among the operators of several fields.
- Smaller fields may not be economic in the OCS offshore California unless the operator is willing to accept a lower return on his investment.
- If technical considerations do not require additional platforms to develop reservoirs, the rate of return is higher with a minimum number of platforms.

- o If reservoir thickness, hydrocarbon distribution, or drilling depth dictate development with several plat forms for a smaller field the operator must be willing to accept a lower rate of return.

AVAILABILITY OF INVESTMENT CAPITAL

The accessibility of refineries and a large petroleum market in California have helped to make the California OCS a significant investment center of offshore petroleum ventures. The availability of capital for investment in exploration and development of the oil and gas resources in Lease Sale No. 73 area depends on:

- Future levels of profits of the oil companies.
- Capital spending in offshore development.
- Predicted future petroleum product availability and market conditions.
- Future oil prices.
- Local refinery feedstock needs.
- Federal taxes and credits.
- Interest in California OCS vs. other regions.

Profits are a major source of investment capital. In addition, a profitable company can borrow capital more easily and at lower interest rates than an unprofitable company. An analysis of the performance of 24 oil companies, which together comprise a significant force in the oil industry, has been conducted which indicates the profits of this group were up to 10.2% in 1978.[1] Expectations for future years are highly optimistic. Ac cording to the Wall Street Journal, "... Oil company stocks have so far turned in a strong performance in 1979...".[2]

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[1]Oil and Gas Journal, 1976, U.S. Offshore Frontiers: How promising are they? v. 74, no. 3, pp. 17-22.

[2]Wall Street Journal, Oct. 3, 1979.

Decontrol of domestic crude prices should expand investment opportunities for the oil industry. The Department of Energy has predicted that domestic oil prices should at least double by 1995. Decontrol will make prospects offshore more attractive and may enable some marginal prospects to be developed economically.

The Oil and Gas Journal, points out that planned capital spending increased by 14.4% in 1979.[3] The windfall profits tax will reduce to some extent the favorable impact on earnings of oil price decontrol.

The Chase Manhattan Bank's 1977 study of 27 national and multinational oil companies indicates that, while areas outside the United States are declining in interest, the United States continues to be an area of prime interest for investment. Decline of interest in foreign countries has been largely due to discouraging drilling results in some countries, loss of crude through nationalization and purchase, and increasing costs.[4]

Adequate investment capital will probably be available for the total United States. How that capital will be allocated within the U.S. is subject to a number of factors. Large discoveries of crude in other regions could limit the availability of capital for Lease Sale No. 73. Conversely, if future feedstock needs in California increase and the evaluation of Lease Sale No. 73 area by industry is favorable, significant capital may be available for bids. Capital availability for bids on Lease Sale No. 73 is impossible to forecast at the present time.

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[3] Oil and Gas Journal, 1979, "U.S. Industry's Spending to Soar Past $33 Billion", v. 77, No. 8, pp. 57-62.

[4] Chase Manhattan Bank, the Energy Economic Division, 1979, I Chase Manhattan Plaza, New York, N.Y. 10015

Significant additional discoveries in the areas of Lease Sale Nos. 48, 53, and 68 probably would increase the attractiveness of the California OCS for capital investment. In addition, equipment and manpower already involved in operations on Sale Nos. 48, 53 and 68 leases may be utilized to explore and develop Lease Sale No. 73 tracts. This may effectively minimize expenditures and in turn increase return on investment.

In conclusion, investment capital will probably be available for Lease Sale No. 73 provided that profits, capital spending, crude prices and industry interest continue their recent trends.

MANPOWER AVAILABILITY

Exploitation of petroleum reserves involves three phases of activity--exploration, development, and production. The exploration phase encompasses seismic and related geophysical surveys, exploratory drilling, and "step out" or delineation drilling to assess the size and characteristics of a discovery. The development phase involves construction and placement of necessary platforms, drilling the optimum number of production wells for the field, and construction and placement of the equipment and pipelines necessary to process the hydrocarbons and transport them to an onshore processing plant, refinery or port for export. The production phase involves the day-to-day operation and maintenance of the production wells, production equipment, and pipelines, and the workover of wells later in their producing life.

The three phases of petroleum exploitation overlap and all three may occur simultaneously. Manpower requirements for each phase differ. For example, exploratory work is not particularly labor intensive, and wildcat crews come and go with drilling contractors. The development phase, on the other hand, requires a higher level of manpower and much of this manpower is used in the construction and transportation industries. Much of the labor directly associated with drilling and installing crude processing equipment is skilled. Because of automation, the production phase does not require a substantial work force. This work force will include experienced oil field personnel recruited or transferred from other fields by the operators.

An offshore drilling and construction program typically requires a large number of contractors who supply special services and sophistocated equipment. These contractors usually have experienced personnel who are dispatched to jobs around the world. Many of the contractors provide speciality services that require only short visits to the field, however, the drilling and construction crews remain at the site for longer periods.

Currently manpower problems do exist in offshore drilling. A recent study shows a 100% turnover rate for offshore crews per year. The manpower problems faced by industry could be exacerbated by high turnovers and the ever increasing complexity of equipment for deepwater drilling because this equipment will need more highly trained personnel for operation and maintenance.

The oil industry is not only highly competitive in the recruitment of experienced personnel, but is in competition with other industries such as those developing synthetic fuels. While the shortage of professionals will be somewhat ameliorated in the future by the nationwide increase of enrollment in petroleum engineering schools as well as the intensive training of non-petroleum engineers for working in the field of petroleum engineering, the manpower outlook for exploring and developing leases resulting from Sale No. 73 is uncertain.