UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

REGIONAL GEOLOGY, SEISMICITY, AND POTENTIAL GEOLOGIC HAZARDS AND CONSTRAINTS, OCS OIL AND GAS LEASE SALE 53, NORTHERN AND CENTRAL CALIFORNIA

(SALE 53 PART A HELD MAY 28, 1981)

BY

William C. Richmond, Deborah J. Burdick,
Diane Phillips, and Paula J. Norris

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This report has not been edited for conformity
with Geological Survey editorial standards
or stratigraphic nomenclature

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ABSTRACT

Existing and potential geologic hazards and constraints were identified by interpretation of high-resolution geophysical profiles for five offshore areas of northern and central California. The study encompasses 243 tracts selected for inclusion in Federal Outer Continental Shelf Oil and Gas Lease Sale 53. Geologic hazards identified in the Sale 53 area are (1) areas of high incidence of seismic activity; (2) active faults; (3) mass transport; and (4) steep slopes (>10°) and steep-walled submarine channels. Constraints identified are (1) filled or shallow buried channels; (2) hyrocarbon seeps, seep mounds, and gas craters; (3) gas-charged sediments; and (4) pressurized shallow gas zones. The U.S. Geological Survey has recommended that a stipulation be applied to 68 tracts in which there is evidence of existing or potential sea-floor instability.

INTRODUCTION

Studies were made to assess the existing and potential geologic hazards and constraints which could adversely affect oil and gas resource development in offshore areas of northern and central California. The study area encompasses 243 tracts (aggregating 532,588 hectares) selected by the Department of the Interior for inclusion in Federal Outer Continental Shelf (OCS) Oil and Gas Lease Sale 53.[1/] The boundaries of the regular tracts are 4,800 m on

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[1/] The study area covers the original proposed area for Federal Outer Continental Shelf Oil and Gas Lease Sale 53. The sale was subsequently divided into two parts: Sale 53, part A, took place on May 28, 1981, and included the Santa Maria area (tracts 129-243). The remaining four areas may be included in a future lease sale.

a side and each complete tract contains 2,340 hectares. Geologic hazards and constraints are identified in five offshore areas of northern and central California between the Oregon border and Point Conception (fig. 1): Eel River, Point Arena, Bodega, Santa Cruz, and Santa Maria. The U. S. Geological Survey recommended that a stipulation be applied to 68 of the 243 tracts in which there is evidence of existing or potential sea-floor instability over a major portion of a tract.

For purposes of this study, geologic hazards are defined as any geologic features or processes, existing or potential, that would inhibit the development of oil and gas resources. Hazards that are present in the Sale 53 area are high incidence of seismicity, mass transport of unconsolidated to semi-consolidated sediments, active faults, steep (>10°) slopes, and steep-walled canyons. Geologic features that are hazardous in their present state, but whose effects can feasibly be lessened through existing technology and design, are considered to be constraints on development. These second-order geologic hazards are buried channels, water-column anomalies (hydrocarbon seeps), gas-charged sediments, and shallow gas (bright reflectors). In tracts where hazards and constraints are identified, special engineering procedures may be required to set bottom-founded structures, or proposed drilling sites may have to be relocated.

This paper summarizes the regional geologic setting and seismicity, and the geologic hazards and constraints for individual areas offered in Sale 53. Included are 1:100,000-scale maps of the five proposed sale areas showing potential geologic hazards and constraints (pls. 1-6).

DATA COLLECTION AND ANALYSIS

This report is based on the interpretation of high-resolution seismic reflection profiles collected by Fairfield Industries, Inc. under contract to the U.S. Geological Survey (contract 14-08-0001-18254). Data were collected from July 1979 through June 1980. The contractor supplied data-reduction services and delivered a final technical report with accompanying maps to the U.S. Geological Survey in December 1980. These data were also interpreted by USGS personnel. About 10,600 line-km of nonproprietary, multisensor, high-resolution data were collected on an approximate 1.0 x 2.0-km grid over the sale area. About 35-45 line-km of geophysical data were obtained from each complete tract. Geophysical systems used in the survey were echo sounder, 3.5 kHz subbottom profiler, side-scan sonar, and multi-trace, mini-sleeve exploder with separate recordings made for one millisecond and one-quarter millisecond sample rates.

Microfilm copies of these data (USGS Data Set PA 18254) are available for public inspection at the Office of the Deputy Conservation Manager, Offshore Field Operations, U.S. Geological Survey, 1340 W. Sixth St., Suite 160, Los Angeles, California 90017. The complete or partial data set can be purchased from the NOAA/EDS National Geophysical and Solar-Terrestrial Data Center in Boulder, Colorado.

Two ships were used in this survey--*M/V Widgeon* and *M/V Peacock*--both using identical geophysical equipment. Navigational services were subcontracted

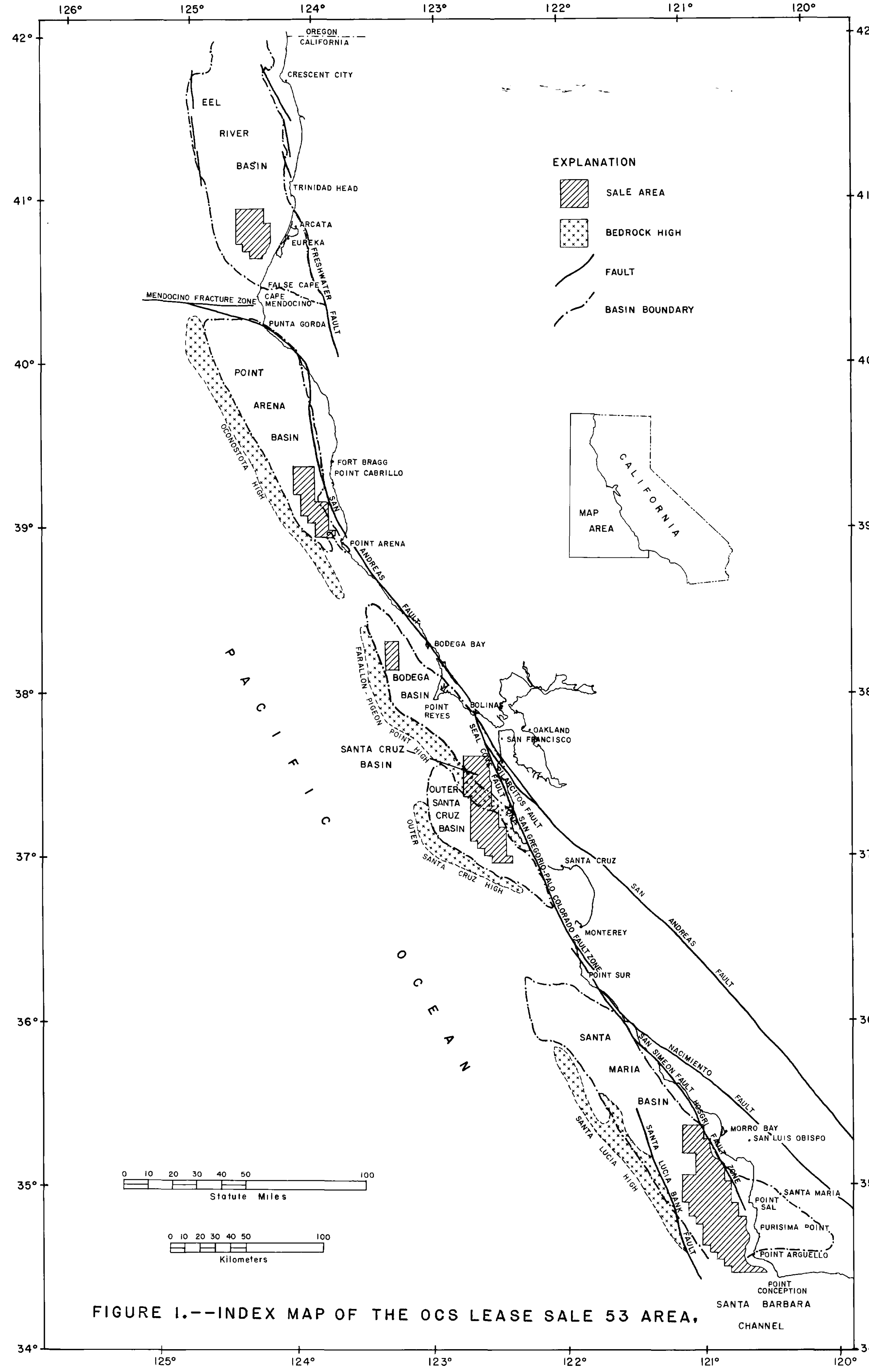

FIGURE 1.--INDEX MAP OF THE OCS LEASE SALE 53 AREA.

to Navigational Services, Inc. Navigation and positioning were maintained by utilizing Argo and Mini-Ranger systems.

REGIONAL GEOLOGIC SETTING

The northern and central California OCS, between the Oregon border and Point Conception, contains the probable offshore extension of two major structural and physiographic provinces--the Coast Ranges and the Transverse Ranges. The OCS north of Point Arguello lies adjacent to and is the probable offshore extension of the Coast Range province which is characterized by a northwest structural grain with subordinate west trends. In contrast, the central California OCS, south and west of Point Arguello, is the offshore extension of the Transverse Range province, whose dominant structural grain is west with a minor northwest trend superimposed on it.

The five Sale 53 areas correspond to five Neogene-aged structural basins (fig. 1). Faults, many of which are active, form the basin margins. According to Silver (1974) and Blake and others (1978), the basins along the California coast were formed by extension associated with the San Andreas fault system. As deduced from the age of the oldest basinal sediments, the basins probably originated about late middle Miocene time.

The basins overlie either of two different basement complexes: the Franciscan assemblage or the Salinian block complex. The Franciscan assemblage, (ranging in age from Jurassic to Eocene), is found in the northern Coast Ranges east and northeast of the San Andreas fault and in the southern Coast Ranges southwest of the Nacimiento fault and north of the Santa Barbara Channel. The predominant rock type in the Franciscan assemblage is graywacke with varying amounts of shale, greenstone, chert, and limestone. Also included in the assemblage are ultramafic rocks and metamorphic rocks of the zeolite, blueschist (glaucophane schist), and eclogite facies. The Salinian block complex, composed of granitic and metamorphic rocks, is located between the San Andreas and Nacimiento faults in central California and separates the two groups of Franciscan basement rocks. Although all five basins are structurally similar, the basins developed on the Franciscan rocks show more varied structural style than those developed on granitic basement (Hoskins and Griffiths, 1971; Blake and others, 1978).

The following discussion represents a synthesis of data gathered for this study and published data from Hoskins and Griffiths (1971) and McCulloch and others (1977). A complete discussion of the geology of the northern and central California OCS is beyond the scope of this paper.

Eel River Basin

The offshore Eel River basin extends from False Cape, south of Eureka, north into offshore Oregon (fig. 1). The offshore basin is 200 km long and 20 km wide; it extends inland for about 50 km along the Eel River. The onshore part of the basin is known as the Humboldt basin. The basin axis trends northwest onshore and swings to the north offshore. Onshore, the basin is bordered on the south by the False Cape shear zone and on the northeast by the Freshwater fault. Offshore, the basin is bordered on the east by a series of north-northwest-trending en echelon faults from Trinidad Head to the Oregon border. The western border of the offshore basin is marked by a subparallel series of basement ridges and high-angle faults along the outer plateau/upper slope of the continental margin.

Major offshore structures parallel the basin trend. According to McCulloch and others (1977), folds in Pliocene and younger strata on the continental slope and adjacent marginal plateau have sea-floor expression and are cut by high-angle reverse faults which are the result of east-west to northeast-southwest compression. Locally, there is some suggestion of shale flowage or diapirism in the offshore basin. The central part of the basin is relatively undeformed. Onshore, Pleistocene strata are gently folded along older structural axes.

Eel River basin contains about 29,170 cu km of marine Neogene strata (Hoskins and Griffiths, 1971). Core hole data from onshore wells indicate that the Neogene section ranges in thickness from 1,800 m to 3,500 m or greater and consists of siltstone, mudstone, and shale with local beds of conglomerate and sandstone (Ogle, 1953; Hoskins and Griffiths, 1971). Paleogene strata have not been identified in Eel River basin. The basin is underlain by Franciscan rocks (metasedimentary and igneous rocks) of Cretaceous-Jurassic age.

Point Arena Basin

The north-trending Point Arena basin, 170 km long and 20-50 km wide, extends offshore from south of Point Arena to west of Fort Bragg (fig. 1). The basin is bounded on the east by the San Andreas fault, on the south by the Point Arena fault, on the north by the Mendocino fracture zone, and on the west by the Oconostota Ridge, a partially buried structural high (McCulloch and others, 1977; Blake and others, 1978).

Major structures within the basin parallel the basin trend. Long, narrow folds and associated faults parallel the San Andreas fault west of Point Arena; several folds and faults diverge from the San Andreas fault as it curves back parallel to the coast between Fort Bragg and Point Arena (Hoskins and Griffiths, 1971). According to McCulloch and others (1977), Neogene structure is complex at the south end of the basin but to the north, Neogene strata show only minor deformation and unconformably overlie highly deformed Paleogene strata.

Point Arena basin contains about 12,500 cu km of Neogene sedimentary rocks (Hoskins and Griffiths, 1971). A composite stratigraphic column compiled by Hoskins indicates that Point Arena basin contains as much as 3,600 m of Neogene siltstone, claystone, and shale with minor amounts of gravel and sandstone. The basin is underlain by Franciscan rocks.

Bodega Basin

Bodega basin is an elongate, shallow Miocene synclinorium that extends offshore from San Francisco north to about latitude 38°45'N (fig. 1). The basin is about 180 km long and averages 25 km in width. According to McCulloch and others (1977), the basin is bounded on the southwest by the Farallon-Pigeon

Point High; is bounded on the east by the San Andreas and down-to-basin faults along which granitic basement has been elevated; and merges to the south with the Santa Cruz basin west of San Francisco (Hoskins and Griffiths, 1971).

Pre-Neogene structures are complex and may have a different structural grain than the north-northwest trends developed in younger strata (Hoskins and Griffiths, 1971; McCulloch and others, 1977). Right-lateral shear, associated with the San Andreas fault and regional compression, accompanied the transition to north-northwest faulting and folding (parallel to basin axis). Large, closed anticlines and high-angle reverse faults resulted from compression. This latest episode of deformation, which began in late Pliocene, continues today (McCulloch and others, 1977).

Bodega basin contains more than 6,670 cu km of Neogene strata (Hoskins and Griffiths, 1971). A composite stratigraphic column of Bodega basin compiled by Hoskins shows more than 4,100 m of Neogene strata consisting of siltstone, claystone, and shale with lesser amounts of sandstone and cherty shale. According to McCulloch and others (1977), the basin overlies the Salinian block complex consisting of granitic and gneissic rocks.

Outer Santa Cruz Basin

The Outer Santa Cruz basin extends northwest from Monterey for more than 100 km across the shelf onto the continental slope (fig. 1). The average width of the basin is 25 km. The basin is bounded on the northeast by the Pigeon Point High, the southern extension of the granitic Farallon structural high, and on the west by the Outer Santa Cruz High. Both structural highs are fault controlled. The basin terminates on the the southeast against the San Gregorio-Palo Colorado fault zone described by Greene (1977). East of the fault, the Salinas basin may be the onshore extension of the Outer Santa Cruz basin.

The predominant structural trend of the Outer Santa Cruz basin is northwest. The basin also plunges to the northwest. The pre-upper Miocene section is moderately folded and moderately to complexly faulted (McCulloch and others, 1977). These features do not continue into the younger rocks.

The Outer Santa Cruz basin contains about 5,830 cu km of Neogene strata (Hoskins and Griffiths, 1971) which are more than 3,000 m thick. Basement rocks underlying the basin are believed to be Cretaceous-Jurassic granitic rocks (Hoskins and Griffiths, 1971) of the Salinian block complex.

Santa Maria Basin

The offshore Santa Maria basin parallels the coast from about Point Arguello northwest to Point Sur (fig. 1). The offshore basin is approximately 230 km long and 40 km wide. It is bounded on the northeast by Franciscan rocks elevated by major coastal faults (San Simeon and Hosgri faults), and on the west by the Santa Lucia High, a Cretaceous-aged block uplifted along the Santa Lucia Bank fault. The northwest end of the basin continues onto the continental slope; the southeast end abuts the Hosgri fault zone which partially separates it from the onshore Santa Maria basin, a lowland wedge between the Coast and Transverse Ranges.

The structural grain of the Santa Maria basin parallels the basin trend. The structural trend in the northern part of the basin parallels the shoreline and the bordering Santa Lucia High (McCulloch and others, 1977). The complex folding and faulting in the Paleogene rocks persists into the Neogene rocks, but is considerably less extensive in Quaternary rocks (Hoskins and Griffiths, 1971; McCulloch and others, 1977).

Upper Cretaceous to Quaternary sedimentary rocks are found in and bordering the Santa Maria basin. Pre-middle Miocene rocks usually occur as isolated pockets along the southern border (Hoskins and Griffiths, 1971). According to Blake and others (1978), the onshore basin contains a Neogene marine sequence as thick as 4,500 m. About 7,500 cu km of Neogene strata are present in the Santa Maria basin (Hoskins and Griffiths, 1971). The Neogene section consists of siltstone, mudstone, and shale with lesser amounts of chert, tuff, and sandstone (Howell and others, 1978). Basement rock underlying the basin most likely consists of the Franciscan assemblage and strata equivalent to the Great Valley sequence (McCulloch and others, 1977; Howell and others, 1978). Hoskins and Griffiths (1971) suggested that the basement rocks may be granitic, based on the structural style and on the presence of granitic cobbles and coarse-grained arkosic sandstone on Santa Lucia High.

SEISMICITY

The northern and central California OCS is within the circum-Pacific volcanic and seismic belt that has been active throughout middle and late Cenozoic time. Earthquakes in northern and central California have been instrumentally recorded by the University of California, Berkeley since 1887. The number of seismographic stations associated with the University of California increased from six in 1942 to 19 in 1979 (McKenzie, 1981). This network extends from Arcata on the north to about 36° N latitude on the south. Since 1932, the California Institute of Technology has maintained a seismic network in southern California. Numerous earthquakes of magnitude 5 and greater have been recorded in the northern and central California OCS from 1900 to 1974, and their epicenters are plotted on figure 2. The southern part of the Sale 53 area lies in the gap between the two seismic networks; therefore, many small magnitude events (<4.0) probably were not detected and the locations of those recorded may be unreliable.

Eel River Basin

The offshore Eel River basin is underlain by the actively subducting Gorda plate. The southern part of the offshore Eel River basin is within the transition zone between the San Andreas fault-Mendocino fracture zone to the south and the obliquely underthrusting continental margin to the north. This change in tectonic regime is reflected by the pattern of seismicity (Bolt and Miller, 1971). The offshore portion of the Eel River basin is undergoing internal deformation due to the oblique underthrusting of the

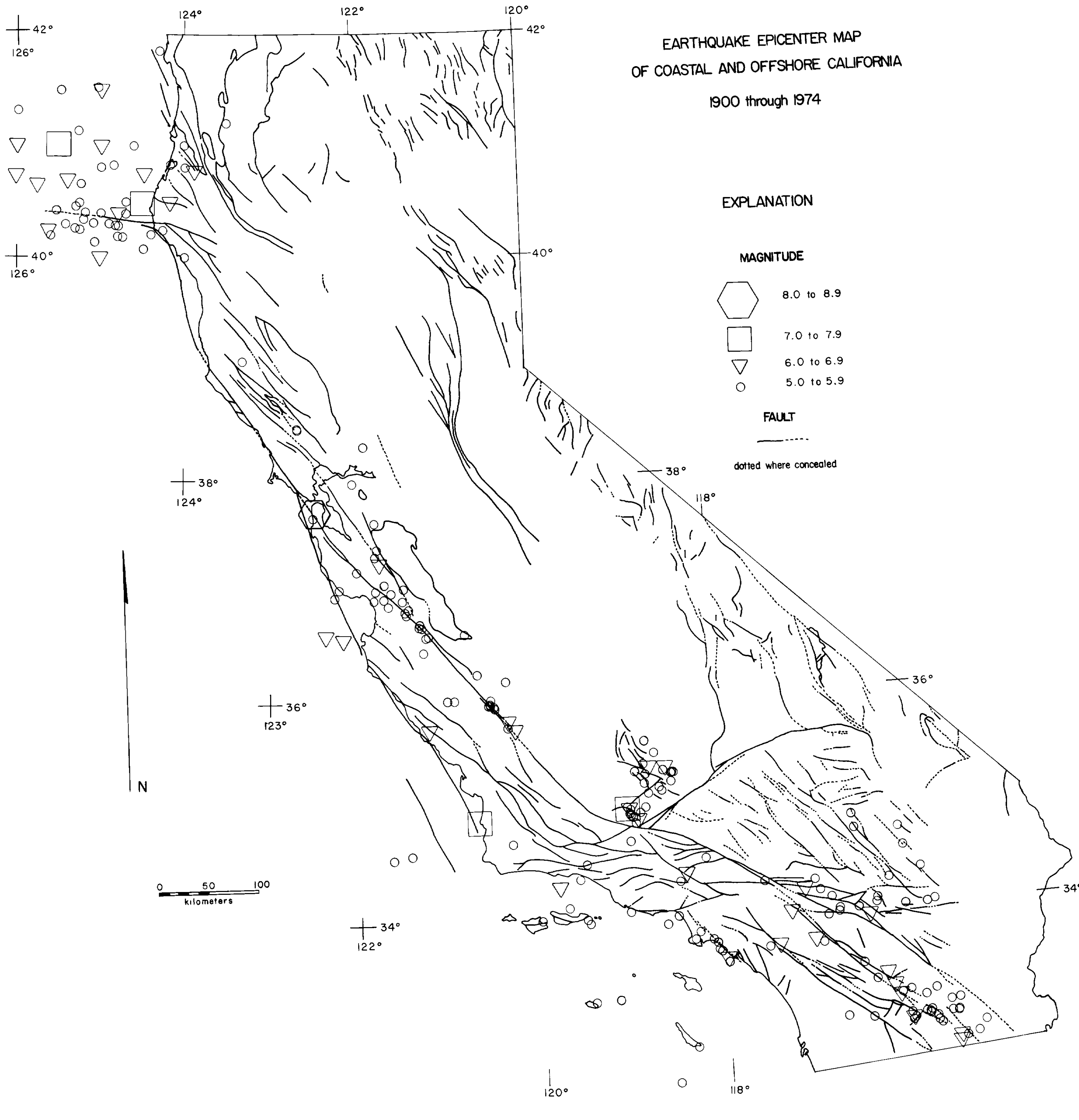

Figure 2.--Earthquake epicenters for events M≥5 in coastal California from 1900 through 1974.

continental slope under the North American Continent (Tobin and Sykes, 1968), as well as deformation along its fault-bounded borders.

The offshore area of northern California is considered to be one of the most seismically active areas in North America (Seeber and others, 1970; Allen, 1968). Between 1853 and 1973, more than 250 earthquakes occurred in the general area of the Eel River basin. Twenty-three of these events were of magnitude 5 or greater (McCulloch and others, 1977).

The San Andreas fault zone bends westward at Cape Mendocino and merges with the Mendocino fracture zone 10 km south of Eel River basin. The San Andreas fault-Mendocino fracture zone is characterized by right-lateral movement and is believed capable of producing a maximum probable earthquake of magnitude 8.3 (Greensfelder, 1974; Smith, 1975).

Expected bedrock acceleration for the Eel River basin is between 0.1 *g* and 0.2 *g* for a 100-year return and about 0.6 *g* for a 2,500-year return (Thenhaus and others, 1980). This is consistent with bedrock acceleration values for all northern and central California offshore areas.

Point Arena Basin

Poor coverage of the region by the existing seismographic networks makes evaluation of seismicity in the Point Arena basin difficult. Several earthquakes of magnitude 4.5 and greater have been recorded along the western margin of the basin (McCulloch and others, 1977).

The potential for strong ground motion over the entire Point Arena basin is great owing to the proximity of the San Andreas fault-Mendocino fracture zone (McCulloch and others, 1977). Maximum probable earthquake for the San Andreas fault zone in the Point Arena area is estimated to be magnitude 8.3 (Greensfelder, 1974; Smith, 1975). Expected seismically induced bedrock acceleration for the Point Arena basin is about 0.2 *g* to 0.3 *g* for a 100-year return and about 0.6 *g* for a 2,500-year return, as estimated by Thenhaus and others (1980).

Bodega Basin

Active faulting in Bodega basin is largely limited to the eastern margin in the vicinity of the San Andreas fault (McCulloch and others, 1977). The estimated maximum probable earthquake for the San Andreas fault zone is magnitude 8.3 (Greensfelder, 1974; Smith, 1975).

Seismically induced bedrock acceleration for the Bodega basin is expected to be between 0.2 *g* and 0.3 *g* for a 100-year return and about 0.6 *g* for a 2,500-year return (Thenhaus and others, 1980).

Outer Santa Cruz Basin

The Outer Santa Cruz basin is a seismically active area. Numerous faults occur within this basin and several of them show recent offsets. The Outer

Santa Cruz basin is located in the central California coastal region which lies in the gap between the University of California, Berkeley and California Institute of Technology seismic networks. Due to this gap in instrumental coverage, accurately locating the epicenter of a seismic event and timing the event is difficult (Gawthrop, 1975).

The offshore central California region is characterized by a series of subparallel northwest-trending faults. Several major faults are noted within or bounding the Outer Santa Cruz basin--the San Gregorio-Palo Colorado fault zone, the Seal Cove fault zone, the Pilarcitos fault, and the Pigeon Point High faults. Also, the San Andreas fault lies onshore as close as 20 km to the east of the Outer Santa Cruz basin and offshore passes within 15 km northeast of the sale area. Maximum probable earthquake for this segment of the San Andreas fault zone is magnitude 8.3 (Greensfelder, 1974; Smith, 1975).

The San Gregorio-Palo Colorado fault zone forms part of the eastern boundary of the Outer Santa Cruz basin. This fault zone is characterized by a complex of braided to subparallel fault traces over its 125-km length. Some of these individual traces within the 3-5 km wide zone show late Pleistocene and Holocene offset. Instrumentally recorded seismicity is also associated with the San Gregorio-Palo Colorado fault zone. This fault zone is considered to be active (Coppersmith and Griggs, 1978), with the maximum probable earthquake estimated at magnitude 6.5 to 7.0 (Greensfelder, 1974; Slosson and Associates, 1978).

The Seal Cove fault zone, a possible northward extension of the San Gregorio-Palo Colorado fault zone, lies immediately northeast of the sale area, eventually joining the San Andreas fault zone near Bolinas (Cooper, 1973).

The Pilarcitos fault lies onshore to the east of the Outer Santa Cruz basin and is subparallel to both the San Andreas fault and the Seal Cove fault zone. This fault passes offshore immediately to the northeast of the Seal Cove fault zone (Cooper, 1973).

Pigeon Point High is a fault-controlled structure forming the northeastern boundary of the Outer Santa Cruz basin. Several epicenters have been located offshore along the margin of the basin in the area of Pigeon Point High, but the exact relationship of these epicenters to the faults mapped in the area is unknown (Howell and others, 1978).

Expectable seismically induced bedrock acceleration in the Outer Santa Cruz basin is between 0.1 g and 0.3 g for a 100-year return and about 0.6 g for a 2,500-year return (Thenhaus and others, 1980).

Santa Maria Basin

The southern part of the offshore Santa Maria basin overlies the transition zone between two physiographic and tectonic provinces. The transition from the dominantly west trend of the western Transverse Ranges to the northwest trend of the southern Coast Ranges occurs in a zone approximately 32 km wide between Point Arguello and Point Sal. This transition zone is described as a zone of tectonic fight (Hamilton and Jahns, 1978). The competing lateral movements are accommodated by compressive strain with attendant thrusting, bending, and vertical offsets.

Several faults are noted in the southern part of the offshore Santa Maria basin--the Hosgri fault zone, the Santa Lucia Bank fault, and the Lompoc fault zone. The Hosgri fault zone is at least 145 km in length and varies along its length from a single break to several breaks over a zone approximately 2,000 m wide. Geophysical evidence indicates that the Hosgri fault zone has been active during late Quaternary time (Payne and others, 1979). Smith (1974) estimates the maximum probable earthquake for the Hosgri fault zone at magnitude 6.5. McCulloch and others (1980) estimate the maximum probable earthquake on the Hosgri fault zone at magnitude 7.3 based on Gawthrop's (1978a) relocation of the 1927 Lompoc earthquake.

The Santa Lucia Bank fault forms the eastern boundary of the Santa Lucia Bank and is located 40-50 km offshore. This fault shows substantial vertical offset along its 120-km length. An earthquake swarm occurred near the southern end of the Santa Lucia Bank fault in 1969 (Hamilton and Jahns, 1978). Seismic events as large as magnitude 5.8 were recorded. This earthquake swarm, in addition to geophysical data, indicates that this fault is active.

The Lompoc fault zone is a pair of prominent subparallel faults lying 17 km west of Purisima Point. The westernmost of these two faults is a reverse fault 13 km in length showing Holocene displacement (Earth Science Associates (ESA), 1974).

Seismicity of the offshore region in the area of the Santa Maria basin is characterized by a relatively low number of instrumentally determined events. A gap exists in this region between the University of California, Berkeley and California Institute of Technology seismic networks, and this gap may be responsible for the low number of recorded events. Most earthquakes recorded in this region between 1932 and 1977 fell in the 3.0 to 4.5 magnitude range (Payne and others, 1979). Historically, the region has produced several large-magnitude earthquakes.

Expectable seismically induced bedrock acceleration in the offshore Santa Maria basin is between 0.1 g and 0.2 g for a 100-year return and about 0.6 g for a 2,500-year return (Thenhaus and others, 1980).

GEOLOGIC HAZARDS

Mass Transport

Mass transport of sediment on the northern and central California continental margin consists of slides, slumps, and sediment creep. Slides (glides) are identified as either rigid or semiconsolidated masses translated along discrete shear planes with relatively minor internal flow (Dott, 1963). Slump, a term often used synonymously with slide, refers to rotational sliding of sedimentary units along a discrete shear surface (Dott, 1963). Sediment creep refers to the very slow and nearly continuous, gravity-induced downslope movement of the top layers of unconsolidated sediment. Creep does not require rigid sediment or translation along a shear plane.

Faults

Faults in general are not considered hazardous to oil and gas resource development except where (1) they are considered active as indicated by offset of recent sediments (Quaternary) where sedimentation has been nearly continuous, (2) they intersect or offset the sea floor, or (3) they have a historic record of important earthquake activity or seismic slip (for example, the San Andreas fault). Active faults are hazardous from the standpoints of both rupture and potential sources of shaking. Surface faults may act as escape routes for pressurized subsurface fluids to reach the surface.

Steep Slopes/Submarine Canyons

Slopes and submarine canyon walls are arbitrarily classified as flat, gentle, moderate, or steep according to the inclination. Flat slope is defined as horizontal sea floor. Slopes of less than 5° are considered gentle, slopes of 5-10° are moderate, and slopes of greater than 10° are steep. Only steep-walled canyons and steep slopes, especially those with sediment cover, are considered to be hazards.

CONSTRAINTS

Buried Channels

Buried channels are identified on high-resolution geophysical profiles by the irregular erosional contact between the younger infilling sediments and the older sediments. The infilling sediments may show crossbedding or unconformable bedding. The channels were cut during periods of lower sea level and subsequently buried by transgressing seas or by shifting submarine canyon/fan systems. Shallow-buried channels are considered to be constraints because of load-bearing capacity contrasts between the infilling sediments and the surrounding sediments. Contrasts in bearing capacity can exist over short vertical and horizontal distances within heterogeneous channel fill. Permeable channel fill can cause fluid loss during drilling.

Hydrocarbon Seeps

Hydrocarbon seeps are identified on 3.5 kHz subbottom profiles and one-quarter millisecond minisleeve exploder profiles as water-column anomalies or bubble trains. Seep mounds are occasionally formed by escaping gas in unconsolidated sediments. Gas seeps occurring in association with bedrock outcrops, steeply dipping beds, or faults are considered constraints. The near-surface structures act as conduits from possible pressurized gas zones and, if intersected during drilling, can act as escape routes for hydrocarbons. Relocation of drillsites can minimize the possibility of hydrocarbon leakage.

The apparent alignment of water-column anomalies is artificial on plates 1-6, inasmuch as they were identified only along track lines. Continuous zones of watercolumn anomalies or anomalies identified on only one system may represent kelp or schools of fish.

Gas-Charged Sediment

Gas-charged sediments are identified as shallow acoustically turbid zones on high-resolution profiles. Gas-charged sediments are zones of unconsolidated to semiconsolidated sediments saturated with interstitial gas under normal to near-normal pressures. Gas-charged sediment is considered to be a constraint because large contrasts in load-bearing capacity may exist within these zones or between these zones and the surrounding sediment. Dissolved gas in interstitial spaces can contribute to spontaneous liquefaction of sediments when subject to cyclic loading under abnormal conditions. Interstitial gas can effectively lower the shear strength of sediments, contributing to the instability of the section.

Shallow Gas

Shallow gas is identified on the basis of amplitude anomalies or bright reflectors on the minisleeve-exploder relative-amplitude sections. Shallow gas zones are confined gas accumulations with possible abnormal pore pressures. Highly pressurized gas zones that are penetrated during drilling operations can cause a blowout. Shallow gas zones could contribute to the instability of a section by effectively lowering the shear strength of the sediment.

EEL RIVER AREA

Setting

The Eel River area, consisting of 27 complete and three partial tracts is adjacent to the California 3-mile line, west of the City of Eureka (fig. 1). About 1,250 line-km of multisensor, high-resolution data were obtained in and fringing the sale area (pl. 1). The survey area is located in the transition zone between the southern end of the north-trending offshore Eel River basin and the northwest-trending onshore part of the basin.

Physiography

The sale area includes parts of three distinct physiographic provinces described by Silver (1971). From east to west, these are the continental shelf, the plateau slope, and the marginal plateau (Eel plateau) located between Trinidad and Eel Canyons. The break between the edge of Eel plateau and the continental slope is 16 km west of the survey area. Eel Canyon is located just outside the southwest corner of the sale area.

The continental shelf, in the southeast corner of the area, is the relatively flat portion of the sea floor shallower than the 500-foot (152.4-m) isobath (pl. 1; tracts 013, 018, 022, 023, and 025-030). The shelf is nearly flat and featureless. Within individual tracts, relief is less than 40 m and the slope is usually less than 0.4° NW, although slopes may be as great as 1.2° NW near the shelf break (tracts 017, 021, and 025).

Between the shelf and the marginal plateau, the north-northwest-trending plateau slope is inclined 2.0°-3.5° WNW (tracts 003, 004, 007, 008, 011, 012, 015, 016, 019, 020, 021, and 024). The plateau slope generally lies between the 500-foot (152.4-m) and 1,300-foot (396.2-m) isobaths and is characterized by a highly irregular sea floor, especially where downslope movement has occurred. Local undulations in these areas show as much as 18 m of relief (tracts 004, 011, and 018). Relief of the plateau slope within individual tracts ranges from 100 m (tract 019) to more than 250 m (tract 016).

The marginal plateau (Eel Plateau) is the gently sloping western and northwestern part of the survey area seaward of the 1,300-foot (396.2-m) isobath (pl. 1; tracts 001, 002, 003, 005, 006, 009, 010, 014, and 015). The plateau is inclined 1.0°-1.5° W. The surface of the plateau is jumbled and hummocky where underlain by mass transport deposits but is otherwise smooth, with slight undulations. Relief within individual tracts ranges from 80 m to 195 m. A series of northwest-trending bedrock ridges are exposed on the plateau (tracts 001, 002, 003, 007, 014, and 019). These ridges have a maximum relief of 110 m and slopes as steep as 7.5°.

Many of the ridges on Eel plateau are possibly diapiric in nature (Field and others, 1980). Younger sediments, where present, are bowed upward by the diapiric intrusions and are mapped as anticlines. The cores of some of these ridges (diapirs), where exposed at the sea floor, are shale or cohesive muds of Pliocene age (Field and others, 1980). Possible diapirs are located in the north-central sale area (pl. 1; tracts 001, 002, 003, 006, 007, and 011) and along and outside the western boundary of the sale area (tracts 005, 014, and 019). These northwest-trending structures plunge southeast under the sediment cover. Young, flat-lying sediments (Holocene?) on the plateau are stretched and upturned at the base and flanks of the diapiric ridges, an indication of the recency of piercement.

Potential Geologic Hazards

Mass Transport

Two zones of mass transport were mapped in the sale area. The largest failure zone, about 175 sq km in area, is located on the west side of the sale area and covers 2.5-100 percent of tracts 005, 006, 009, 010, 011, 014, 015, 016, 019, 020, 021, and 024 (pl. 1). This zone comprises at least three coalescing slides. Declivity ranges from 3.6° on the upper part of the failure zone to 0.8° on the lower part. Several previous slides underlie the surface slides to a depth of about 200 m and extend 1-3 km beyond the boundaries of the surface slide. The most recent slides are less than 40 m thick along gently dipping slip surfaces. Sea-floor topography over the slides is very chaotic and hummocky. Tensional fractures and associated normal faulting at the surface of the slides form discontinuous troughs and ridges, with less than 5 m of relief, perpendicular to the downslope movement. There is a possible head scarp (pull apart) with 5°-7° slope at the head of the slide zone (tracts 011 and 016) which is evidence of dislocation and movement of the sediment unit. The zone gradually dies out to the north (tracts 005 and 006); therefore, the boundary is hard to define and is questionable as indicated (pl. 1).

The second zone of mass transport is located along the plateau slope in in the northeast part of the sale area (pl. 1; tracts 003, 004, 007, 008, 011, and 012). The entire zone (within the sale area) is about 50 sq km in area and covers from 1.5 to 60 percent of the overlying tracts. The slope in this zone is 1.2°-1.8°. At least four individual coalescing rotational slumps are identified but are not differentiated. The sea floor overlying the slumps in the northern two-thirds of the zone is characterized by a series of mounds (2 to 3) which represent rotated slump blocks with as much as 10 m of sea-floor relief. Slump blocks show relatively little internal deformation (rotated bedding) and measure 30-70 m thick. The southern part of the slump zone is characterized by a smooth undulating surface. A well-defined head scarp is present along the entire length of the slump zone.

Faults

The majority of faults in the sale area are associated with diapiric structures or anticlinal upwarps on the Eel plateau and on the continental shelf. Most of these faults can by placed into one of two groups: 1) those along which diapiric structures were uplifted or emplaced (pl. 1; tracts 001, 002, 007, 025, 026, 029, and 030), or 2) those formed as the result of extension or thinning of the sediment cover over the tops of buried diapiric structures or upwarps (pl. 1; tracts 001, 005, 006, 007, 009, 010, 011, 014, 019, 020, 025, 026, 027, 029, and 030). Those faults associated with the growth of diapirs show large vertical displacement that could not be measured. They trend northwest, parallel to the structures, and range in length from 3 to 6 km. They offset the sea floor on the flanks of upwarps just west of tract 001 and in tract 007. These faults are probably of Holocene age. Faults associated with an upwarping of the sediments in tract 025, 026, 027, 029, and 030 are west-trending and range in depth from 30 to 140 m. Tensional faults above the trends of buried diapiric structures or upwarps (one in tracts 001, 005, 006, and 009 and one in tracts 014, 019, 020, and 024) show relatively little vertical offset, less than 5 m, and cut the sea floor in tract 019. The tensional fractures range in length from 1.5 to 5.0 km and are less than 120 m below sea floor. The faults that cut the sea floor are Quaternary in age. The age of the deeper faults is unknown.

Constraints

Hydrocarbon Seeps

Possible hydrocarbon seeps occur scattered along the outer shelf and plateau slope in the sale area (pl. 1; tracts 004, 008, 011, 012, 013, 016, 017, 021, 022, 025, 026, 029, and 030). Seeps are usually associated with zones of shallow gas-charged sediment. On portions of lines ER 022, ER 024, ER 028, ER 030, ER 040, ER 050, ER 067, and ER 069, continuous zones of anomalies were observed in the upper part of the water column on one-quarter millisecond, mini-sleeve exploder profiles and probably represent schools of fish.

Gas-Charged Sediment

Probable gas-charged sediment completely masks and eliminates subbottom reflectors in more than 35 percent of the sale area. All zones of gas-charged sediment identified are underlying the plateau slope and outer shelf environment. The largest zone, about 220 sq km in area, trends northeast across the center of the area (pl. 1; tracts 007, 008, 011, 012, 013, 016, 017, 018, 020-026, and 028). One to 100 percent of each of the above tracts contain gas-charged sediment. Five smaller zones of gas-charged sediments, ranging from 2.5 sq km to more than 12 sq km in area, fringe the large zone. All gas-charged sediment zones range from 5 to 50 m below the sea floor.

Shallow Gas

No extensive zones of shallow gas were identified in the Eel River area. Small zones, ranging from 0.5 to 4.5 sq km in area, are scattered in the subsurface underlying the shelf and plateau slope (pl. 1; tracts 003, 004, 007, 008, 013, 021, 022, 025, 026, 027, 029, and 030). Gas zones range in depth from 55 to 340 m below the sea floor.

POINT ARENA AREA

Setting

The Point Arena area is located on the continental margin between Point Cabrillo and Point Arena, California, about 10 km west of Mendocino and 20 km southwest of Fort Bragg (fig 1). The sale area consists of 29 complete tracts and one partial tract. About 1,655 line-km of multisensor, high-resolution data were obtained in and adjacent to the sale area (pl. 2).

Physiography

The sale area lies on the narrow continental shelf and slope west of Mendocino. The continental shelf is defined as the area shallower than the 500-foot (152.4-m) isobath and is generally 8-30 km wide in and adjacent to the sale area. Within the sale area, the continental shelf is generally smooth and regular where covered by sediment. In areas where bedrock crops out (tracts 054-059), the sea floor is slightly irregular due to differential erosion of dipping beds which exhibit several meters of relief. The shelf is gently inclined 0.2°-1.9°W. Relief within individual tracts on the shelf ranges from 20 m to 120 m.

The western half of the sale area is located on the upper continental slope, which is inclined 2.0°-4.3° W. Relief within individual tracts on the slope ranges from 220 m to more than 430 m. The heads of three submarine canyons incise the slope along the west margin of the sale area. The southern two canyons are Navarro Canyon in tract 053 and west of tracts 045, 049, and 053, and Arena Canyon west of tract 058. A few kilometers west of the sale area these two canyons show more than 600 m of relief and wall slopes as steep as 11°. Within the sale area, wall slopes do not exceed 5°. An unnamed channel in and west of tract 040 exhibits about 100 m of relief with wall slopes as steep as 5°. A bedrock ridge with as much as 40 m of relief flanks the south side of this channel.

Potential Geologic Hazards

Mass Transport

Submarine slides in the Point Arena area are all found on the slope and on channel walls along the west margin of the sale area (pl. 2). Seven slides were mapped in and adjacent to the sale area, ranging in area from 8 to 19 sq km. The failures occur on slopes of 1.8°-4.8°. Three slides, in tracts 031, 032, 053, and west of 058, are inferred from slightly irregular sea floor. The four slides in the west central sale area (tracts 037, 038, 040, 041, 043, 045, and 049) are shallow surface features with the depth of disturbance less than 10 m. These slides are characterized by a slightly hummocky sea floor and slightly distorted internal reflectors.

Faults

Most faults in the sale area are associated with north-northwest-trending buried basement ridges that approach but do not intersect the sea floor. Most of the faults do not cut the Quaternary section and are restricted to the basement rocks. One fault in the northeast corner of tract 055 offsets the base of the Quaternary section about 30 m. Faults in basement rocks can be traced 1-14 km and range in depth from 10 to 390 m below the sea floor; the depth is governed by the depth of burial of the ridges. The buried ridges generally plunge to the northwest; therefore, the shallowest faults are principally in the southeast corner of the sale area (tracts 057, 059, and 060) and the deepest faults are in the northwest (tracts 038, 040, and 041).

Few faults are found in the relatively undeformed Neogene section. These range in length from 1 to 3 km and are located in tracts 036, 037, 040, and 049.

The San Andreas fault, located 1-10 km east of the sale area, trends N. 17° W. and is a 1-6-km-wide zone north and east of Point Arena (Curray, 1966). Scarps with relief of 3-20 m were identified on lines PA 038, PA 044, PA 048, PA 050, PA 080, PA 092, and PA 100 (pl. 2) where they cross the San Andreas fault east of the sale area. Bedrock is uplifted on the east against Quaternary sediment on the west. Hydrocarbon seeps are found above the fault trace east of tracts 039 and 048. Lateral movement along the fault could not be determined in the sale area, but according to Curray (1966), Noyo Canyon, 15 km north of the sale area, has been diverted at least 6 km right-laterally along the San Andreas fault since the Pleistocene.

Constraints

Buried Channels

Buried channels are common on the slope along the west and central portions of the sale area and are associated with the existing canyon systems. The buried channels are generally west-trending. Most of the buried channels are filled channels on the sea floor, although some are buried as deep as 100 m below the sea floor. Relief within buried or filled channels is generally less than 100 m but is as high as 250 m in the channel mapped in tract 056.

Hydrocarbon Seeps

Possible hydrocarbon seeps occur exclusively on the shelf and upper slope where water depths are less than 215 m. Seeps (water-column anomalies) are generally associated with bedrock outcrops or areas where a veneer of sediment covers bedrock. In tracts 042 and 044, seeps are found above gas-charged sediment. On portions of lines PA 006, PA 012, PA 014, PA 016, PA 029, PA 034, PA 035, PA 050, PA 052, PA 056, PA 064, and PA 066 (pl. 2), continuous zones of anomalies were observed in the water column on one-quarter millisecond, mini-sleeve exploder profiles and may represent kelp or schools of fish.

Gas-Charged Sediment

Gas-charged sediment covers about 50 sq km within and adjacent to the sale area. Four separate zones were mapped and range in area from 2 to 35 sq km. All zones of near-surface, gas-charged sediment are found associated with buried, seaward-dipping beds in the shelf break region (pl. 2; tracts 033, 036, 039, 042, 044, 050, 051, 053, 054, 056, and 058).

Shallow Gas

Ten zones of shallow gas were mapped in the Point Arena area (pl. 2). These zones range from 2 sq km to more than 20 sq km in area. Depth of gas below the sea floor ranges from 50 to 260 m. Shallow gas in tracts 039, 042, 047, 048, 051, 052, 055, and 058 is associated with faults in the highly deformed lower Neogene section. The two largest zones east of tracts 033, 036, 039, and 042 are in the relatively undeformed, flat-lying upper Neogene section.

BODEGA AREA

Setting

The Bodega area consists of eight complete tracts in northern Bodega basin 23 km west of Bodega Bay (fig. 1). About 661 line-km of multisensor, high-resolution data were obtained in the sale area (pl. 3).

Physiography

The sale area lies on the continental shelf west of Bodega Bay. The depth of the shelf within the sale area ranges from 108 to 225 m. The sea floor is generally smooth and regular with an average slope of 0.4° SW; slope ranges from 0.2° SW in the northeast to 1.0° WSW in the southwest. Relief within individual tracts ranges from 16 m (tract 062) to 85 m (tract 067). A surficial layer of unconsolidated sediment extends over the entire sale area, ranging in thickness from 9 m in the southwest to 30 m in the northeast.

Bodega Canyon lies west and southwest of the sale area (pl. 3). The submarine canyon trends northwest to the west of tract 067 and curves to trend west outside of tract 065. Maximum relief in the canyon is about 610 m. Canyon walls are as steep as 4.5°.

Potential Geologic Hazards

Faults

A northwest-trending parallel set of faults was identified in the southwest quarter of tract 067 (pl. 3). The faults are 125-135 m below the sea floor with minor apparent offset (less than 5 m).

Constraints

Hydrocarbon Seeps

Possible hydrocarbon seeps are identified in the northeast sale area (pl. 3; tracts 061, 062, and 064). Water-column anomalies along lines BD 026 and BD 030 were identified on side-scan sonographs only and may represent schools of fish.

Shallow Gas

Several small bright reflectors, 106-196 m below the sea floor, were identified in tract 065 (pl. 3). These zones are too small to show at map scale 1:100,000 and are not considered hazards.

SANTA CRUZ AREA

Setting

The Santa Cruz area consists of 54 complete and six partial tracts 35 km northwest of Santa Cruz and adjacent to the California 3-mile line (fig. 1). The area surveyed includes the southern portion of the Bodega basin, the southeast end of the Farallon-Pigeon Point High, and the central portion of the Outer Santa Cruz basin. A total of 2,594 line-km of multisensor, high-resolution data was obtained in the sale area (pl. 4).

Physiography

The Santa Cruz area is located on a part of the relatively wide continental margin of the central California OCS. Most of the sale area lies on the 25-50 km wide continental shelf between San Francisco and Santa Cruz. The shelf break and upper slope fringe the west and southwest margins of the sale area. In the sale area, water depths range from 32 to 385 m and relief within individual tracts ranges from 10 to 266 m. The shelf is gently inclined 0.1°-1.5° SW. At water depths greater than 150 m (the shelf break), slopes are 3°-5° SW. The sea floor is generally smooth and featureless over most of the area but is irregular over bedrock exposures in the central sale area and is pockmarked along the outer shelf and shelf break.

The head of Ascension Canyon cuts the slope and outer shelf on the southern tip of the sale area (pl. 4; tract 128). There is more than 150 m of relief in the canyon and canyon walls are as steep as 12°. Unconsolidated sediments floor the canyon and form a thin layer on the canyon walls.

An unnamed group of southwest-trending channels incise the upper slope in tracts 108, 114, and 119, along the western margin of the sale area (pl. 4). These channels show less than 50 m of relief and have wall-slopes as steep as 12.5° locally.

Potential Geologic Hazards

Faults

Most faults in the Santa Cruz area are in the highly deformed, older basinal sediments on the flanks of the buried Farallon-Pigeon Point High (fig. 1). The crest of the high, which trends northwest across the center of the sale area, appears to be unfaulted. The southwest flank of the high is intensely faulted, especially in tracts 116, 117, 118, 121, and 122 (pl. 4). Individual fault traces in this zone are 2-15 km long. Where measured, vertical separation is less than 50 m. Neogene-aged basin sediments that overlie the older faulted rocks are essentially unfaulted on the southwest flank.

The northeast flank of the Farallon-Pigeon Point High is deeper in the section, mostly below the maximum penetration depths of the geophysical systems used in the survey. Where observed, the northeast flank is as highly deformed as the southwest flank. Several of the major faults in the older rocks cut part of the Neogene section (pl. 4; tracts 070, 071, and 074).

The northwest-trending Seal Cove fault zone in the northeast corner of the sale area (pl. 4; tracts 072, 076, and 080) cuts the sea floor along at least a part of its trace. This fault zone, which consists of two to three major traces, parallels, and is probably related to, the onshore San Gregorio fault, 3-4 km to the east. Gas in the fault zone obscures the geophysical data, so faulting characteristics could not be determined.

Slopes/Submarine Canyons

The two submarine canyon systems that are incised into the upper slope of part of the west and southwest sale area (pl. 4; tracts 114 and 128) have wall slopes as steep as 12.5°. Unconsolidated sediments are as thick as 5 m on the walls of Ascension Canyon in tract 128 (pl. 4). Slope of the inter-channel area in tract 114 is locally as steep as 10° (pl. 4).

Constraints

Buried Channels

Eight buried channels were identified in and adjacent to nine tracts in the Santa Cruz area (pl. 4). Six of the buried channels are related to the modern canyons and channels. These six channels are relatively shallow, less than 100 m below the sea floor, and are mapped as segments, traceable on two to three track lines. The largest buried channel is more than 9 km long and 3 km wide. It is buried less than 30 m below the sea floor adjacent to the unconformity between the granitic basement high and the Neogene-aged basin sediments.

Hydrocarbon Seeps

Water-column anomalies (possible hydrocarbon seeps) are concentrated above and in areas immediately adjacent to steep-dipping bedrock outcrops (pl. 4; tracts 091, 092, 093, 094, 095, 097, 098, 099, and 118). These concentrations of anomalies may represent kelp and fish in the shallow water above the rocky sea floor. Anomalies were mapped above buried fault traces in tracts 096, 101, 102, 108, 110, and 118 (pl. 4).

Hydrocarbon seeps with seep mounds(?) and craters (pockmarks) were identified associated with gas-charged sediment in tract 081, 108, and 119 (pl. 4).

Gas-Charged Sediment

Gas-charged sediment covers about 350 sq km within and adjacent to the sale area. Two zones were mapped and are about 85 and 250 sq km in area. Both gas-charged sediment zones are associated with near-surface, seaward-dipping beds in the shelf break region along the west and southwest margins of the sale area. The sea floor above the largest zone, over 50 km long, is locally pockmarked, possibly indicating gas craters and degassing of sediments. Hydrocarbon seeps were found above gas-charged sediment zones.

Shallow Gas

Shallow gas is rare in the Santa Cruz area. Six zones were mapped in seven tracts (pl. 4). These zones are all small, ranging in area from 0.4 to 1.5 sq km. Depth of shallow gas below the sea floor ranges from 30 to 400 m. Three zones, in tracts 107, 116, 117, and 122, are related to fault zones.

SANTA MARIA AREA

Setting

The Santa Maria area is located adjacent to the California 3-mile zone between Morro Bay and Point Conception (fig. 1). The sale area consists of 94 complete and 21 partial tracts. A total of 4,444 line-km of multisensor, high-resolution data was obtained in and adjacent to the sale area (pls. 5 and 6). The survey area overlies the southern part of the offshore Santa Maria basin and the transition zone between the Transverse Range province and the Coast Range province.

Physiography

The survey area overlies part of the relatively wide continental margin of south-central California. The relatively flat (<0.5°) and narrow (5-25 km wide) coastal shelf, defined as the area shallower than the 500-foot (152.4-m) isobath, borders parts of the east and northeast survey area. The remainder of the survey area overlies a gentle ramp or slope, inclined 0.8°-1.5° west to southwest, that extends to Santa Lucia Bank and the continental slope 60-110 km offshore. Average slope in individual tracts ranges from 0.2° to 3.4°.

Water depth in the sale area ranges from about 50 m along parts of the eastern margin to about 600 m along the southwest margin of the area. Relief within individual tracts ranges from 15 m (pl. 6; tract 176) to more than 350 m (pl. 6; tracts 239 and 240).

The Santa Maria area is characterized by a variety of sea-floor features. The sea floor exhibits a generally regular surface but is broken by outcrops of bedrock and a series of submarine channels.

The largest sea-floor features observed within the sale area are the rugged outcrops and their associated rubble. Two large outcrops pierce the sea floor in the central sale area. The largest outcrop forms a northwest-trending ridge, 16 km long and as much as 2.5 km wide; maximum relief along this ridge is about 170 m. The second ridge-forming outcrop is the north-northwest-trending sea-floor expression of the Lompoc anticline. This ridge measures about 13.5 km long and as much as 2.2 km wide with about 56 m of sea-floor relief. Outcrops with minor relief are observed along the eastern margin of the area on the coastal shelf.

Four submarine channels--the upper reaches of the Arguello Canyon system--incise the sea floor in the southern sale area. These channels cut the outer coastal shelf and slope and are not identified on the sea floor shallower than the 300-foot (91.5-m) isobath. The channels range from 1.0 to 2.5 km wide and are incised 50-160 m into the sea floor. Channel walls are moderate to very steep with slopes ranging from 7° to 25°. Levee deposits are identified flanking the channels in water depths greater than 180 m.

A 15-km-long, 600-900-m-wide scarp(?) or depression is located on the slope, seaward of the coastal shelf, 8-13 km west and southwest of the Point Buchon-Point San Luis coastline (pl. 5; tracts 137, 141, 142, 145, 149, 150, 154, and 155). A superficial mound of sediment, 10-20 m high and 2-4 km wide, lies seaward of this depression. The mound is undeformed and is conformable with the underlying sediment. The mound probably is not related to the scarp or depression and most likely represents primary sedimentary deposition.

Potential Geologic Hazards

Mass Transport

Four zones of mass transport are identified in the Santa Maria area on slopes of 1°-2°. A large zone, probably representing a single event or failure, is mapped in the west-central survey area (pl. 5; tracts 156-159 and 162-165). The zone is greater than 90 sq km in extent inside the sale area and about 115 sq km overall. The depth of disturbance is less than 15 m over most of the zone and is very shallow in the southern three tracts (pl. 5; tracts 162, 163, and 164). The sea floor is hummocky over most of the zone.

Three questionable zones of mass transport, possible sediment creep or debris on the sea floor, are mapped in the sale area. One zone (pl. 5; tract 161), about 2.3 sq km in area, was identified on a single line and is relatively insignificant. The other two zones, 41 and 43 sq km in area, are located in the west-central survey area (pl. 5; tracts 172 and 173; pl. 6; tracts, 178, 179, 180, 184, 185, 186, 191, 192, 193, 197, and 198). These two zones, characterized by a slightly hummocky and debris-strewn surface, are highly questionable and show no, or very limited, subbottom disturbance. Side-scan sonographs show rubble on the sea floor over at least part of the two zones.

Faults

Faulting is mostly confined to the northeast and east margins and the southern third of the sale area. Few faults were mapped in the west and central sale area and those appear to be relatively minor. Four major, potentially active fault zones or areas of faulting, all previously mentioned in the literature, are mapped--the Hosgri fault zone, the Purisima fault zone, the Lompoc fault zone, and an area of intense faulting west and south of Point Arguello (the transition zone between the Coast and Transverse Ranges).

The Hosgri fault zone, named by Wagner (1974), is the 120-km southward extension of the onshore San Simeon fault (Hall, 1975). The fault zone forms a 2-6 km wide zone along the east and northeast margin of the sale area (pls. 5 and 6). Tracing the fault zone south of Point Sal is nearly impossible because of the complex structure in the transition zone between the Coast and Transverse Ranges. This north-northwest-trending fault zone is about 87 km long in the survey area and consists of numerous splays and segments 3-40 km long. The major fracture zone is about 70 km long within and adjacent to the sale area.

Fault planes are rarely obvious on profiles, but appear to be vertical where identified. Payne and others (1979) state that the fault planes dip between 45° and 90°. Where fault planes are identified, the east side is generally upthrown with respect to the west, but the relative displacement can vary along a single fault trace. The traces of faults in the Hosgri fault zone cut the sea floor in tracts 131, 138, 142, 146, 151, 155, 189, and 196, and offset the sea floor in tracts 131, 134, 146, 151, and east of tract 134 (pls. 5 and 6). The major trace in the fault zone offsets the sea floor in tracts 131 and 146 (pl. 5). Elsewhere in the fault zone, the major trace is as deep as 30 m below the sea floor and minor segments are as deep as 250 m.

The Hosgri fault zone is characterized by both lateral and extensional movements. There has apparently been at least 80-95 km of right slip along the Hosgri fault zone since Pliocene time (Hall, 1978). According to Wagner (1974), the apparent vertical separation in the fault zone, based on the offset of an unconformity on top of the pre-Tertiary unit, ranges from 458 to 1,830 m. In the sale area, apparent vertical separation was nearly impossible to measure owing to the difficulty of correlating reflectors across a fault and to the complex structure in the fault zone. Maximum displacement of Quaternary sediment is 45 m downthrown to the west along the major fault trace (pl. 8; tract 189). Vertical separation on a fault splay in the major zone in tract 196 is 15-30 m.

The Purisima fault zone (trend) is an informal name (ESA, 1974) given to a 26-km-long, north-northwest-trending disturbed zone about 5 km west of the Hosgri fault zone (pls. 5 and 6). Evidence for faulting is inconclusive along at least part of the fault zone where it is thought to exist on the basis of discordant dips across the line of inflection of a large upwarp. Fault splays comprising the Purisima fault zone range in length from 2.0 to 11.5 km and are usually less than 150 m subbottom. Fault segments cut the sea floor in tracts 188 and 195 (pl. 6) and appear to offset the sea floor along at least a part of their length. The west side of the fault is upthrown relative to the east side.

The name Lompoc fault zone was applied by ESA (1974) to a pair of prominent subparallel faults located about 17 km west of Purisima Point (pl. 6). The north-northwest-trending Lompoc fault zone is as much as 2 km wide and 25 km long; individual faults in the zone are 3-10 km long. The fault zone parallels the Lompoc anticline, which is exposed for 13.5 km along the sea floor. Maximum surface topography (anticlinal upwarp) associated with the Lompoc fault zone is 56 m. The westernmost part of the fault zone consists of five segments 3-10 km long, with about 4 km of length having possible surface expression (pl. 6; tracts 194, 200, 201, and 207). The remainder of the western fault zone is as much as 200 m subbottom. The western part of the Lompoc fault zone is a series of reverse faults which parallel the west flank of the Lompoc anticline and dip about 70° E (ESA, 1974). Vertical displacements of 150-300 m have been measured along this zone (ESA, 1974). The eastern part of the fault zone consists of two segments, 4 and 4.5 km long, with the southern segment being inferred. The eastern zone follows the crest and east flank of the Lompoc anticline and shows no surface expression. The fault is east-dipping with subbottom depth ranging from 50 to 140 m.

West and south of Point Arguello, the coastal shelf and slope are dominated by west-to-north-northwest-trending faults (pl. 6). The faults range in length from 2.5 to 15.5 km and generally range in depth from 5 to 40 m subbottom, although some are as deep as 90 m. A 3-km-long fault segment in tracts 237 and 238 cuts the sea floor but exhibits no offset (pl. 6).

Although the relative displacement is variable on different faults, the western or southern block is generally downthrown. The vertical separation could not be reliably measured on any of the faults. Dip of fault planes is variable and ranges from vertical to about 45° NE.

Focal mechanism studies and fault plane solutions by Gawthrop (1975, 1978b) indicate northeast compression in the area west and southwest of Point Arguello, suggesting thrusting, with the northern block being upthrust. This agrees with the works of McCulloch and others (1977) and Yerkes and others (1980), who have interpreted faults southwest of the Arguello slope as west-to-northwest-trending, northeast-dipping reverse faults. Yerkes and others (1980) suggest that some of these faults show Quaternary activity.

Slopes/Submarine Canyons

Moderate slopes have been measured on the flanks of the outcrop ridges in the central sale area. Slopes average 4.0° to 6.8° in individual tracts but are as steep as 8.2° locally (pl. 6; tracts 177 and 178). These ridges are barren of sediment so there is no problem of unstable sediment masses associated with the steeper slopes.

Submarine channels in the southern part of the sale area, which comprise the upper reaches of the Arguello Canyon system, incise at least part of 13 tracts (pl. 6). Unconsolidated sediments floor all of these channels and form at least a thin skin on the channel walls. Steep wall slopes, greater than 10°, are common in all of the channels (pl. 6; tracts 226, 227, 228, 231, 232, 233, 235, 236, 237, and 239) and slopes greater than 20° were measured in three tracts (pl. 6; tracts 233, 235, and 237). The combination of steep slopes and thin sediment cover suggests the possibility of unstable sediment masses on the channel walls.

Constraints

Buried Channels

Three areas of buried channeling are identified in the Santa Maria area (pls. 5 and 6). The major area of buried channels is the southern third of the sale area. Several subparallel, southwest-trending buried channels are associated with modern sea-floor channels. At least three of the buried channels are bifurcating channels. Depths from the sea floor to the top of the channel fill range from 0 m, where surface channeling has cut into the fill, to 210 m.

Two buried channels and one buried depression are identified in the sale area between Point Sal and Purisima Point. These buried channels trend west and southwest. Depths beneath the sea floor range from 85 m in the filled depression to 340 m in the buried channels.

Three southwest-trending buried channels were identified in the north sale area (pl. 5). The top of the channel fill is 150-200 m below the sea floor.

Hydrocarbon Seeps

Abundant hydrocarbon seeps (water-column anomalies) are identified along the east part of the Santa Maria area. These seeps occur almost exclusively where the sea floor is shallower than the 600-foot (182.9-m) isobath. Seeps are most abundant in the four areas adjacent to promontories--southwest of Point Arguello, west of Purisima Point in association with both the Hosgri fault zone and the Lompoc trend, west of Point Sal, and south and southwest of Point San Luis.

Gas-Charged Sediment

Gas-charged sediment identified in the Santa Maria area covers 508 sq km.

The largest zone of gas-charged sediment, located in the middle of the area, covers 425 sq km of the sale area. Nine tracts are entirely within this zone (pl. 5; tracts 158, 159, 160, 164-167, and 173; pl. 6; tract 180) and the zone covers 15-75 percent of twelve additional tracts (pl. 5; tracts 149, 150, 152, 153, 154, 157, 161, 163, 168 172, and 174; pl. 6; tract 181). All other zones of gas-charged sediment are south of the large zone and range in extent from 1.4 to 2.3 sq km.

Shallow Gas

Approximately 178 sq km of the surveyed area or 7 percent of the sale area is underlain by shallow gas. The largest zone covers 15.2 sq km along the Lompoc anticline (pl. 6; tracts 186, 187, 194, and 200). Depths to shallow gas zones range from 30 to 500 m below the sea floor. Shallow gas is most abundant along major fault zones and along the flanks and crests of anticlinal structures within the Santa Maria basin.

CONCLUSIONS

Geologic hazards and constraints were identified and evaluated for each tract in the five areas of offshore northern and central California as a basis for recommendation of withdrawal or stipulation prior to the formal announcement of the sale. The U.S. Geological Survey recommended that a stipulation be applied to 68 tracts showing evidence of existing or potential sea-floor instability (table 1). High-resolution geophysical data taken within these tracts indicate areas of potential mass transport of sediment, steep-walled submarine canyons, steep slopes, and active faulting. However, these tracts can be developed from stable locations either within the tracts or adjacent to the tracts. Further data acquisition and analysis on a more detailed grid will be required of lessees or operators before drilling will be permitted on leases resulting from the sale. Table 1, which lists all tracts in the Sale 53 part A and proposed Sale 53 part B, shows potential geologic hazards and constraints determined in this evaluation.

Table 1.--Potential hazards and constraints, OCS Lease Sale 53 tracts

Tract No.	HAZARDS				CONSTRAINTS				
	Mass transport	Steep slope	Steep-walled canyon	Fault (*active)	Shallow gas	Water-column anomaly (seep)	Gas-charged sediment	Buried channel	Tracts stipulated
EEL RIVER AREA (plate 1)									
001				X					X
002				X					X
003	X			X	X		X		X
004	X			X	X	X	X		X
005	X			X					X
006	X			X					X
007	X			X	X		X		X
008	X				X	X	X		X
009	X			X					X
010	X			X					X
011	X			X		X	X		X
012	X					X	X		X
013					X	X	X		
014	X			X					X
015	X						X		X
016	X					X	X		X
017						X	X		
018							X		
019	X			X					X
020	X			X			X		X
021	X				X	X	X		X
022					X	X	X		
023							X		
024	X			X			X		X
025				X	X	X	X		
026				X	X	X	X		
027				X	X				
028							X		
029				X	X	X	X		
030				X	X	X	X		
POINT ARENA AREA (plate 2)									
031	X			X				X	
032	X			X					
033							X		X
034				X					
035				X					

Table 1.--Potential hazards and constraints, OCS Lease Sale 53 tracts (cont.)

Tract No.	HAZARDS				CONSTRAINTS				
	Mass transport	Steep slope	Steep-walled canyon	Fault (*active)	Shallow gas	Water-column anomaly (seep)	Gas-charged sediment	Buried channel	Tracts stipulated
036				X	X		X		
037	X			X				X	X
038	X			X				X	X
039					X		X		
040	X			X					
041	X			X				X	X
042				X	X		X		
043	X			X					X
044				X		X	X		
045	X							X	X
046	X								
047				X	X				
048				X	X	X			X
049	X			X				X	X
050							X		
051				X	X		X		
052				X	X	X			
053	X						X	X	
054							X	X	
055				X	X				
056						X	X	X	
057				X		X			
058					X	X	X		
059				X					
060				X					
BODEGA AREA (plate 3)									
061						X			
062						X			
063									
064						X			
065					X				
066									
067				X					
068									

Table 1.--Potential hazards and constraints, OCS Lease Sale 53 tracts(cont.)

Tract No.	HAZARDS				CONSTRAINTS				Tracts stipulated
	Mass transport	Steep slope	Steep-walled canyon	Fault (*active)	Shallow gas	Water-column anomaly (Seep)	Gas-charged sediment	Buried channel	
SANTA CRUZ AREA (plate 4)									
069				X	X				
070				X					
071				X					
072				X*			X	X	X
073				X			X		
074				X					
075				X					
076				X*			X		X
077				X			X		
078									
079				X					
080				X					
081				X		X	X		
082				X		X			
083				X					
084				X					
085				X		X			
086				X		X		X	
087				X				X	
088				X					
089				X					
090				X				X	
091						X		X	
092				X		X		X	
093				X		X			
094						X			
095				X		X			
096				X		X			
097				X		X			
098				X		X			
099				X		X			
100									
101				X		X			
102				X		X			
103				X					

Table 1.--Potential hazards and constraints, OCS Lease Sale 53 tracts(cont.)

Tract No.	HAZARDS: Mass transport	Steep slope	Steep-walled canyon	Fault (*active)	CONSTRAINTS: Shallow gas	Water-column anomaly (seep)	Gas-charged sediment	Buried channel	Tracts stipulated
104							X		
105									
106				X					
107				X	X				
108						X	X	X	
109									
110				X		X			
111				X					
112				X					
113				X					
114		X	X	X			X	X	X
115				X					
116				X	X				
117				X	X				
118				X		X			
119			X	X		X	X	X	
120				X					
121				X					
122				X	X	X			
123							X		
124					X				
125				X					
126				X	X		X		
127				X			X		
128			X			X	X	X	X
SANTA MARIA AREA (plates 5,6)									
129								X	
130				X	X			X	
131				X*	X	X		X	X
132								X	
133								X	
134				X*	X			X	
135								X	
136								X	
137				X	X			X	
138				X*	X				X

Table 1.--Potential hazards and constraints, OCS Lease Sale 53 tracts(cont.)

Tract No.	HAZARDS: Mass transport	HAZARDS: Steep slope	HAZARDS: Steep-walled canyon	HAZARDS: Fault (*active)	CONSTRAINTS: Shallow gas	CONSTRAINTS: Water-column anomaly (seep)	CONSTRAINTS: Gas-charged sediment	CONSTRAINTS: Buried channel	Tracts stipulated
139									
140									
141					X				
142				X*	X				X
143				X*	X	X			X
144									
145					X				
146				X*	X				X
147				X*		X			X
148				X					
149					X		X		
150				X*	X	X	X		X
151				X*	X	X			X
152				X			X		
153							X		
154					X	X	X		
155				X*	X	X	X		X
156	X			X					X
157	X			X			X		X
158	X						X		X
159	X						X		X
160							X		
161	X			X			X		X
162	X								X
163	X						X		X
164	X						X		X
165	X						X		X
166							X		
167							X		
168				X			X		X
169									
170							X		
171				X			X		
172	X						X		
173	X						X		

Table 1.--Potential hazards and constraints, OCS Lease Sale 53 tracts (cont.)

Tract No.	HAZARDS: Mass transport	Steep slope	Steep-walled canyon	Fault (*active)	CONSTRAINTS: Shallow gas	Water-column anomaly (seep)	Gas-charged sediment	Buried channel	Tracts stipulated
174				X			X		
175				X	X		X		X
176				X					
177				X					
178	X			X					
179	X			X			X		
180	X						X		
181				X	X	X	X		
182				X	X				X
183				X					
184	X								
185	X				X		X		
186	X			X	X		X		
187				X	X		X	X	
188				X*	X			X	
189				X*	X	X			X
190								X	
191	X							X	
192	X				X			X	
193	X				X		X		
194				X*	X		X	X	
195				X*	X	X			
196				X*	X	X			X
197	X			X					
198	X			X					
199					X				
200				X*	X	X			
201				X*	X	X			
202				X				X	
203				X		X			X
204				X					
205					X	X			
206				X	X	X			
207				X*	X	X			
208				X	X	X		X	

Table 1.--Potential hazards and constraints, OCS Lease Sale 53 tracts(cont.)

Tract No.	HAZARDS: Mass transport	HAZARDS: Steep slope	HAZARDS: Steep-walled canyon	HAZARDS: Fault (*active)	CONSTRAINTS: Shallow gas	CONSTRAINTS: Water-column anomaly (seep)	CONSTRAINTS: Gas-charged sediment	CONSTRAINTS: Buried channel	Tracts stipulated
209				X	X	X			X
210				X		X			X
211									
212				X	X			X	
213				X	X	X		X	
214				X	X			X	
215				X	X			X	
216				X	X	X			
217				X		X			X
218									
219				X	X			X	
220								X	
221						X	X	X	
222				X	X		X	X	
223				X	X	X		X	
224				X	X				
225				X				X	
226			X				X	X	X
227			X		X		X	X	X
228			X	X	X	X	X	X	X
229				X	X		X		
230				X					
231			X					X	X
232			X		X		X	X	X
233			X		X		X	X	X
234				X	X		X		
235			X				X	X	X
236			X	X	X		X	X	X
237			X	X	X	X	X	X	X
238				X	X	X	X		
239			X	X	X			X	X
240				X	X	X		X	
241				X	X	X	X		
242				X	X	X			
243				X		X			

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