UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

# GEOLOGIC HAZARDS AND CONSTRAINTS IN THE AREA OF OCS OIL AND GAS LEASE SALE 48, SOUTHERN CALIFORNIA

(SALE HELD JUNE 29, 1979)

by

William C. Richmond, L. James Cummings,
Scott Hamlin, and Mohamed E. Nagaty

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

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## SYSTEM OF MEASUREMENT UNITS

| *To convert English units* | *Multiply by* | *To obtain Metric units* |
|---|---|---|
| Feet | 0.3048 | Meters (m) |
| Mile, statute | 1.609 | Kilometers (km) |
| nautical | 1.852 | Kilometers (km) |
| Square miles, statute | 2.590 | Square Kilometers ($km^2$) |

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ABSTRACT

A geophysical survey, about 4,900 line-miles of multisensor high-resolution data, was run in 217 tracts selected by the U. S. Department of the Interior for sale in the southern California Federal Outer Continental Shelf (OCS) Oil and Gas Lease Sale 48. The geophysical systems used in the survey were a 7 kHz tuned transducer, a 1.5 kJ Acoustipulse, and a dual-channel optically stacked 10 kJ sparker with accompanying digitally processed shallow seismic profiles (deconvolved dual-channel sparker). Existing and potential geologic hazards and constraints were determined from the geophysical data. The geologic hazards in the Sale 48 area are mass movement of sediments, shallow faults, steep slopes, and steep-walled submarine canyons; constraints to oil and gas development include shallow gas, gas-charged sediments, water-column anomalies, and seep mounds. Of the original 217 tracts, 69 were withdrawn from the Sale by the U. S. Department of the Interior; 18 tracts, showing evidence of past or potential sea-floor instability, were included in the sale, but with stipulations attached. Ultimately, 148 tracts were offered in the Lease Sale of June 29, 1979.

INTRODUCTION

The U. S. Geological Survey has made a complete assessment of the geologic environment with regard to safe petroleum resource development in 217 tracts selected by the Department of the Interior for sale in the Federal Outer Continental Shelf (OCS) Oil and Gas Lease Sale 48. Potential and existing geologic hazards were identified from high-resolution geophysical profiles in 10 areas (shown on 12 plates) throughout the southern California OCS, south of Point Arguello (fig. 1): two in the Santa Barbara Channel region (Point Conception area and Santa Barbara Channel area); four on the outer ridges and banks (Santa Rosa area, Dall Bank area, Tanner-Cortes Banks, and Santa Barbara Island area); and four along the coastal shelves and banks between Los Angeles and San Diego (San Pedro area, Dana Point, Oceanside area, and San Diego area). A total of 69 of the original 217 tracts was withdrawn from the sale. The U. S. Geological Survey recommended that stipulations be applied to 17 of the remaining 148 tracts for which there is evidence of past or potential sea-floor instability.

Geologic hazards are defined as any natural features or processes, existing or potential, that would inhibit the safe development of oil and gas resources. Hazards that are encountered in the Sale 48 area are mass movement of unconsolidated to semi-consolidated surface sediments, shallow

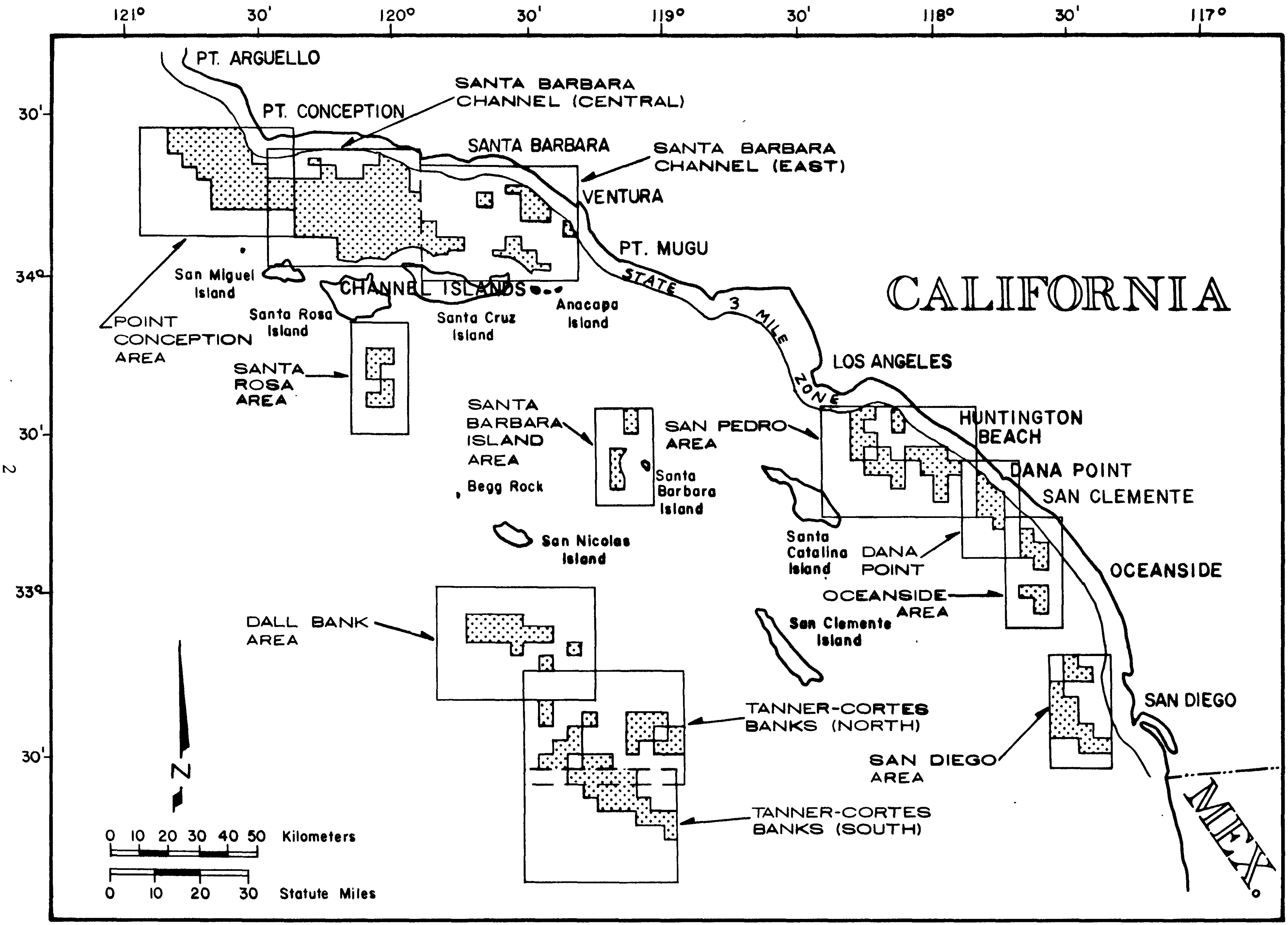


Figure 1.--Index map of OCS Lease Sale 48. Individual areas discussed in text are outlined and stippled.

faults, and steep (>7°) slopes and steep-walled canyons. Geologic features that are considered hazardous in their present state but whose effects can be lessened through existing technology and design are referred to as constraints. These second-order geologic hazards include water-column anomalies, seep mounds, gas-charged sediments, and shallow gas (bright spots). 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 describes the geologic hazards and constraints that are found in the southern California OCS. Geologic hazards and constraints are described, as are the general setting and physiography for the 10 areas. Geologic hazards for the 10 areas are shown on plates 1-12.

## DATA COLLECTION AND ANALYSIS

High-resolution seismic reflection profiles collected by McClelland Engineers, Inc. (from September 1977 through March 1978) under contract to the U. S. Geological Survey (contract 14-08-0001-17200) are interpreted in this report. The contractor supplied data-reduction services and compiled preliminary reports and geologic hazards maps (scale 1:48,000) for each area. These maps were later extensively modified by U. S. Geological Survey personnel using base maps supplied by the contractor. A total of about 4,900 line-miles of multisensor, high-resolution data was collected on a 0.5 x 1.5-mile grid. About 24-30 line-miles of geophysical profiles were obtained from each tract. The geophysical systems used in the survey were a 7 kHz tuned transducer, a 1.5 kJ Acoustipulse, and a dual-channel optically stacked 10 kJ sparker with accompanying digitally processed shallow seismic profiles (deconvolved dual-channel sparker). The interested reader should see USGS Data Set PA 17200 for a detailed description of geophysical data acquisition.

These data (USGS Data Set PA 17200), on microfilm and paper copies, are available for public inspection at the Office of the Oil and Gas Supervisor, 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.

The ships used in this survey, *M/V Widgeon* (primary) and *M/V Sea Mark* (secondary), had identical geophysical equipment. Navigational systems provided by the contractor were an Argo medium-frequency phase-comparison positioning system and a MINIRANGER III ranging system. The navigational system has a reported accuracy of ± 50 feet.

## REGIONAL GEOLOGIC SETTING

The elongate region offshore between Point Arguello, Calif. and Isla Cedros, Baja California del Norte, Mexico, named the "continental borderland" by Shepard and Emery (1941), is characterized by the highly irregular topography of basins and ridges. The part of this region north of the U.S.A.-Mexico border is referred to as the southern California continental borderland (fig. 2) and covers the westernmost extent of two of several major structural and geomorphic provinces in southern California--Transverse Range province and Peninsular Range province.

The Santa Barbara basin, a tectonic depression that forms the western part of the Neogene-age Ventura basin, is the submerged southwestern part of the Transverse Range province (Vedder and others, 1969). The characteristic west-trending structural grain of the Transverse Range province (transverse to the distinct north-northwest structural grain of California) is reflected in the major structures within the Santa Barbara basin, especially in the eastern part of the basin, as well as in the Santa Ynez Mountains to the north and the Channel Islands to the south. The basin floor is composed of as much as 4,000 feet of Quaternary sediments that are gently folded and faulted in most areas but are undeformed in many others (Curran and others, 1971; Vedder and others, 1974). The shelves and upper slopes of the basin are mantled by a very thin layer of sediment. Below the Quaternary-age basin fill are more than 50,000 feet of highly folded and faulted Tertiary and Cretaceous strata (Vedder and others, 1969). The present-day Santa Barbara Channel is a west-trending silled basin that has a maximum water depth of about 2,050 feet; it is about 80 miles long and 25 miles wide.

That part of the southern California continental borderland south of the Channel Islands that extends 40-160 miles west to the Patton escarpment is the offshore extension of the Peninsular Range province. This area is characterized by a series of complexly folded and faulted north-northwest-trending ridges and basins that parallel the structural grain of the onshore Peninsular Range province. The basins are under water depths of about 2,000-6,000 feet, whereas water depths above the flat-topped ridges and coastal shelves are usually less than 500 feet. Coastal shelves are commonly very narrow, the widest being only 15 miles, for example, the Santa Monica and San Pedro shelves.

Rocks and sediments in the southern California continental borderland range in age from Cretaceous through Holocene. On the outer ridges (for example, Santa Rosa-Cortes Ridge) sediments of late Tertiary to Quaternary age are sparse and generally occur as isolated pockets 15-65 feet thick (Greene and others, 1975; Field and Richmond, 1980). Along the coastal shelves, unconsolidated sediments are extensive and as much as 650 feet thick. Correlative deposits are as much as 1,100 feet thick in the Santa Monica and San Pedro basins (Vedder and others, 1974). Constructional marine terraces (Pleistocene?), locally more than 2.5 miles wide, encircle Tanner-Cortes Banks (Greene and others, 1975), and erosional remnants of correlative deposits have been identified on the northern Santa Rosa-Cortes Ridge (Field and Richmond, 1980). These unconsolidated sediments overlie pre-upper Tertiary sediments and sedimentary rocks, volcanic rocks, and, in isolated occurrences, metamorphic and plutonic rocks.

For more information on the southern California continental borderland the interested reader should refer to the following publications: Emery (1960), Moore (1969), Vedder and others (1974), Greene and others (1975), Roberts (1975), Welday and Williams (1975), Howell (1976), and Junger (1979).

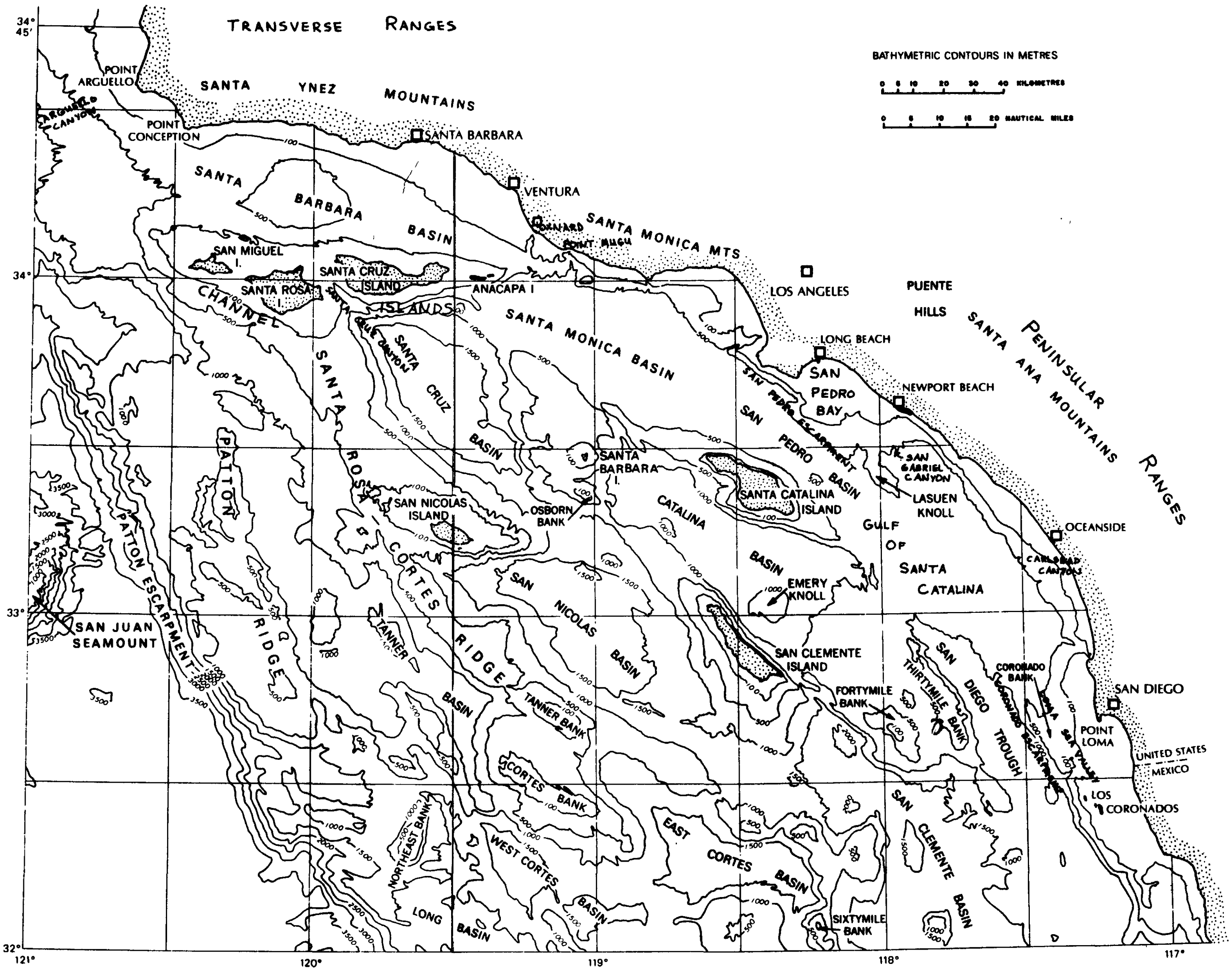


Figure 2.--Topographic map of the southern California continental borderland (modified after Vedder and others, 1974).

## SEISMICITY

The southern California continental borderland is within the circum-Pacific volcanic and seismic belt that has been active throughout middle and late Cenozoic time. Tectonism has accelerated during the latter part of this era, with maximum activity occurring in Quaternary time (Hamilton and others, 1969).

Earthquakes in the borderland have been monitored since the 1920's, although reliable accounts of California earthquakes date from 1800. Since 1932 instrumentally recorded earthquakes throughout southern California have been reported by the California Institute of Technology (Hileman and others, 1973). More than 20 earthquakes of magnitude 6.0 or greater have occurred in southern California since 1912. The largest earthquake centered in offshore southern California, magnitude 7.5, occurred west of Point Arguello in 1927 (Hamilton and others, 1969). Epicenters of the major earthquakes in southern California during 1932-1972 are plotted on figure 3, which shows events greater than or equal to magnitude 4.

## POTENTIAL GEOLOGIC HAZARDS

### Mass Movement

Mass movement of sedimentary rocks in the southern California continental borderland is in the form of slides, slumps, and sediment creep. Slides (glides) are identified as either rigid or semi-consolidated masses along discrete shear planes with relatively minor internal flow (Dott, 1963). Slumps, a term often used synonymously with slides, refers to rotational sliding of sedimentary units along discrete shear planes (Dott, 1963). Sediment creep, on the other hand, does not require rigid sediment or translation along a shear plane. Creep refers to the very slow and nearly continuous downslope movement due to gravity of the top layers of unconsolidated sediment.

### Faults

Faults in general are not considered hazardous to petroleum resource development. Faults are considered hazardous when 1) they are considered active as indicated by offset of most recent sediments (Quaternary) where sedimentation has been essentially 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 Palos Verdes Hills fault zone). Identification of active faults provides data on the nature of the hazard 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. Also, fluid injection may reactivate deeper faults (thought to be inactive) causing subsidence.

### Steep Slopes/Submarine Canyons

Slopes and submarine canyon walls are arbitrarily classified as flat, gentle, moderate, or steep according to the steepness of the slope or canyon wall. Flat slope is defined as horizontal sea floor. Slopes less

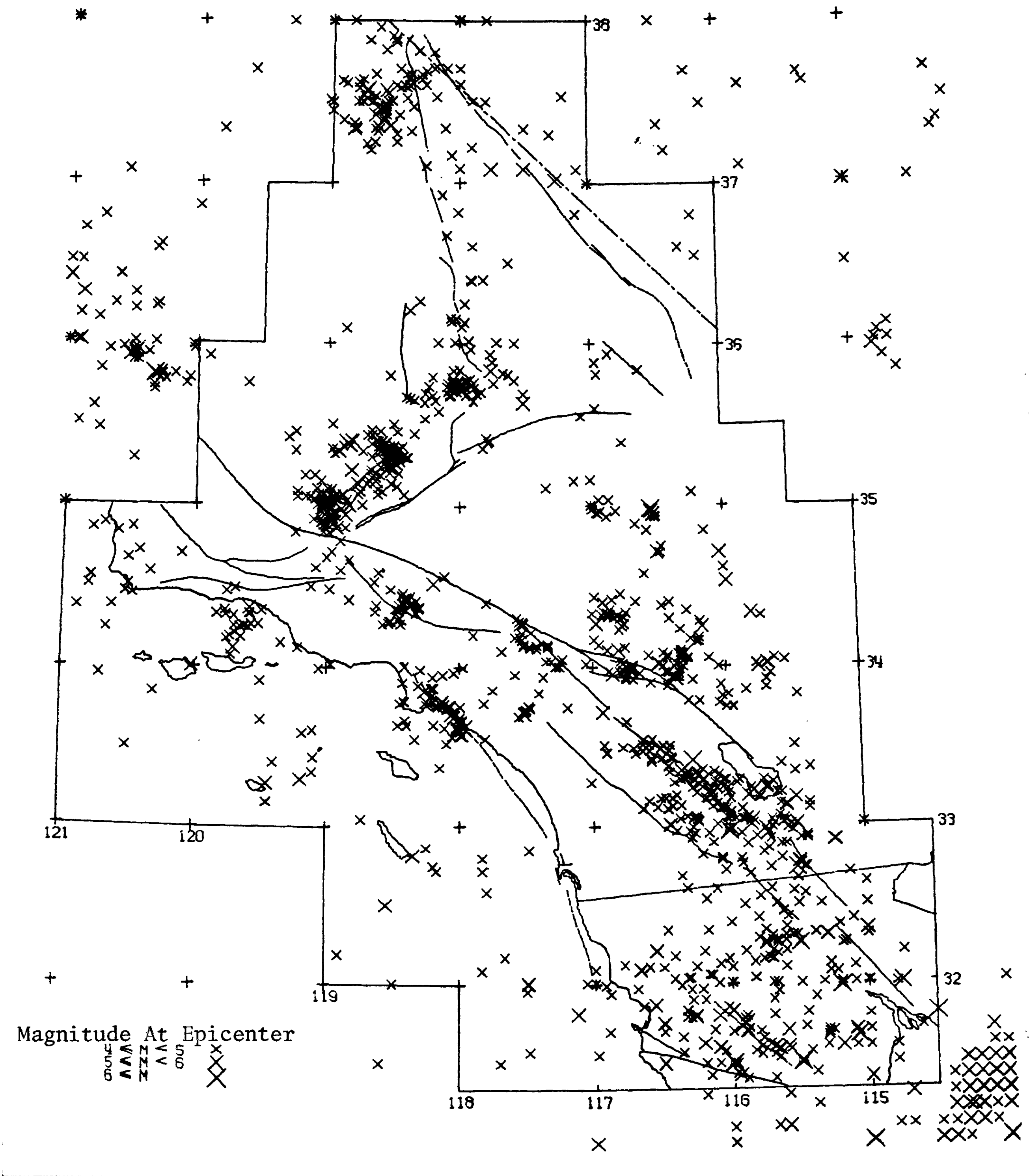


Figure 3.--Earthquake epicenters for events M $\geq$ 4 in southern California from 1932 through 1972 (from Hileman and others, 1973).

than 4° are considered gentle, slopes of 4°-7° are moderate, and slopes greater than 7° are steep. Only steep-walled canyons and steep slopes, especially those with sediment cover, are considered to be hazards.

## CONSTRAINTS

### Water-Column Anomalies

Water-column anomalies identified on 7 kHz subbottom profiles may represent hydrocarbon seeps or bubble trains. Seep mounds are occasionally formed by escaping gas in unconsolidated sediments. Water-column anomalies (gas seeps) occurring in association with bedrock outcrops, steeply dipping beds, and faults are considered constraints. The near-surface structures act as conduits from pressurized gas zones at depth and, if intersected during drilling, can act as escape routes for hydrocarbons. Relocation of drillsite can minimize the possibility of hydrocarbon leakage.

### Gas-Charged Sediments

Gas-charged sediments are identified as shallow acoustically turbid zones on 7 kHz profiles. The zones range from 1 to 30 sq km in areal extent and usually range between 3 to 50 m below the sea floor. Gas-charged sediments are zones of unconsolidated to semi-consolidated sediments saturated with interstitial gas under normal to near-normal pressures. Gas-charged sediments are considered constraints because large contrasts in bearing capacities may exist between these zones and the surrounding sediments. Dissolved gas in interstitial spaces can contribute to spontaneous liquefaction of sediments when subject to cyclic loading under abnormal conditions (Hall and Ensminger, 1979). 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 spots" on deconvolved sparker profiles. Shallow gas deposits refer to confined gas accumulation with possible abnormal pore pressures. Highly pressurized gas zones that are penetrated during drilling operations can cause a blowout. The shallower gas zones can contribute to the instability of a section by effectively lowering the shear strength of the sediment.

## POINT CONCEPTION AREA

### Setting

The Point Conception area is located just west of the Santa Barbara Channel and is adjacent to the California 3-nautical mile line southwest of Point Conception (fig. 1). The Point Conception area is located in the northwestern corner of the southern California continental borderland and in the transition zone from the borderland physiography on the south to a narrow continental margin on the north (fig. 2). Most of the area is on a southwest-facing slope. A total of 657 line-miles was surveyed in 23 complete and 7 partial tracts (pl. 1).

## Physiography

The sea floor of the Point Conception area is characterized by a gentle (about 2°) southwest-facing slope incised by five southwest-trending submarine channels (pl. 1). A nearly flat shelf (the outer limit of which is defined by the 350-foot isobath) in the northeast part of the area has a maximum slope of about 4°.

Water depth in the survey area ranges from about 250 feet in the northeast corner to more than 2,300 feet in the southwest. Overall relief is about 2,050 feet. Within individual tracts, relief ranges from 250 feet to 1,100 feet.

Five southwest-trending submarine channels cross the area (pl. 1). The northernmost channel probably is related to the Arguello Canyon system, whereas the central and southern channels, at least in part, are associated with the Conception fan system (Fischer, 1972). All the channels are less than 8,000 feet wide. The three channels that head at the shelf break are deeply incised near their heads and become very shallow to the southwest. Locally, poorly defined levees border the four central and southern channels; levees are best developed on the central reaches of the channels seaward of the point at which channel gradient decreases.

## Hazards

Geologic hazards were identified in most of the tracts in the Point Conception area (pl. 1). The identified hazards are steep-walled canyons or channels, mass movement of sediment with associated slide scars, and shallow faults.

At least part of each of the five channels that transect the survey area has slopes greater than 7° and is considered hazardous. The south-southwest-trending channel in the northwest part of the survey area covers about 25 percent of the center of tract 001 and has wall slopes as steep as 12°. Three channels in the central part of the area are steeply graded at their heads and become increasingly gentle to the southwest. The heads of these channels cover 50 percent of tract 11 and 20 percent of tract 12; the channel walls commonly slope 7° to 9° in these tracts. The southern channel covers as much as 40 percent of tracts 34, 49, and 50, and has walls that slope less than or equal to 7° along its entire length.

Areas of mass movement, many with associated slide scars, are scattered throughout the area (pl. 1). Most of the mass movement on the slope is a combination of sediment creep and slides. The largest area of mass movement covers parts of tracts 007, 008, and 13 and has a total area of about 15 square miles. Slide scarps or gas craters(?) commonly are associated with this mass. The largest single slide is found in tracts 003, 004, and 10, and affects the top 100 to 150 feet of sediment. The four channels in the central and southern parts of the area are partly to almost completely filled with slumped material. These are rotational slumps, as much as 500 feet thick, and probably represent terrace deposits slumped from within the channel.

Shallow faults, found mostly in the south and southwest parts of the survey area (pl. 1, for example tracts 21, 22, 31, 32, 48, and 49), trend west to northwest and range in length from 0.5 to 2.5 miles. They extend from the surface to 1,125 feet below the sea floor. Age and vertical separation of these faults could not be determined. Three areas of shallow faulting extend down to 200 feet below the sea floor in tracts 48 and 49. These three areas may represent a single fault zone. In the northern part of the survey area, several west-northwest-trending faults in tracts 003, 004, and 10 are tensional features associated with slumping. These faults offset the sea floor slightly (less than 5 feet) and probably are Holocene in age.

### Constraints

Constraints on development identified in the Point Conception area are shallow gas and water-column anomalies.

Shallow gas zones are the most common constraint in the area. Such zones range in area from 0.5 to 18 square miles and in depth from 150 to 1,075 feet below the sea floor. The largest clustering of shallow gas zones is found in the southern part of the survey area; most are associated with fault zones (pl. 1, for example tracts 31, 32, 48, and 49).

Water-column anomalies are scattered through six tracts. Anomalies in the northern half of the survey area are in unconsolidated sediment (pl. 1, tracts 004, 11, 12, 15, and 17). Two anomalies, one with an associated seep mound, are along two shallow faults in tract 17. The lone anomaly identified in the southern survey area (tract 51) is below the shelf break on the Channel Islands platform and extends through hard bedrock on the sea floor.

## SANTA BARBARA CHANNEL (EAST AND CENTRAL)

### Setting

The Santa Barbara basin, the northernmost basin in the continental borderland (Shepard and Emery, 1941), is located between the northern Channel Islands platform on the south and the west-trending coastline from Ventura to Point Conception on the north (fig. 2). The western part of the basin opens into the Pacific Ocean. The basin is bordered on the east by the coastline between Ventura and Point Mugu. This trend is named the Santa Barbara Channel (fig. 1). The survey areas contain 1,694 line-miles of tracklines covering 57 complete and 21 partial tracts (pls. 2 and 3). The Santa Barbara Channel central consists of 47 complete and 11 partial tracts (pl. 2); the Santa Barbara Channel east consists of 10 complete and 10 partial tracts divided into five separate groups (pl. 3).

### Physiography

Santa Barbara Channel is an elongate west-trending silled basin; sill depth at the western end of the basin is about 1,560 feet.

The westernmost part of the survey area (pl. 2, tracts 18, 26, 35-41, 52-58, 66-70) is covered by a large fan, the Conception submarine fan (Fischer, 1972, 1976). The distal part of the fan supposedly extends eastward beyond the central part of the basin. Several shallow northwest-trending levee-topped(?) fan channels are found in tracts 18, 26, and 38 (pl. 2). According to Fischer (1976), these channels, which issue from the Gaviota submarine canyons, are being actively abraded.

Water depth within the survey areas ranges from 70 feet, adjacent to the State waters south of Ventura (pl. 3, tract 87) in the eastern basin to 1,939 feet in the central basin (pl. 2, tract 71). Total relief within the survey areas is 1,869 feet. Relief within individual tracts is variable, ranging from about 10 feet in the deep central basin, to more than 1,250 feet along the basin slope in the southern part of the area.

The bathymetry does not reflect the locally undulated surface which has a relief of 5-10 feet. Over much of the northern and central survey areas the basin slope and floor are very irregular and hummocky, reflecting the mass movement of sediment over large areas on the sea floor.

The shelf flanking the survey area has a slope of less than 3°. Beyond the shelf break at 350 feet (pl. 2), the basin slope is typically 5°-8°, but at isolated localities (pls. 2 and 3, tracts 19, 20, 88-94) the basin slope is 10°-15°. At depths greater than 1,500 feet, the slope of the basin becomes gentler and the sea floor is nearly horizontal (0.5°) in the deep central basin (pl. 2, tracts 59 and 71).

## Hazards

Three hazards which would prevent the safe development of oil and gas resources in the Santa Barbara Channel area are steep slopes, mass movement of sediment, and shallow faults. Steep slopes and mass movement are almost entirely confined to the central area (pl. 2), whereas major faults (Pitas Point and Oak Ridge faults) are confined to the east part of the area (pl. 3).

The basin slopes flanking both the north and south sides of the survey area average 5° to 8°. At isolated localities in tracts 19, 20, and 88-94 steep slopes of 10°-15° were measured on Acoustipulse profiles.

More than 20 percent of the central Santa Barbara basin is covered by areas of unstable sediment. Two areas of mass movement in the north-central part of the basin each cover more than 60 square miles. The zone of sediment disturbance in these two masses is well over 300 feet thick in many places. Each mass displays several episodes of creeping and sliding. These masses give the sea floor a hummocky appearance. Tensional depressions and possible slide scars are identified on the upper part of these slides.

Slides, most less than 3 square miles in area, are shown near the base of the basin slope at isolated localities throughout the central Santa Barbara Channel (pl. 2). These slides appear to affect only the top 50 feet of sediment.

Shallow faults trending west-northwest to west are common. An area of closely spaced shallow faults, underlying about 40 square miles of sea floor in the west-central part of the basin, was mapped as an area of minor faulting (pl. 2). Faults in this zone come within 50 feet of the sea floor and are vertically displaced less than 25 feet. A series of west-trending faults 1-4 miles long was mapped on the basin slope and outer shelf in the south part of the survey area. These faults are at least 200 feet below the sea floor and offset the base of the Quaternary section about 30 feet. The remainder of the faults in the central part of the basin show very minor offset, usually within the Pleistocene section. These faults are no older than Pleistocene and are potentially active.

Two west-trending faults, the Pitas Point and Oak Ridge, in the easternmost part of the survey area (pl. 3, tracts 47, 64, 75, and 76) are active; these faults cut Quaternary strata and extend to within 10 feet of the sea floor. The northern fault, the Pitas Point, is downthrown on the south; the southern fault, the Oak Ridge, is downthrown on the north and is vertically displaced about 13 feet in the uppermost strata. The sea floor is bowed upward above the Oak Ridge fault. Latest movement on these faults probably occurred during Holocene time.

Both of these faults in the eastern Santa Barbara Channel were described by Greene (1976). The Pitas Point fault is a north-dipping reverse fault that displaces a buried late Pleistocene erosion surface about 80 feet, up on the north; it cuts Holocene strata but not the sea floor. The Oak Ridge fault is a steep south-dipping reverse fault. Pleistocene strata are upthrown on the south more than 445 feet; no sea-floor displacement is known.

## Constraints

Constraints to oil and gas resource development are common in the Santa Barbara Channel. Shallow gas and gas-charged sediments are found in both the central and eastern parts of the basin. Water-column anomalies are limited to the shelf areas in the central part of the Channel. Seep mounds occur in the central basin and on the edge of the Channel Islands Platform.

Shallow gas is found in strata underlying more than 30 percent of the central part of the basin (pl. 2). Shallow gas zones occur at a depth of 125-1,125 feet below the sea floor. The largest shallow gas zone mapped, in the north-central part of the basin, is more than 150 square miles in area and is, at least in part, associated with a shallow fault zone.

Gas-charged sediments in the eastern Santa Barbara Channel were identified by anomalous reflections or by acoustically turbid zones on Acoustipulse profiles. Two separate zones of gas-charged sediments were mapped, one associated with a group of small faults in tract 63 and the other with the Oak Ridge fault zone in tracts 64, 65, 75, and 76 (pl. 3). These gas zones are commonly 15-75 feet below the sea floor.

Water-column anomalies, all associated with bedrock, are scattered on the shelf bordering the southern part of the area (pl. 2, tracts 98-101) and are common on the shelf in tract 19 in the northern part of the area. Fischer and Stevenson (1973) describe in detail such anomalies or seeps on the northern shelf of the basin south of Coal Oil Point. Mounds were identified in tracts 53, 77, 78, and 100 and may be related to gas seepage but have no water-column anomalies associated with them. Possible gas craters associated with a zone of shallow faults and gas are found in the southern half of tract 63 in the eastern part of the basin (pl. 3).

## SANTA ROSA ISLAND AREA

### Setting

The Santa Rosa Island area (pl. 4) is about 6 miles south of Santa Rosa Island and 50 miles southwest of Ventura, California (fig. 1). About 147 line-miles were surveyed in six tracts located on the west side of the northernmost extension of the Santa Rosa-Cortes Ridge (fig. 2). The northern part of the ridge is bordered on the east by Santa Cruz Canyon and Santa Cruz basin; on the west, it is flanked by a broad apron extending from the base of the ridge toward Patton Ridge (fig. 2).

### Physiography

Nearly 60 percent of the Santa Rosa Island area consists of the flat-topped Santa Rosa-Cortes Ridge. Water depths along the ridge are less than 400 feet. A bifurcated channel, trending N. 80° W., cuts the ridge in the northern part of the area (pl. 4, tracts 109, 110, and 111). The channel is as much as 12,000 feet wide and attains a maximum depth of more than 750 feet as it opens to the west. Slope of the channel sides ranges from 2° to 5°. Locally, slopes of nearly 7° were measured on Acoustipulse profiles. The south-southwestern part of the area is a basin slope (tracts 113 and 114). Slope dips range from 6° to 13° to the southwest. Locally, dips are as steep as 20°.

Water depth ranges from 381 feet on the ridge top to more than 2,400 feet on the basin slope in the southwest part of the area. Overall relief in the area is 2,020 feet. Relief within individual tracts is variable ranging from 40 feet in tract 112 to 2,000 feet in tract 113. Slopes on the ridge are commonly less than 1°. Sea-floor mounds and adjacent depressions have more than 20 feet of relief, and slopes as much as 4° are found in tracts 112 and 114.

### Hazards

The most obvious hazards to safe development in at least a part of three tracts in the Santa Rosa Island area are the steep-walled submarine channel in the north and the steep basin slope in the south-southwest part of the area (pl. 4). Shallow faults were mapped in five tracts (tracts 109-112 and 114).

Steep-walled (>7°) submarine channels are found in the southwest corner and center of tract 109 and in the southwest corner of tract 110. The remainder of the channel has gentle to moderate slopes and does not appear to present any constraints to development. The steep basin slope, with slopes as high as 20°, covers about 80 percent of tract 113. A poorly defined slide, about 7,000 feet long and 60 feet thick, was identified on one survey line (C-054) across the basin slope in the southeast quarter of tract 113.

West-to-north-northwest-trending faults, identified in tracts 109-112 and 114, cut the surface of the exposed bedrock on the flat-topped ridge but show no surface offset and do not cut modern sediments (pl. 4). A maximum vertical displacement of 25 feet was measured. Faulting is not considered to be active because faults do not offset the ridge (or modern sediment, where present) that Field and Richmond (1980) believe is a Pleistocene erosion surface (younger than 2 million years).

### Constraints

Water-column anomalies are found in the northeast corner of tract 113 and in the north-central part of tract 112, where they occur along a northwest-trending fault and on its projected trend.

## SANTA BARBARA ISLAND AREA

### Setting

The Santa Barbara Island area is adjacent to the California 3-nautical-mile zone north and west of Santa Barbara Island, and is about 46 miles west-southwest of Los Angeles (fig. 1). About 123 line-miles were surveyed in five tracts on the west and central Santa Barbara Island platform (pl. 5). The platform is bordered on the west, northeast, and southeast by Santa Cruz, Santa Monica, and Catalina basins, respectively (fig. 2). Directly south of the platform (4 miles south of Santa Barbara Island) is Osborn Bank, which is bordered on the south by San Nicolas basin (fig. 2). Deep, narrow saddles extend northwest and southeast from the platform to Santa Cruz and Santa Catalina Islands, respectively.

### Physiography

Santa Barbara Island area is characterized by a series of west-northwest-trending ridges and canyons incised into the upper slope and platform edge. In tracts west of the island, three canyons range in width from 4,000 feet (tract 119) to 12,000 feet (tract 117). The widest canyon is also the deepest (1,800 feet below sea level). Slopes within the canyons generally range from 4° to 14° but are as high as 17° locally. The sea floor in the northern tracts is dominated by a northwest-trending ridge that slopes gently (<1°) to the northeast and more steeply (<6°) to the southwest. The head of a small, southeast-opening canyon cuts the southeast part of tract 116. The canyon head is about 8,000 feet wide and 1,150 feet below sea level.

Water depth ranges from 500 feet in the two tracts north of the island to more than 1,800 feet in a canyon floor in the western tracts. Overall relief in the Santa Barbara Island area is more than 1,300 feet. Relief in individual tracts ranges from 300 to 1,200 feet. Slopes are highly variable, ranging from less than 1° to 17° in individual tracts. The steepest slope measured, 17°, is a canyon wall in tract 118.

### Hazards

Geologic hazards in the Santa Barbara Island area are steep-walled submarine canyons, mass movement, and shallow faults. Three west-northwest-trending submarine canyons cover about 80 percent of tract 117, 60 percent of tract 118, and 10 percent of tract 119 (pl. 5). The slopes of canyon walls range from 4° to 14°, and are locally as steep as 17°. The head of a major submarine canyon is incised into the island platform in the southeast corner of tract 116. Wall slopes greater than 7° are common within this canyon.

A 6,000-foot-wide by 8,000-foot-long slump lies on the floor of the large canyon in tract 117 (pl. 5). The base of the slump is difficult to identify but is about 300 feet below the sea floor. This slump material probably was derived from a levee deposit that slid into the canyon after being undercut by debris flowing through the canyon.

West-northwest-trending faults, 0-375 feet below the sea floor and 1-1.5 miles long, occur in all tracts (pl. 5). Faults cut the surface in areas of exposed bedrock, and nowhere cut Holocene sediments. Age of faulting is not known.

### Constraints

Three small patches of shallow gas, possibly associated with faults, were found 500-825 feet below the sea floor in tracts 117 and 118 (pl. 5).

## SAN PEDRO AREA

### Setting

The San Pedro area consists of 3 partial and 18 complete tracts south-southwest of Palos Verdes Peninsula and west of Huntington Beach (fig. 1, pl. 6). The survey area is on the coastal shelf of San Pedro Bay and on the slope of the San Pedro escarpment. The San Pedro Channel and Gulf of Santa Catalina border the survey area on the southwest and southeast. About 493 line-miles of data were obtained from the four groups of tracts.

### Physiography

The San Pedro area (pl. 6) covers parts of the San Pedro shelf, sea valley, and escarpment, the San Gabriel Canyon, and several unnamed ridges and canyons. Water depth ranges from 75 feet on the shelf (tract 121) to more than 2,650 feet (tract 127) at the base of the San Pedro escarpment. Overall relief is as much as 2,575 feet.

The San Pedro shelf (tracts 120-124) has a gentle slope less than 1° SW. The break in slope marking the edge of the shelf ranges in depth from about 200 to 300 feet. Relief on the shelf is about 225 feet; in individual tracts relief ranges from less than 50 to 150 feet. Local relief, in the form of gentle sea-floor bulges, is about 5 feet.

The southwestern part of the survey area is underlain by the San Pedro escarpment, which forms the east slope of San Pedro basin. Slope relief is about 2,200 feet. Average slope is about 5° to the southwest; locally, maximum slope approaches 30° (tracts 127 and 132). San Pedro sea valley (tracts 120 and 123) and San Gabriel canyon (tracts 131, 136, 137, and 139), are incised into this slope (pl. 6). These canyons are 1,000-6,000 feet wide. Relief is about 1,000 feet in the San Pedro sea valley and about 300 feet in San Gabriel Canyon. Maximum slopes in these two canyons are 11° and 8°, respectively. The relief in the area of the three ridges on the upper slope (northeast of the escarpment) of San Pedro basin is about 600 feet (tracts 128, 132, and 133).

## Hazards

Geologic hazards found in the San Pedro area are steep slopes, steep-walled canyons, mass movement of sediments, and two major fault zones (Palos Verdes Hills fault zone and Cabrillo(?) fault zone; pl. 6).

Steep slopes are the most common hazard. Although the slope of San Pedro escarpment averages 5° and is considered moderate, local slopes as steep as 30° have been measured in tract 127 (pl. 6). A northwest-trending channel in the central part of tract 132 has local slopes on the north wall as steep as 30°. Canyon walls as steep as 11° were measured in San Pedro sea valley, which covers nearly 25 percent of tract 120 and 10 percent of tract 123. San Gabriel Canyon, which consists of two to three channels covering 20 to 60 percent of tracts 124, 131, 134, 136-139, has wall slopes of 5° to 7° in much of the area.

Five areas of mass movement are found in the study area (pl. 6). Slides in tracts 138 and 139 are less than 2 square miles in area and are considered insignificant. The floor of San Pedro sea valley (tracts 120 and 123) is underlain by more than 100 feet of channel fill and slumped terrace deposits. Walls of the valley are mostly covered by shallow slumps. A shallow poorly defined slump of unknown thickness covers the southwest part of tract 125 and extends southeastward through the center of tract 127. This slump is about 5 square miles in area and movement is downslope to the southwest. The largest slump mapped is about 22 square miles in area and covers 60 to 90 percent of tracts 129, 130, and 135. This slump is more than 250 feet thick. A tensional depression is found at the head of the slump.

The probable offshore extension of the Cabrillo(?) fault zone extends through the west-central part of the San Pedro area (pl. 6, tracts 123, 125, 126, 128, 133, 134, and 138). Faults in the zone are usually less than 375 feet below the sea floor but some are as deep as 625 feet. Faults cut the sea floor where Tertiary bedrock is exposed but not where overlain by Holocene sediments (Greene and others, 1975). The latest of repeated onshore movement along the fault zone is of Holocene age (Greene and others, 1975). The fault zone is continuous for about 19 miles in the survey area; individual faults within the zone are 1-7 miles long. Maximum vertical displacement in the zone is difficult to determine but appears to be less than 150 feet in upper Tertiary(?) or Pleistocene rocks. The main zone is commonly downthrown on the northeast.

The Palos Verdes Hills fault zone trends northwest, parallel to the Cabrillo trend, across the center of the map (pl. 6, tracts 121, 128, 134, 135, and 139). Individual faults in the zone are from 2 to 7 miles long. Within the survey area, maximum vertical displacement in the shallow Tertiary bedrock is about 200 feet.

Beyond the survey area the Palos Verdes Hills fault zone extends for at least 45 miles. Greene and others (1975) report that vertical separation on the fault is more than 6,000 feet and significant strike-slip separation is likely. The fault cuts Holocene sediment and shows sea-floor offsets north of the survey area.

Shallow faults that are not part of the Cabrillo and Palos Verdes Hills fault zones are mapped in tracts 120, 124, 127, 131, 132, 136, and 140 (pl. 6).

### Constraints

Constraints to oil and gas resource development found in the San Pedro area are shallow gas and water-column anomalies.

Shallow gas zones occur in scattered localities throughout the area (pl. 6). Gas zones are commonly less than 1.5 square miles in area and are usually 40-375 feet below the sea floor; some are as deep as 1,250 feet. Most of the gas zones are associated with the Palos Verdes Hills fault zone.

Water-column anomalies are found in three tracts (121, 123, and 126). Anomalies in tract 121 are associated with a group of faults in exposed bedrock. Anomalies along the projected trace of the Cabrillo(?) fault zone in tracts 123 and 126 are in unconsolidated sediments.

## DANA POINT

### Setting

The Dana Point area is southwest of Dana Point and west of San Clemente, adjacent to the California 3-nautical-mile zone. The area covers a part of the slope and basin seaward of the narrow coastal shelf. About 132 line-miles of data were obtained from four complete and two partial tracts (pl. 7).

### Physiography

The sea floor throughout most of the Dana Point area is relatively smooth except for some channeling and hummocky topography in areas of mass movement. Several south-southwest-trending channels, about 1,000 feet wide with 15-50 feet of relief, cross a part of the shelf and basin in tracts 143 and 145; only one is shown in tract 143 (pl. 7). These channels are the lower parts of the group of channels that incise the slope directly southwest of Dana Point. A broad (7,000-foot-wide), low-relief, southeast-trending channel is at the base of the slope in tracts 142, 144, 145, and 146 (pl. 7).

Water depth ranges from about 1,100 feet in the northeast corner of the area (tract 143) to more than 2,450 feet along the south border (tract 146). Overall relief in the area is about 1,350 feet. Relief in individual tracts ranges from 300 to 1,100 feet. Slopes within the area average about 2° to 3° SW. Maximum slope (15°) was recorded on the walls of a southwest-trending channel in tracts 143 and 145.

## Hazards

Geologic hazards found in the survey area are mass movement of sediments, steep slopes, steep-walled canyons, and shallow faults. Slopes as steep as 15°, measured on a channel wall in tracts 143 and 145, are very localized.

Two areas of mass movement cover about 75 percent of the Dana Point area and from 50 to 95 percent of each tract (pl. 7). A slumped mass, as much as 350 feet thick, was deposited at the base of the slope in tracts 141, 142, 143, 145, and 146 (pl. 7). This mass changes in character laterally. It thins to less than 200 feet northwestward in tract 142 and consists of shallow sediment creep in tract 141. Thickness remains constant in the central and southern parts of the mass. The disturbed sediment apparently moved downslope to the west and southwest.

Another slump, about 4 square miles in area, is located in the southwest half of tract 144 (pl. 7). This mass shows little internal deformation and probably represents undercut terrace deposits that slid to the northeast onto the channel floor.

Two faults, 1.5 and 6 miles long, offset deep-seated bedrock in tracts 144 and 146 (pl. 7). Both faults trend northwest, dip vertically, and are downthrown on the northeast. These faults extend to within 375 feet of the sea floor. A vertical displacement of about 250 feet was measured on the southern fault. Neither fault offsets Quaternary sediments.

## Constraints

Several zones of gas were mapped. The largest zone is about 8 square miles in area and ranges in depth from 50 to more than 850 feet below the sea floor (pl. 7, tracts 141 and 142). Four small gas zones, 2-4 square miles in area and ranging from 150 to 925 feet below the sea floor, were mapped in tracts 143 and 146 (pl. 7).

# OCEANSIDE AREA

## Setting

The Oceanside area consists of two groups of tracts on the slope and upper basin seaward of the coastal shelf, about 12 miles west of Oceanside (fig. 1). The northern part of the survey area is composed of four tracts and the southern area three tracts (pl. 8). About 172 line-miles of data were obtained in the area.

## Physiography

The Oceanside area is in a basin and slope environment. The southern tracts are directly seaward of the mouth of Carlsbad Canyon and may be in a submarine fan environment. The basin slope (tracts 149 and 150) is incised by several minor channels (pl. 8). The channels trend south-to-southwest and are shallow, low-relief features having a maximum width of less than 900 feet. A narrow southwest-trending channel crosses the nearly flat basin floor in tract 152.

Parts of the northern tracts and nearly all of the southern tracts have a very irregular, hummocky sea floor, reflecting the underlying mass movement. The basin floor in the southwest corner of the area is nearly flat and featureless (pl. 8, tracts 151 and 153).

Water depth in the survey area ranges from 500 feet in the northeast corner to more than 2,650 feet in the southwest. Relief ranges from 900 to 2,000 feet in the northern tracts and from 250 to 300 feet in the southern tracts. Typical slopes in the northern tracts are 5° to 10°. Slopes as steep as 19° are found at the base of the basin slope in tract 148. In the southern tracts, which cover the basin floor, slopes are less than 1°.

## Hazards

Geologic hazards found in the Oceanside area are steep slopes, mass movement of sediment, steep-walled canyons, and major faulting.

Local slopes of 7° to 10° are common in the northern tracts. A local slope as steep as 19° was measured on an Acoustipulse profile through tract 148. The series of southwest-trending canyons, which constitute about 50 percent of tract 149, have wall slopes of 5° to 10°.

Slide deposits resulting from the mass movement of sediments cover from 10 to 90 percent of each tract in the northern area and 100 percent of the southern area. Three separate slides are mapped in the northern tracts. The largest of these is more than 9 square miles in area and less than 200 feet thick (pl. 8, tracts 148, 149, and 150). This slide has a hummocky surface and is associated with tension fractures and a tensional depression at its head. The other two slides (tracts 147 and 150) are less than 2 square miles in area and are rather poorly defined in the subsurface.

The slide deposit in the southern tracts varies considerably in thickness along strike (parallel to isobaths). The deposit is more than 250 feet thick in the central part of these tracts. The zone of deformation thins to less than 150 feet thick to the northwest and southeast. Acoustipulse penetration is very poor in these areas, so sliding characteristics are difficult to define.

The possible southern extension of the Newport-Inglewood fault zone is located northeast of the survey area. This major northwest-trending strike-slip fault zone is in the onshore Los Angeles basin and in the offshore along the southern California coast. The zone consists of numerous en echelon fractures and is more than 60 miles long; displacements along the zone range from about 600 to 2,500 feet and are consistently right-lateral (Harding, 1973). Harding (1973) and Greene and others (1975) have reported Holocene activity along the Newport-Inglewood fault zone.

A small zone of northwest-trending subparallel faults cuts the northern tracts. This trend is parallel to and may be associated with the offshore Newport-Inglewood fault trend. Fault segments in this zone are from 1 to 4 miles long and 25 to 500 feet deep. Vertical displacement ranges from 10 to 50 feet.

### Constraints

Shallow gas zones are the only constraints to oil and gas resource development found in the Oceanside area. Small pockets of shallow gas, less than 1.5 square miles in area, are scattered in tracts 148-151 (pl. 8). Depth of these zones ranges from 125 to 875 feet below the sea floor. Some gas zones are associated with faults.

## SAN DIEGO AREA

### Setting

The San Diego area is located about 6 miles west of the San Diego coast, on the northern tip of Coronado Bank and adjacent slopes (figs. 1 and 2). The northwest-trending Coronado Bank is flanked on the west by the Coronado escarpment and on the east by the Loma sea valley. About 317 line-miles of data were obtained in 13 complete tracts (pl. 9).

### Physiography

The Coronado Bank is flanked on the west by the steep, west-sloping Coronado escarpment and on the east by a major north-northwest-trending canyon, the Loma sea valley. This submarine valley (canyon) is 5,000-12,000 feet wide. Bedrock forms the west wall, and slope sediments form the east wall. A gentle west-sloping basin floor forms the extreme northern and southwestern parts of the survey area.

Water depth ranges from 400 feet east of the canyon (pl. 9, tract 166) to more than 3,800 feet at the base of the escarpment in the southwest corner of the area (pl. 9, tract 162). Relief from the bank top to the base of the escarpment is 3,400 feet. Relief in individual tracts typically varies from 400 feet north of the bank (tracts 154 and 155) to about 2,600 feet on the escarpment. Relief in Loma sea valley is 300-400 feet.

The sea floor on the bank top is highly irregular with scattered depressions and bedrock outcrops having relief as much as 10 feet. Average slope on the bank top is less than 1°. The west slope of the bank averages 10° to 15° but locally is as steep as 30° (tract 162). At the base of the slope (escarpment) the sea floor flattens into a gently sloping (<1°) basin floor (west part of tract 162). Slopes on canyon walls northeast of the bank are commonly 2° to 5° but locally are as steep as 18°.

## Hazards

Geologic hazards found in the San Diego area are steep slopes and steep-walled canyons associated with the Coronado escarpment and the Loma sea valley, and shallow faults (pl. 9). Slopes averaging 10° to 15° cover 20-60 percent of tracts 157, 158, 160, 162, and 163 (pl. 9). Locally, slopes as steep as 30° are found in tract 162. Loma sea valley underlies 10-60 percent of tracts 157-159, 161, and 163-166. Wall slopes within the valley are generally less than 7° but are as steep as 18° locally.

Faults within the area trend north-northwest, parallel to the regional trend. Few faults are found on the bank top, most are found east of the axis of Loma sea valley. Those on the bank top cut the bedrock sea floor, show no sea-floor offset, and are probably pre-Quaternary faults exposed by erosion of bedrock. Faults east of the bank range in length from 1 to 5 miles. Many faults intersect the sea floor but some fault traces are as deep as 800 feet below the sea floor. Most faults extend to within 50 feet or less of the sea floor. Few faults displace the sea floor; one fault in tract 166 offsets the sea floor 50 feet. Vertical displacement along faults ranges from 15 to 100 feet.

## Constraints

Constraints to oil and gas resource development found in the San Diego area are water-column anomalies and shallow gas. Water-column anomalies most commonly occur in the bedrock surface of the bank top (pl. 9, tracts 163 and 165). One possible seep was identified issuing from unconsolidated sediments on the slope in tract 166. Water-column anomalies do not appear to be associated with faults or shallow gas and probably are related to steeply dipping bedding planes.

Shallow gas zones are found only in the sedimentary rocks underlying the shelf and slope east of the submarine valley and bank. Shallow gas zones range in area from 0.5 to 3 square miles. Depth of gas zones below the sea floor is variable, ranging from 175 to more than 1,200 feet. Most shallow gas zones are associated with faults.

# DALL BANK AREA

## Setting

The Dall Bank area is about 16 miles south of San Nicolas Island and 100 miles southwest of Los Angeles (fig. 1). The survey area is located on the southern Santa Rosa-Cortes Ridge, which is bordered on the west by Tanner basin and on the east by San Nicolas basin (fig. 2). The area surveyed consists of 13 tracts, two of which are about 3 miles southeast of the main group (pl. 10). About 315 line-miles of data were obtained in the area.

## Physiography

Dall Bank is a northwest-trending elongated bank named by Vedder and Toth (1976). The bank is a rough, irregular platform with very steep, irregular slopes on the west and gentle to moderate slopes on the east (pl. 10). An extension of the bank trends northeastward (tracts 175 and 176) from the crest at right angles to the ridge. In the western part of the area is a channel (tract 168) and a small ridge on the upper slope; the channel is about 4,000 feet wide and has about 200-400 feet of relief.

Water depth ranges from 300 feet on the bank top to more than 4,500 feet on the west slope. Overall relief in the area is about 4,200 feet. Relief within individual tracts ranges from 400 feet in tract 176 on the bank top to 2,300 feet in tract 171 on the west slope. Slope within individual tracts is variable, averaging 2°-11°. Locally, in tract 171, slopes as steep as 22° were measured on Acoustipulse profiles.

## Hazards

Geologic hazards found in the Dall Bank area are steep slopes and shallow faults (pl. 10).

Average slope on the steep basin slopes and channel in the western part of area ranges from 5° to 10° (tracts 167, 171-174, and 177). The basin slope along the west side of the bank averages 11° and is as steep as 23° locally (tract 171). The slope on the eastern side of the bank (tracts 178 and 179) is as steep as 8°.

Shallow faults are identified in 10 of the 13 tracts. Most faults cut the sea floor but some are as deep as 250 feet. Faults range in length from 1 to 6 miles, and most faults trend north-northwest, paralleling the regional structure. In tracts 175 and 176, a group of parallel faults trend northeast and displace the sea floor as much as 20 feet vertically. Age of faults and apparent vertical displacement in the subsurface could not be determined.

A major north-northwest-trending fault crosses the eastern side of the bank; this fault is informally named the Dall Bank fault. The fault is vertical and is downthrown on the east. More than 100 feet of sea-floor displacement is measured along this fault trace in tracts 169, 170, and 174 (pl. 10). According to Jennings (1975), the fault shows Quaternary displacement (last 2 million years) but shows no modern movement.

## Constraints

Three types of constraints to oil and gas resource development are identified in the Dall Bank area: shallow gas zones, water-column anomalies, and a seep mound (pl. 10).

Two small shallow gas zones are identified in the survey area (tracts 173 and 178); each zone covers an area of about 1 square mile. The zone in tract 173 is about 500-1,250 feet below the sea floor; the shallow gas zone in tract 178 is associated with faulting and is at a depth of 225-450 feet below the sea floor.

Water-column anomalies and a seep mound are identified in six tracts on the bank top (pl. 10, tracts 170, 174-177 and 179). Water-column anomalies in the northern area, issuing from both bedrock and unconsolidated sediments commonly are associated with surface faults or are along projected trends of faults.

## TANNER-CORTES BANKS

### Setting

Tanner-Cortes Banks area is located on the southernmost part of the Santa Rosa-Cortes Ridge (figs. 1 and 2). These banks are near the western edge of the continental borderland about 110 miles west of San Diego (fig. 2). A total of 851 line-miles of data was obtained from 38 complete tracts (pls. 11 and 12).

### Physiography

Tanner-Cortes Banks are characterized by relatively flat bank tops and steep slopes incised by steep-walled submarine canyons. Other studies have shown that the large-scale folding and faulting of the banks is largely responsible for their topographic expression (Moore, 1969; Greene and others, 1975). Ridges are the surface expression of anticlines, and valleys the surface expression of synclines. The large northwest- and southwest-trending submarine canyons are, in part, fault controlled.

Water depth ranges from sea level at Bishop Rock (tract 208) to more than 4,100 feet in a submarine canyon in tracts 193 and 194. Relief within individual tracts on the bank top ranges from 100 to 300 feet and on slopes ranges from 1,000 to 2,000 feet.

Bank tops are defined by the 400-foot isobath. Slopes on the bank tops are less than 3° and generally average 0.5° to 1°. Local irregularities on the bank tops, such as steep outcrops, have slopes averaging 8°; locally these are as steep as 18° (tract 193). Locally steep-walled canyons have slopes of as much as 23° (tract 214).

### Hazards

Geologic hazards found on Tanner and Cortes Banks are mass movement, steep slopes, steep-walled submarine canyons, and shallow faults.

Areas of mass movement, usually slumps with superimposed sediment creep, occur in small isolated localities on the slopes surrounding Tanner and Cortes Banks. Slumps usually occur on bank slopes, especially in the foreset beds of terrace deposits (pls. 11 and 12, tracts 182, 187, 192, and 193). These slumps range from 0.5 to 5 square miles in area and are usually less than 100 feet thick. Deeper rotational slumps occur as coalescing deposits in canyons (tracts 188, 199, and 214). These deposits average 2-3 square miles in area and are over 200 feet thick. Slumped material probably represents oversteepened canyon terrace deposits that were undercut by channel flow.

Bank slopes, which encircle the area, average 5° to 8° (pls. 11 and 12). Locally slopes greater than 9° are present in every tract in which a bank slope is present. Slopes of 14° to 23° are found in 10 tracts (pls. 11 and 12, tracts 183, 188, 192, 193, 194, 199, 213, 214, 215, and 217).

Steep-walled submarine canyons are found at four locations (pls. 11 and 12). About 5-50 percent of tracts 212-215, 25 percent of tract 199, 20-60 percent of tracts 183, 184, 187, and 188, and 30 percent of tract 192 are cut by canyons. Wall slopes within the canyons range from 2° to 9°. Locally walls as steep as 23° have been measured (tract 214).

Shallow faults are mapped in nearly every tract within the survey area (pls. 11 and 12). The predominant fault trend is northwest; two secondary trends, north-south and east-west, are present. Faults range in length from less than 1 to 6 miles; all fault tops are within 600 feet of the sea floor. Faults showing as much as 39 feet of vertical sea-floor displacement are present in tracts 180, 181, 186, 191, 194, 195, 216, and 217. Several faults in tracts 186, 215, and 217 offset Holocene(?) sediments. Vertical displacements of 5 to 25 feet were measured along these faults. Greene and others (1975) believed that faults offsetting the bank top are active. Movements on deeper faults in bedrock are not dated.

### Constraints

Constraints to oil and gas resource development on Tanner-Cortes Banks are water-column anomalies, seep mounds, and shallow gas. Shallow gas zones are very sparse.

Water-column anomalies or seep mounds are identified in 20 tracts within the survey area (pls. 11 and 12, tracts 183, 187, 190, 193, 195, 196, 197, 199, 200, 203-209, 211, 213, 214, and 215). Seep mounds are usually associated with water-column anomalies and shallow faults are very common in the survey area; water-column anomalies are rarely associated with fault traces.

Shallow gas zones are sparse on Tanner and Cortes Banks. Three zones, each less than 3 square miles in area, were mapped (pl. 11, tracts 181-184, 189, and 194). The upper surfaces of gas zones are about 250-750 feet below the sea floor.

## CONCLUSIONS

Thirteen tracts in the Sale 48 area are located on relatively stable sea floor. No geologic hazards or constraints are found in the following tracts: 25, 35, 36, 52, 73, 74, 85, 87, 102, 104, 108, 122, and 202.

The U. S. Department of the Interior has withdrawn 69 tracts from the Sale 48 area. The U. S. Geological Survey has recommended that a stipulation be applied to 18 additional tracts showing evidence of past or potential sea-floor instability (table 1). High-resolution geophysical data taken within these 18 tracts indicate areas of potential mass movement of sediment, of steep-walled submarine canyons, of steep slopes, and of active faulting. However, these tracts can be developed safely from stable locations either within the tract or adjacent to the tract. Table 1 lists all the tracts in the Sale 48 area where potential geologic hazards and constraints exist.

Table 1.--Tracts exhibiting potential hazards and constraints

| Tract number | HAZARDS | | | | CONSTRAINTS | | | | Tracts withdrawn | Tracts stipulated | Shown on plate no. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mass Movement | Steep Slope | Steep-Walled Canyon | Shallow Fault | Shallow Gas | Water-Column Anomaly | Seep Mound | Gas-Charged Sediment | | | |
| 001--------- | | | X | | X | | | | | | 1 |
| 002--------- | | | | | X | | | | | | 1 |
| 003--------- | X | | | X | | | | | | | 1 |
| 004--------- | X | | | X | | X | | | | X | 1 |
| 005--------- | X | | | X | X | | | | | | 1 |
| 006--------- | | | | | | | X | | | | 1 |
| 007--------- | X | | X | | X | | | | | X | 1 |
| 008--------- | X | | | | X | | | | | X | 1 |
| 009--------- | X | | | | X | | | | | | 1 |
| 10--------- | X | | | X | X | | | | | | 1 |
| 11--------- | X | | X | X | X | X | | | | X | 1 |
| 12--------- | X | | X | | | X | | | X | | 1 |
| 13--------- | X | | | | X | | | | X | | 1 |
| 14--------- | | | | X | X | | | | | | 1 |
| 15--------- | X | | | | X | X | | | | | 1 |
| 16--------- | X | | | X | | | | | | | 1 |
| 17--------- | X | | | X | | X | X | | | | 1 |
| 18--------- | | | | | X | | | | | | 2 |
| 19--------- | X | X | | | | X | | | | X | 2 |
| 20--------- | X | X | | | | | | | X | | 2 |
| 21--------- | X | | | X | X | | | | | | 1 |
| 22--------- | X | | | X | X | | | | | | 1 |
| 23--------- | | | | X | X | | | | | | 1 |
| 24--------- | | | | X | X | | | | | | 1 |
| 25--------- | | | | | | | | | | | 1 |
| 26--------- | X | | | | X | | | | | | 2 |
| 27--------- | X | X | | | X | | | | | | 2 |
| 28--------- | X | X | | | X | | | | | | 2 |
| 29--------- | X | | | | | | | | | | 2 |
| 30--------- | X | X | | | | | | | | | 2 |
| 31--------- | | | | X | X | | | | | | 1 |
| 32--------- | | | | X | X | | | | | | 1 |
| 33--------- | X | | | | X | | | | | | 1 |
| 34--------- | | | X | | X | | | | | X | 1 |
| 35--------- | | | | | | | | | | | 2 |

Table 1.--Tracts exhibiting potential hazards and constraints (continued)

| Tract number | HAZARDS: Mass Movement | HAZARDS: Steep Slope | HAZARDS: Steep-Walled Canyon | HAZARDS: Shallow Fault | CONSTRAINTS: Shallow Gas | CONSTRAINTS: Water-Column Anomaly | CONSTRAINTS: Seep Mound | CONSTRAINTS: Gas-Charged Sediment | Tracts withdrawn | Tracts stipulated | Shown on plate no. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 36--------- | | | | | | | | | | | 2 |
| 37--------- | X | | | | X | | | | | | 2 |
| 38--------- | X | | | X | X | | | | | | 2 |
| 39--------- | X | | | X | X | | | | | | 2 |
| 40--------- | X | | | X | X | | | | | | 2 |
| 41--------- | X | | | X | X | | | | | | 2 |
| 42--------- | X | | | X | X | | | | | | 2 |
| 43--------- | X | | | | X | | | | | | 2 |
| 44--------- | X | | | X | X | | | | | | 2 |
| 45--------- | X | | | X | X | | | | | | 2 |
| 46--------- | | | | | X | | | | | | 3 |
| 47--------- | | | | X | X | | | | X | | 3 |
| 48--------- | X | | X | X | X | | | | X | | 1 |
| 49--------- | X | | X | X | X | | | | | X | 1 |
| 50--------- | X | | X | X | X | | | | | X | 1 |
| 51--------- | | | X | X | X | X | | | | | 1 |
| 52--------- | | | | | | | | | | | 2 |
| 53--------- | | | | | | | X | | | | 2 |
| 54--------- | X | | | | X | | | | X | | 2 |
| 55--------- | | | | | X | | | | | | 2 |
| 56--------- | X | | | X | X | | | | | | 2 |
| 57--------- | X | | | X | X | | | | | | 2 |
| 58--------- | X | | | X | X | | | | | | 2 |
| 59--------- | | | | X | X | | | | | | 2 |
| 60--------- | X | | | | X | | | | | | 2 |
| 61--------- | X | | | | | | | | | | 2 |
| 62--------- | X | | | | | | | | | | 2 |
| 63--------- | | | | X | | X | | X | | | 3 |
| 64--------- | | | | X | X | | | X | X | | 3 |
| 65--------- | | | | | | | | X | X | | 3 |
| 66--------- | | | | X | X | | | | | | 2 |
| 67--------- | | | | X | X | | | | | | 2 |
| 68--------- | X | | | X | X | | | | | | 2 |
| 69--------- | X | | | X | X | | | | | | 2 |
| 70--------- | X | | | X | X | | | | | | 2 |

Table 1.--Tracts exhibiting potential hazards and constraints (continued)

| Tract number | HAZARDS: Mass Movement | HAZARDS: Steep Slope | HAZARDS: Steep-Walled Canyon | HAZARDS: Shallow Fault | CONSTRAINTS: Shallow Gas | CONSTRAINTS: Water-Column Anomaly | CONSTRAINTS: Seep Mound | CONSTRAINTS: Gas-Charged Sediment | Tracts withdrawn | Tracts stipulated | Shown on plate no. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 71---------- | | | | X | X | | | | | | 2 |
| 72---------- | | | | | X | | | | | | 2 |
| 73---------- | | | | | | | | | | | 2 |
| 74---------- | | | | | | | | | | | 2 |
| 75---------- | | | | X | X | | | X | | | 3 |
| 76---------- | | | | X | | | | X | | | 3 |
| 77---------- | | X | | X | X | | X | | | | 2 |
| 78---------- | | | X | X | | | X | | | | 2 |
| 79---------- | | | X | X | | | | | | | 2 |
| 80---------- | X | | X | | | | | | | | 2 |
| 81---------- | X | | | X | X | | | | | | 2 |
| 82---------- | X | | | | X | | | | | | 2 |
| 83---------- | X | | | | X | | | | | | 2 |
| 84---------- | X | | | | | | | | | | 2 |
| 85---------- | | | | | | | | | | | 2 |
| 86---------- | | | | X | | | | | | | 3 |
| 87---------- | | | | | | | | | | | 3 |
| 88---------- | | X | | X | | | | | X | | 2 |
| 89---------- | | X | | X | X | | | | | X | 2 |
| 90---------- | | X | | X | X | | | | | X | 2 |
| 91---------- | X | X | | X | | | | | X | | 2 |
| 92---------- | X | X | | X | | | | | X | | 2 |
| 93---------- | | X | | X | | | | | X | | 2 |
| 94---------- | | X | | X | | | | | X | | 3 |
| 95---------- | | | | X | | | | | X | | 3 |
| 96---------- | | | | X | | | | | X | | 3 |
| 97---------- | | | | X | X | | | | | | 3 |
| 98---------- | | | | X | | X | | | X | | 2 |
| 99---------- | | | | | | X | | | X | | 2 |
| 100---------- | | | | X | | X | X | | X | | 2 |
| 101---------- | | | | X | | X | | | X | | 2 |
| 102---------- | | | | | | | | | X | | 3 |
| 103---------- | | | | X | | | | | X | | 3 |
| 104---------- | | | | | | | | | X | | 3 |
| 105---------- | | | | X | X | | | | X | | 3 |

Table 1.--Tracts exhibiting potential hazards and constraints (continued)

| Tract number | HAZARDS | | | | CONSTRAINTS | | | | Tracts withdrawn | Tracts stipulated | Shown on plate no. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mass Movement | Steep Slope | Steep-Walled Canyon | Shallow Fault | Shallow Gas | Water-Column Anomaly | Seep Mound | Gas-Charged Sediment | | | |
| 106--------- | | | | X | | | | | X | | 3 |
| 107--------- | | X | | | | | | | X | | 3 |
| 108--------- | | | | | | | | | X | | 3 |
| 109--------- | | | X | X | | | | | | X | 4 |
| 110--------- | | | X | X | | | | | | X | 4 |
| 111--------- | | | | X | | X | X | | | | 4 |
| 112--------- | | | | X | | X | X | | | | 4 |
| 113--------- | X | X | | | | X | | | | X | 4 |
| 114--------- | | | | X | | | | | | | 4 |
| 115--------- | | | | X | | | | | | | 5 |
| 116--------- | | | X | X | | | | | | | 5 |
| 117--------- | X | | X | X | X | | | | X | | 5 |
| 118--------- | | | X | X | X | | | | X | | 5 |
| 119--------- | | | X | X | | | | | X | | 5 |
| 120--------- | X | | X | X | | | | | X | | 6 |
| 121--------- | | | | X | | X | | | X | | 6 |
| 122--------- | | | | | | | | | X | | 6 |
| 123--------- | X | X | X | X | X | X | | | | | 6 |
| 124--------- | | | X | X | | | | | | | 6 |
| 125--------- | X | X | | X | X | | | | | X | 6 |
| 126--------- | X | | | X | X | X | | | | | 6 |
| 127--------- | X | X | | X | X | | | | | X | 6 |
| 128--------- | | X | | X | | | | | | | 6 |
| 129--------- | X | | X | | | | | | X | | 6 |
| 130--------- | X | | X | X | X | | | | X | | 6 |
| 131--------- | | | X | X | X | | | | | X | 6 |
| 132--------- | | X | X | X | X | | | | X | | 6 |
| 133--------- | | X | | X | X | | | | X | | 6 |
| 134--------- | | | X | X | X | | | | | | 6 |
| 135--------- | X | | | X | X | | | | X | | 6 |
| 136--------- | | | X | X | | | | | X | | 6 |
| 137--------- | | | X | | | | | | | | 6 |
| 138--------- | X | | X | X | X | | | | | | 6 |
| 139--------- | X | | X | X | X | | | | | | 6 |
| 140--------- | | X | | X | X | | | | | | 6 |

Table 1.--Tracts exhibiting potential hazards and constraints (continued)

| Tract number | HAZARDS: Mass Movement | HAZARDS: Steep Slope | HAZARDS: Steep-Walled Canyon | HAZARDS: Shallow Fault | CONSTRAINTS: Shallow Gas | CONSTRAINTS: Water-Column Anomaly | CONSTRAINTS: Seep Mound | CONSTRAINTS: Gas-Charged Sediment | Tracts withdrawn | Tracts stipulated | Shown on plate no. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 141---------- | X | | | | X | | | | X | | 7 |
| 142---------- | X | | | | X | | | | X | | 7 |
| 143---------- | X | X | X | | X | | | | X | | 7 |
| 144---------- | X | | | X | X | | | | X | | 7 |
| 145---------- | X | X | X | | | | | | X | | 7 |
| 146---------- | X | | | X | X | | | | X | | 7 |
| 147---------- | X | X | | X | | | | | X | | 8 |
| 148---------- | X | X | | X | X | | | | X | | 8 |
| 149---------- | X | | X | X | X | | | | X | | 8 |
| 150---------- | X | X | | X | X | | | | X | | 8 |
| 151---------- | X | | | | X | | | | X | | 8 |
| 152---------- | X | | | | | | | | X | | 8 |
| 153---------- | X | | | | | | | | X | | 8 |
| 154---------- | | | | X | X | | | | X | | 9 |
| 155---------- | | | | X | X | | | | X | | 9 |
| 156---------- | | | | X | X | | | | X | | 9 |
| 157---------- | | | X | X | X | | | | X | | 9 |
| 158---------- | | X | X | X | | | | | X | | 9 |
| 159---------- | | | X | X | X | | | | X | | 9 |
| 160---------- | | X | | X | | | | | X | | 9 |
| 161---------- | | | X | X | X | | | | X | | 9 |
| 162---------- | | X | | | | | | | X | | 9 |
| 163---------- | | | X | X | | X | | | X | | 9 |
| 164---------- | | | X | X | X | | | | X | | 9 |
| 165---------- | | | X | X | | X | | | X | | 9 |
| 166---------- | | | X | X | X | X | | | X | | 9 |
| 167---------- | | X | X | X | | | | | | | 10 |
| 168---------- | | | | X | | | | | | | 10 |
| 169---------- | | | | X | | | | | | | 10 |
| 170---------- | | | | X | | X | | | | | 10 |
| 171---------- | | X | X | | | | | | | | 10 |
| 172---------- | | X | X | | | | | | | | 10 |
| 173---------- | | X | | X | X | | | | | | 10 |
| 174---------- | | X | | X | | X | | | | X | 10 |
| 175---------- | | | | X | | X | | | | | 10 |

Table 1.--Tracts exhibiting potential hazards and constraints (continued)

| Tract number | HAZARDS: Mass Movement | HAZARDS: Steep Slope | HAZARDS: Steep-Walled Canyon | HAZARDS: Shallow Fault | CONSTRAINTS: Shallow Gas | CONSTRAINTS: Water-Column Anomaly | CONSTRAINTS: Seep Mound | CONSTRAINTS: Gas-Charged Sediment | Tracts withdrawn | Tracts stipulated | Shown on plate no. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 176---------- | | | | X | | X | | | | | 10 |
| 177---------- | | X | | | | | X | | | | 10 |
| 178---------- | | X | | X | X | | | | | | 10 |
| 179---------- | | X | | X | | X | | | | | 10 |
| 180---------- | | X | | X | | | | | | | 11 |
| 181---------- | | X | | X | X | | | | | | 11 |
| 182---------- | X | X | | X | X | | | | | X | 11 |
| 183---------- | | X | X | X | X | X | | | | | 11 |
| 184---------- | X | X | X | X | X | | | | | | 11 |
| 185---------- | X | X | | X | | | | | | | 11 |
| 186---------- | | | | X | | | | | | | 11 |
| 187---------- | X | X | X | X | | X | | | | | 11 |
| 188---------- | X | X | X | X | | | | | | | 11 |
| 189---------- | | | | X | X | | | | | | 11 |
| 190---------- | | | | X | | X | | | | | 11 |
| 191---------- | | X | | X | | X | | | | | 11 |
| 192---------- | X | X | X | X | | | | | | | 11 |
| 193---------- | X | X | | X | | | X | | | | 11 |
| 194---------- | | X | | X | X | | | | | | 11 |
| 195---------- | | X | | X | | X | | | | | 11 |
| 196---------- | | | | | | X | | | | | 11 |
| 197---------- | | | X | | | X | X | | | | 11 |
| 198---------- | | | | X | | | | | | | 11 |
| 199---------- | X | X | X | X | | X | | | | | 11,12 |
| 200---------- | | | | X | | X | | | | | 11,12 |
| 201---------- | | | | X | | | | | | | 11,12 |
| 202---------- | | | | | | | | | | | 11,12 |
| 203---------- | | | | X | | X | | | | | 11,12 |
| 204---------- | | X | | X | | X | | | | | 11,12 |
| 205---------- | | X | | X | | X | | | | | 11,12 |
| 206---------- | | | X | X | | X | | | | | 12 |
| 207---------- | | | | X | | X | | | | | 12 |
| 208---------- | | | | X | | X | | | | | 12 |
| 209---------- | | X | | X | | X | | | | | 12 |
| 210---------- | | X | X | X | | | | | | | 12 |

Table 1.--Tracts exhibiting potential hazards and constraints (continued)

| Tract number | HAZARDS | | | | CONSTRAINTS | | | | Tracts withdrawn | Tracts stipulated | Shown on plate no. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mass Movement | Steep Slope | Steep-Walled Canyon | Shallow Fault | Shallow Gas | Water-Column Anomaly | Seep Mound | Gas-Charged Sediment | | | |
| 211---------- | | X | | X | | X | | | | | 12 |
| 212---------- | | X | X | X | | | | | | | 12 |
| 213---------- | | X | X | X | | X | X | | X | | 12 |
| 214---------- | X | X | X | X | | X | X | | X | | 12 |
| 215---------- | X | X | X | X | | X | | | X | | 12 |
| 216---------- | | | | X | | | | | X | | 12 |
| 217---------- | X | X | | X | | | | | X | | 12 |

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