UNITED STATES DEPARTMENT OF THE INTERIOR

MINERALS MANAGEMENT SERVICE

AND

GEOLOGICAL SURVEY

# A SUMMARY OF GEOLOGIC HAZARDS FOR PROPOSED OCS OIL AND GAS LEASE SALE 68, SOUTHERN CALIFORNIA

BY

Deborah J. Burdick and William C. Richmond

OPEN-FILE REPORT 82-33

1982

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[Plates in pocket]

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## SYSTEM OF MEASUREMENT UNITS

| To convert English units | Multiply by | To obtain Metric units |
|---|---|---|
| Mile, statute | 1.609 | Kilometers |
| nautical | 1.852 | Kilometers |
| Acre | 0.405 | Hectares |

# A SUMMARY OF GEOLOGIC HAZARDS FOR PROPOSED OCS OIL AND GAS LEASE SALE 68, SOUTHERN CALIFORNIA

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## ABSTRACT

A geophysical survey, consisting of about 6,880 line-km of multisensor, high-resolution, seismic reflection data, was run in 161 of the 221 tracts tentatively selected by the U.S. Department of the Interior for inclusion in the southern California Outer Continental Shelf Oil and Gas Lease Sale 68. Geologic hazards identified in the study area for which stipulations are recommended are active faults, mass transport, steep slopes (>10°), and steep-walled submarine canyons. Geologic hazards whose effects can be mitigated through existing technology and design and are not considered cause for stipulation are shallow faults, buried and filled channels, shallow gas, gas-charged sediments, hydrocarbon seeps, and unstable fan deposits. The Minerals Management Service has recommended that a stipulation be applied to 83 tracts where there is evidence of existing or potential sea-floor instability over a significant portion of the tract. Further data acquisition and analysis on a more detailed grid will be required of lessees or operators before drilling will be permitted on leases issued as a result of the sale.

## INTRODUCTION

Existing and potential geologic hazards have been identified by interpretation of high-resolution, seismic reflection profiles to evaluate possible adverse effects on development of oil and gas resources offshore southern California. The Department of the Interior has tentatively selected 221 tracts (encompassing 1,112,975 acres) for inclusion in the proposed Federal Outer Continental Shelf (OCS) Oil and Gas Lease Sale 68. The study area encompasses 161 of those tracts (aggregating 810,314 acres) in the Santa Barbara Channel and the southern California continental borderland (fig. 1). The boundaries of the regular tracts are 3 statute miles on a side, and each complete tract contains 5,760 acres.

Geologic hazards are defined as existing or potential geologic features or processes that could inhibit the development of oil and gas resources. Most geologic hazards are potential rather than actual and continuous threats. In tracts where geologic hazards are identified, special engineering procedures may be required before bottom-founded structures and facilities are approved, and proposed drilling sites will have to be carefully located. Unless geologic hazards are taken into account in the design, installation, and operation of offshore facilities, such phenomena could cause pollution, damage, or loss of lives or equipment. Geologic hazards identified in the Sale 68 area for which stipulations are recommended are active faults, mass transport over a significant portion of the tract, steep slopes (>10°), and steep-walled submarine canyons. Geologic features that are hazardous in their present state, but whose effects can be feasibly mitigated through existing technology and design

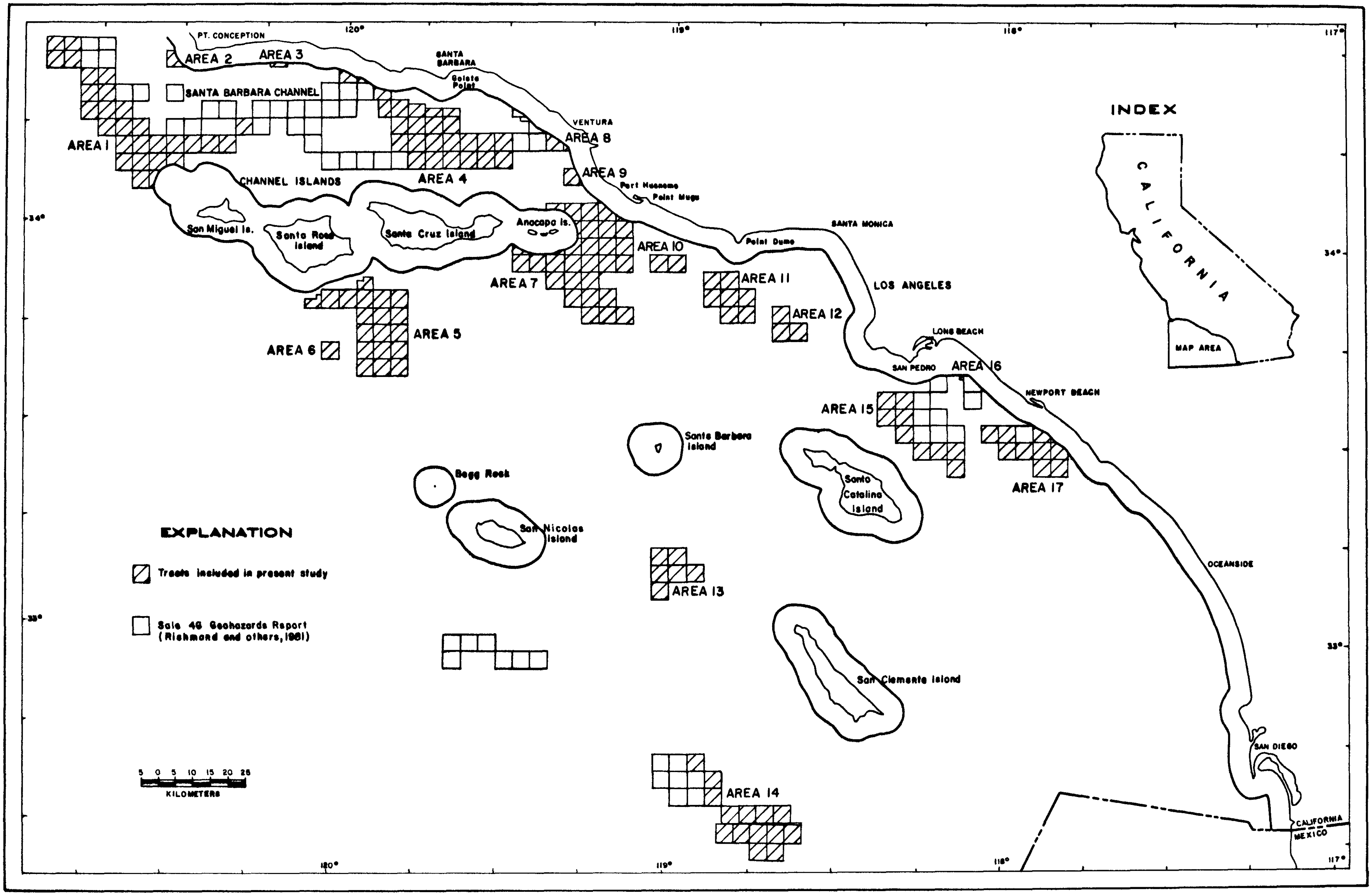

Figure 1.--Index map of the OCS Lease Sale 68 area.

are not considered cause for the recommendation of geologic hazards stipulations. Within the Sale 68 area, these hazards are shallow faults, buried and filled channels, shallow gas, gas-charged sediments, hydrocarbon seeps, and unstable fan deposits. The Minerals Management Service has recommmended that a stipulation be applied to 83 tracts in which there is evidence of existing or potential sea-floor instability over a significant portion of the tract. Geologic hazards identified in each tract proposed for Sale 68 are listed in Table 1.

Included in the tracts selected for Sale 68 are tracts that were previously selected for OCS Lease Sale 48 (table 2). The geologic hazards interpretation and assessment for the Sale 48 tracts is summarized by Richmond and others (1981). Twenty-four tracts currently included in proposed Lease Sale 68 were previously stipulated for or withdrawn from Lease Sale 48. Eight tracts were stipulated in Sale 48--Sale 68 tracts 7, 8, 13, 34, 170, 172, 176, and 199. Tract 13 was resurveyed and interpreted; a stipulation for steep slopes was again recommended. The high-resolution data for the remaining previously stipulated tracts were reviewed with the following recommendations: a stipulation for active faults was again recommended for tracts 170 and 199; a stipulation for mass transport was again recommended for tracts 7, 8, 34, and 172; and a steep slope and steep-walled canyon stipulation was again recommended for tracts 170 and 176. Sixteen tracts included in Sale 68 were withdrawn from Sale 48--Sale 68 tracts 9, 12, 33, 36, 60, 68, 73, 74, 165, 167, 174, 175, 180, 181, 182, and 183. Eleven of the 16 tracts were resurveyed and reinterpreted for Sale 68. A mass transport stipulation was recommended for tracts 12, 36, 174, 175, and 182. A steep slope and steep-walled canyon stipulation was recommended for tracts 9, 60, and 183. Owing to engineering considerations, steep slope has been redefined from slopes greater than 7° to slopes greater than 10°. As a result of this redefinition, no stipulation was recommended for tracts 33, 180, and 181. The remaining five tracts--68, 73, 74, 165, and 167--were withdrawn from Sale 48 owing to reasons other than geologic hazards. Review of the high-resolution data over these five tracts did not indicate cause for geologic hazards stipulations or withdrawal.

All or part of 33 tracts that were in the original group of tracts selected for Sale 68 are within the extended Channel Islands Marine Sanctuary and, subsequently, were withdrawn from the Sale and are not included in the geohazards survey. Existing Minerals Management Service data gathered by the USGS (U.S. Geological Survey, 1975a; Vedder, 1975; Wagner, 1975), BBN--Geomarine Services Company (1974), and McClelland Engineers, Inc. (U.S. Geological Survey, 1979) are sufficient for specific hazards analysis and recommendation for all but tract 99. Application of professional judgement and analysis of existing data near tract 99 provides sufficient evidence that no deletion option is necessary. A general stipulation incorporating stipulations for active faults, mass transport, and steep slopes was recommended for tract 99.

Three tracts located in the northern Santa Barbara Channel, tracts 65, 66, and 67, were not included in the proposed sale area until after the start of procurement for the Sale 68 geologic hazards survey. A general stipulation incorporating stipulations for active faults, mass transport, and steep slopes was recommended for tracts 65, 66, and 67 because available data did not support elimination of the hazard stipulation categories.

This paper summarizes the regional geology and describes the geologic hazards identified in the southern California OCS. Included are 1:100,000-scale maps of the potential geologic hazards identified in the 161 tracts of the study area (pls. 1-10).

## Data Acquisition

This report is based on the interpretation of existing data and seismic reflection profiles collected by Racal-Decca Survey, Inc., under contract to the U.S. Geological Survey (contract no. 14-08-0001-19236). Data were collected from October 1980 through February 1981. About 6,880 line-km of nonproprietary, multisensor, high-resolution data were collected on an approximate 0.5 x 1.5-mile grid over the study area. Geophysical systems used in the survey were 3.5 kHz subbottom profiler, 100-400 J 40-tip minisparker, and 8.4 kJ sparker. Side-scan sonar and a multichannel digital recording of the sparker data were collected at water depths less than 300 m. Computer processing of the multichannel digital data was subcontracted to Exploration Processing Corporation.

The M/V Mediterranean Seal was the ship used throughout the survey. Navigation and positioning were maintained by use of Decca Trisponder and Hi-Fix systems interfaced with an automated positioning data acquisition and display system. The positioning accuracy for the Decca Trisponder is ±3 m and for the Decca Hi-Fix is ±15 m.

Microfilm copies of these data (USGS Data Set 19236) are available for public inspection at the Office of the Deputy Minerals Manager for Field Operations, Minerals Management Service, 1340 West Sixth Street, Suite 160, Los Angeles, California 90017. The complete or partial data set may be purchased from NOAA, Environmental Data and Information Service, National Geophysical and Solar-Terrestrial Data Center, Boulder, Colorado 80303.

## Regional Geologic Setting

Tracts tentatively selected for inclusion in OCS Lease Sale 68 lie in the structurally complex part of the California OCS that includes the Santa Barbara Channel and the southern California continental borderland. The southern California OCS covers the westernmost extent of two major structural and geomorphic provinces in southern California--the Transverse Range province and the the Peninsular Range province.

The Santa Barbara basin, the submerged southwestern part of the Transverse Range province, is a tectonic depression that forms the western extension of the onshore Neogene-aged Ventura basin (Vedder and others, 1969). This trend is commonly referred to as the Santa Barbara Channel. The channel extends 130 km along its east-west axis and averages 40 km in width. Maximum water depth in the channel is about 625 m.

Major geologic structures within the Santa Barbara Channel reflect the west-trending structural grain of the Transverse Range province. The major structures in the Santa Barbara Channel region are east-west oriented folds and faults; for example, the Rincon trend; the Santa Ynez, Pitas Point, and Oak Ridge faults; and the Santa Rosa Island/Santa Cruz Island/Malibu Coast fault zone, which marks the southern boundary of the basin (fig. 2). This structural grain may be superimposed on a northwest trend in older, buried structures (Howell and others, 1978).

The Channel floor is composed of Quaternary sediments, as much as 2,000 m thick, 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 slopes of the Channel, although barren of sediment in places, are generally mantled by a very thin layer of sediment. Bottom sediments in the central part of the Channel are predominately silt and clay. Rates of sediment erosion and deposition vary within the Channel. The average rate of deposition in the deep central basin is about 2 mm per year (Fleischer, 1972). Sediment discharged by the Santa Clara River during major floods has formed layers more than 15 cm thick on the shelf west of Oxnard; this sediment is eroded by wave and current action and redeposited over wide areas of the shelf and basin (Drake and others, 1972).

Underlying the Quaternary-aged basin fill are more than 15,000 m of highly folded and faulted Tertiary and Cretaceous strata (Vedder and others, 1969). Cretaceous and Paleogene strata are principally thick beds of sandstone and siltstone. Neogene strata generally consist of sands in the lower part and fractured shale with minor sand in the upper part. Middle Miocene volcanic centers are located along the northwest and south margins of the Channel. These are the Tranquillon volcanics described by Dibblee (1950) and the Santa Cruz Island volcanics described by Nolf and Nolf (1969), respectively.

The southern California continental borderland, south of the Channel Islands and extending 65-255 km 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 Ranges. The basins are at water depths of 600-2,000 m, whereas water depths above the flat-topped ridges and coastal shelves are usually less than 150 m. Coastal shelves are commonly very narrow. The widest shelves, for example, the Santa Monica and San Pedro shelves, are only 25 km across.

Rocks and sediments in the southern California continental borderland range in age from Cretaceous to Holocene. The outer ridges--Patton and Santa Rosa-Cortes Ridges--are uplifts of pre-Tertiary rocks with an onlapping sequence of Neogene sandstone and shale. The Santa Rosa-Cortes Ridge is upfolded Paleogene and Cretaceous hemipelagic sediments and turbidites. The outer ridges are sites of erosion, and the outer basins are sites of deposition. Sediments of late Tertiary to Quaternary age, consisting of sand, mud, or shell hash, are sparse on the ridge tops and generally occur in isolated pockets 5-20 m thick (Greene and others, 1975; Field and Richmond, 1980). The western basins contain as much as 3,000 m of Neogene sediments. The basins east of Santa Rosa-Cortes Ridge contain more than 2,500 m of Paleogene and Neogene

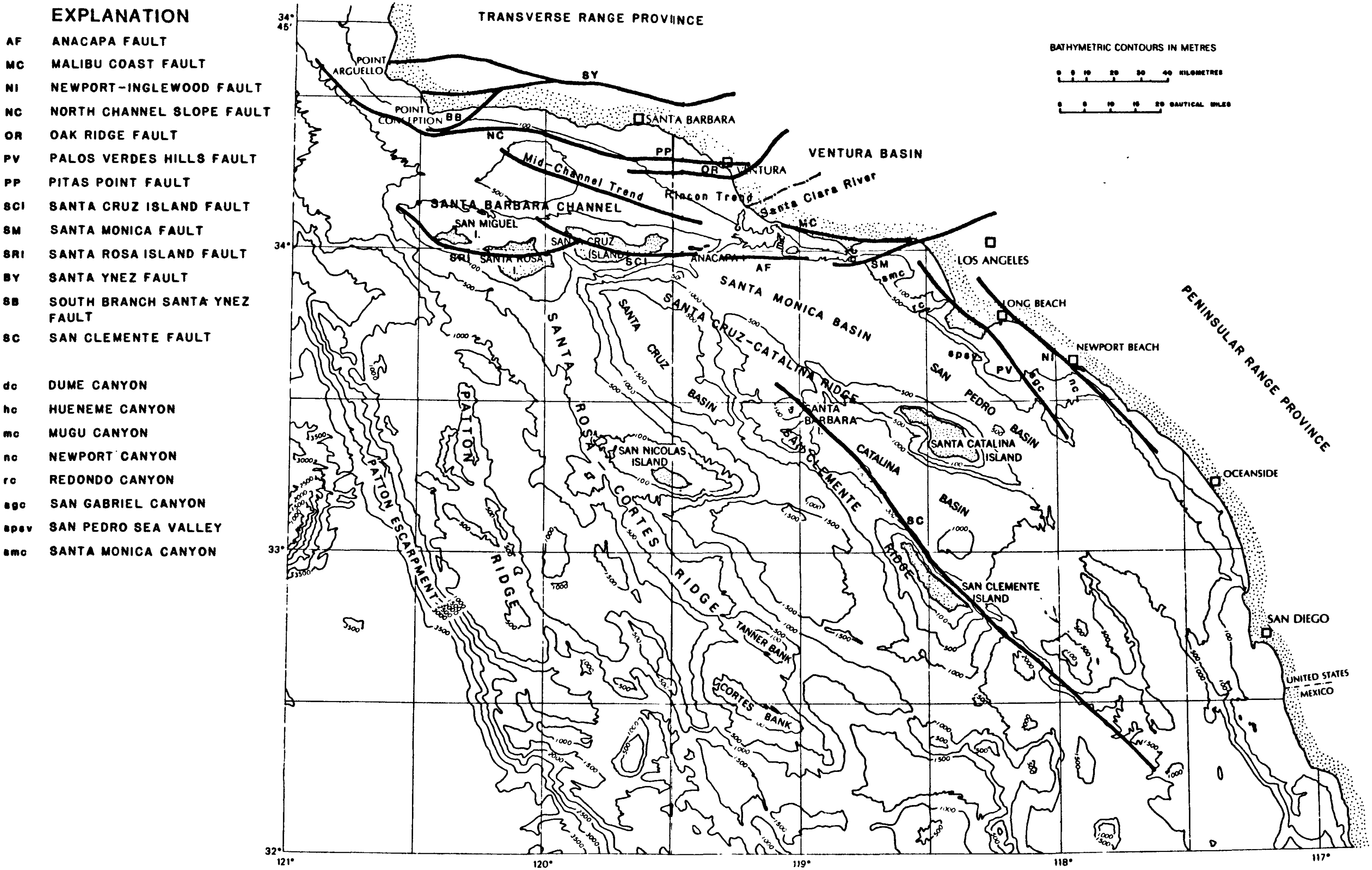

Figure 2.--Structure map of the southern California OCS.

sediments as well as mid-Tertiary volcanics. Quaternary sediments are as much as 1,200 m thick in the outer basins.

The inner ridges--Santa Cruz-Catalina and San Clemente Ridges--are composed of metamorphic basement rocks (Catalina Schist) that are intruded by Neogene plutonic rocks and overlain by volcanic rocks (Howell and others, 1978). Overlying and buttressing these metamorphic and igneous units are Neogene sandstone and shale. Paleogene or Cretaceous siltstone, sandstone, and conglomerate are found at the southeast end of Santa Catalina Island (Howell and others, 1978). The coastal shelves consist mainly of tightly folded late Neogene sandstone and shale. Along the coastal shelves, Quaternary sands and muds are extensive, as much as 200 m thick; correlative deposits are as much as 2,000 m thick in Santa Monica and San Pedro Basins.

## GEOLOGIC HAZARDS

### Seismicity

Southern California is a portion of the complex Pacific-American plate boundary that is within the circum-Pacific volcanic and seismic belt. This area has been tectonically 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).

Reliable accounts of California earthquakes date from the early 1800's and in southern California, they have been monitored since the 1920's. Since 1932, the California Institute of Technology has maintained a seismic monitoring network in southern California (fig. 3). A network of seismographic stations surrounding the Santa Barbara Channel was established by the U.S. Geological Survey in 1969. This network includes stations on San Miguel and Santa Cruz Islands; a third station was installed on Anacapa Island in 1973. The University of Southern California (USC), under contract to the U.S. Geological Survey, monitors the seismicity of the Dos Cuadras oil field in the Santa Barbara Channel. The USC seismic network, consisting of four sea-floor stations and three land-based stations, has been fully operational since January 1979. The U.S. Geological Survey is now contracting with USC to establish a seismic monitoring network around the Beta oil field on the San Pedro shelf.

Seismic activity poses a hazard in terms of both ground acceleration and rupture along fault planes. Ground shaking associated with earthquake activity can trigger mass transport of sea-floor sediments. Velocity, acceleration, displacement, direction of motion, frequency, and duration of motion are factors in determining the effects of an earthquake on sediments, foundations, and bottom-founded structures and facilities (Bouma, 1981). Regional and local geology and the local structural pattern affect the potential hazard of seismic activity.

The Santa Barbara Channel has a history of significant seismic activity. Five destructive earthquakes have been documented in the Santa Barbara Channel: 1812, estimated magnitude 7.0-7.5; 1925, magnitude 6.3; 1941, magnitude 6.0; 1973, magnitude 6.0; and 1978, magnitude 5.1. The epicenters for the 1812, 1925, and 1941 earthquakes are poorly located (Lee and others, 1979). The

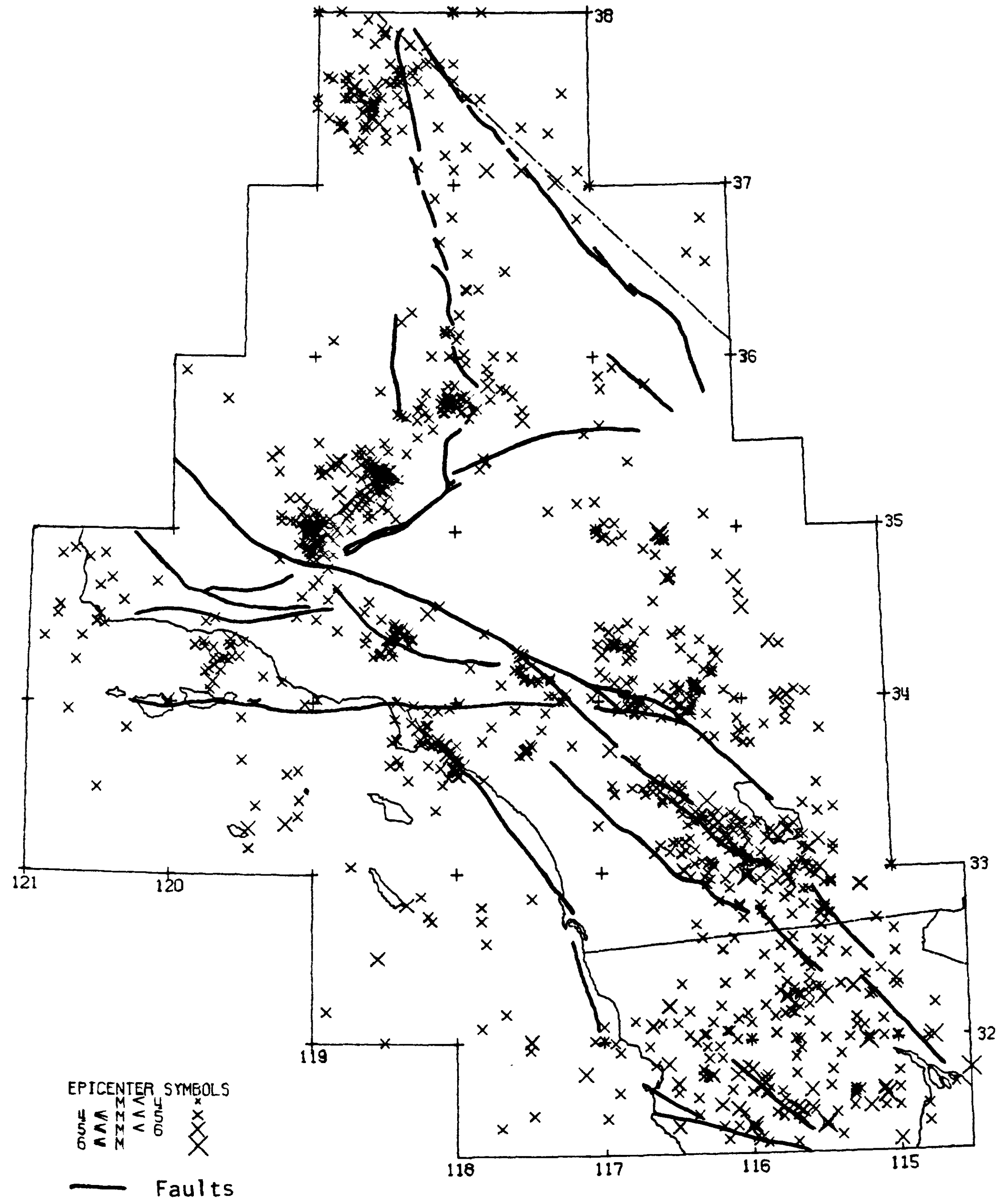

Figure 3.--Earthquake epicenters for events greater than or equal to magnitude 4.0 in southern California from 1932 through 1972 (from Hileman and others, 1973).

western Santa Barbara Channel earthquake of 1812 produced a tsunami and caused structural damage to several southern California missions. The largest documented earthquake centered offshore California, magnitude 7.3, occurred on November 4, 1927, northwest of the Santa Barbara Channel. A tsunami generated by the main shock affected many parts of the channel.

The maximum credible earthquake for the Santa Barbara Channel estimated by the U.S. Geological Survey (1975b) is magnitude 6 with a recurrence interval of 20 years. This value is probably too low if the magnitudes for the 1812 and 1925 earthquakes have been correctly estimated (Vedder and others, 1980).

Studies of the 1970-1975 seismic activity in the Santa Barbara Channel by Lee and others (1979) show that the epicenters aligned with east-trending reverse faults. Epicenters are concentrated in the central channel, extending from the Goleta-Santa Barbara area to the Mid-Channel fault, and in the east part of the channel, offshore of Point Mugu. Fault-plane solutions geometrically associate one or more events with segments of the Red Mountain, Pitas Point-Ventura, Mid-Channel, and other east-trending faults (Lee and others, 1979).

Seismic activity in the southern California continental borderland reflects modern tectonic activity (Greene and others, 1975). Although there is an extensive seismographic network onshore southern California, the seismicity coverage offshore is sparse. Seismicity data are scant and inconclusive. Predictions of maximum credible earthquakes and recurrence intervals have not been established for the continental borderland.

Seismicity of the inner basin and ridge area is most prominent in four areas: (1) the offshore area between Point Mugu and Point Dume, (2) the vicinity of the Malibu Coast fault, (3) the Palos Verdes Hills-Coronado fault zone, and (4) the area adjoining the Newport-Inglewood/Rose Canyon fault zone (Greene and others, 1975; Vedder and others, 1980). Earthquakes recorded in the vicinity of the Mugu-Santa Monica shelf are all less than magnitude 5. Events of less than magnitude 4 occur along a broad northwest trend on the Mugu-Santa Monica shelf.

Seismicity coverage of the outer basins and ridges is practically nonexistent. Earthquake epicenters are randomly scattered in the Santa Rosa-Cortes Ridge area. Most of the events in this area range in magnitude from 2.5 to 4.5. Significant earthquakes have been reported in the vicinity of the San Clemente fault and offshore San Nicolas Island (Hileman and others, 1973). Tanner-Cortes Banks lie beyond the limits of the existing seismographic network; therefore many events in this area probably were not detected and the locations of those recorded may be unreliable.

## Faulting

Faults in general are not considered hazardous to petroleum resource development. Active faults, however, pose a hazard to offshore operations and facilities. Faults are considered active where they offset young (Quaternary) sediments in regions where sedimentation has been essentially continuous, where they offset the sea floor, or where they have a historic record of earthquake activity or slip. Active faults are hazardous because of possible ground rupture and as potential sources of shaking. Active faults may act as conduits along which pressurized, subsurface fluids can reach the surface. Withdrawal or injection of fluids may reactivate deeper faults thought to be dormant and may cause subsidence.

Offshore southern California is cut by numerous faults, many of which are considered active. In the Santa Barbara Channel region, active faults in or adjacent to the study area include the South Branch Santa Ynez, north channel-slope, Mid-Channel, Pitas Point, and Oak Ridge faults (fig. 2). An unnamed series of faults at the base of the Channel Islands Platform in the southwest Santa Barbara Channel, sometimes referred to as the south channel-slope fault zone, is also considered active. Several of the above mentioned faults are considered capable of generating large magnitude earthquakes (U.S. Geological Survey, 1976; Yerkes and others, 1981).

The South Branch Santa Ynez fault is 21 km long. The fault trends S. 45° W. and dips 60° NE. at the shore line. According to Yerkes and others (1981), onshore evidence indicates both left-lateral and reverse separation. The left-lateral component of movement could be as large as 550 m onshore and 820 m offshore; reverse separation is as large as 915 m. Fischer (1972) places the age of latest movement as late Pleistocene to Holocene; this is consistent with the age determined by Yerkes and others (1981) based on offset of stream terraces onshore. The South Branch Santa Ynez fault does not cut the Sale 68 area, but comes within 9.5 km west and northwest and about 10 km north of portions of the sale area (pls. 2 and 3; tracts 10, 23, and 24).

The west-trending north channel-slope fault, the possible western extension of the Pitas Point fault, is an inferred north-dipping, high-angle (60°-85°), reverse fault that parallels the north slope of the Santa Barbara Channel. Yerkes and others (1981) believe the north slope of the channel to be controlled by vertical movement along this fault. As much as 530 m of reverse separation (south block down) is inferred since Pliocene time. Yerkes and others (1981) consider the north channel slope to be a fault scarp formed largely before late Pleistocene time. The east end of the fault trend crosses the Sale 68 area west and southwest of Goleta Point (pl. 3; tracts 13, 60, 61, and 62).

The west-northwest-trending Mid-Channel fault refers to a series of faults through the central trough of the Santa Barbara Channel. Yerkes and others (1981) mapped a 64 km zone of faults parallel to the channel axis, but they do not discuss characteristics. Yerkes and Lee (1979) described a seismically active part of this fault, directly south of Santa Barbara, as a fault-bounded, gentle anticline (Twelve-mile reef) cut by three faults that show as much as 50 m of post-Pliocene vertical separation (pl. 4; tracts 79, 80, 92, and 93). The fault trend mapped by Yerkes and others (1981) parallels the channel axis north of Santa Cruz Island (pls. 3 and 4; tracts 77, 78, 79, 80, 92, 93, and 94). These faults range in depth from 0 to 70 m subbottom in the sale area and are associated with the Twelve-mile reef, the site of recent seismic activity.

The Pitas Point fault, the western extension of the onshore Ventura fault, extends more than 30 km across the eastern channel shelf to where it connects with the north channel-slope fault. The fault is a north-dipping (>80°), reverse fault that displaces a buried post-late Pleistocene erosion surface about 25 m up on the north (Greene and others, 1978). The fault extends into Holocene deposits to within 3 m of the sea floor, but does not displace the sea floor (Greene and others, 1978; Richmond and others, 1981). The fault is 4-5 km north of and parallel to the northern border of the sale area (pls. 3 and 4; tracts 78-82).

The Oak Ridge fault is a steep (>35°), south-dipping, reverse fault. Greene and others (1978) believe the west-trending zone of deformation is the outstanding structural feature in the eastern Santa Barbara Channel. The most intense faulting and folding is along the west end of the fault; the eastern part of the zone is characterized by isoclinal folding. Pleistocene strata are upthrown more than 135 m on the south, although no sea-floor displacement is known (Greene and others, 1978). Richmond and others (1981) report more than 4 m of vertical separation in Holocene strata and describe the sea floor as bowed upward, but not cut, above the fault. A segment of the Oak Ridge fault is mapped for more than 29 km across the study area (pl. 4; tracts 82, 85, and 86). The fault ranges from 0 to 20 m subbottom and cuts the sea floor locally (pl. 4; north of tracts 80 and 81). As much as 12 m of vertical displacement of Holocene strata was measured (tracts 85 and 86). Gas-charged sediments are associated with the entire length of the fault in the study area and gas is found seeping into the water column along the fault (tract 82).

A west-trending fault system consisting of the Santa Rosa Island, Santa Cruz Island, Anacapa, Malibu Coast, and Santa Monica faults separates the Santa Barbara Channel from the southern California continental borderland. All of these faults show evidence of recent activity--offset of Holocene deposits and correlation with earthquake epicenters. Faults in the system are primarily reverse with 40°-70° N. dip, but a lateral component of separation does exist. As much as 2,250 m of post-late Miocene vertical separation (up on the north) has been measured in this fault system (Yerkes and others, 1965; Junger and Wagner, 1977). Junger (1979) described a possible 300 m left-lateral offset of modern stream channels on Santa Cruz Island. The only fault in this system mapped within the study area is the west end of the Santa Monica fault, at the base of the slope south of Point Dume. East of Mugu Canyon, the fault cuts the base of the Quaternary and extends to within 35 m of the sea floor (pl. 7; tract 123). The western extension of the fault, between Point Dume and the Anacapa fault on the southeast Channel Islands Platform, was not identified on high-resolution geophysical data. Thick Holocene fan deposits at the mouths of Hueneme and Mugu Canyons and rugged topography associated with the submarine canyon environment mask any indication of shallow faulting in the area.

In the southern California continental borderland, many shallow, near surface faults were mapped on the mainland shelf and on the outer ridges. Beneath the flanks of the ridges and in the basins, faults are less numerous but are longer and have greater apparent vertical separation than faults on the ridge crests (Vedder and others, 1980).

Active faults mapped on the mainland shelf and in the inner basins include the Cabrillo, Palos Verdes Hills, and Newport-Inglewood fault zones. Two unnamed potentially active fault zones were mapped along the base of Santa Monica and San Pedro shelves (pls. 7 and 8; areas 12 and 15).

The offshore extension of the northwest-trending Cabrillo fault zone parallels the shelf break along the western margin of the San Pedro shelf (pl. 8). The fault zone is 1-3 km wide and individual faults in the zone are 2-18 km long. The total fault zone is more than 27 km long. Faults in the zone are as deep as 75 m subbottom but do cut the sea floor where bedrock is exposed (pl. 8; tracts 160 and 181). About 30 m of vertical separation, downthrown on the northeast, was measured in Pleistocene(?) sediments (tract 181). The latest onshore movement along the fault zone is of Holocene age (Greene and others, 1975).

The Palos Verdes Hills fault zone, more than 80 km long, is a steep-dipping, reverse fault that displaces onshore basement rocks more than 1,500 m upthrown on the west (Yerkes and others, 1965). According to Junger and Wagner (1977), the fault cuts Quaternary beds offshore and upwarps the sea floor in many areas. Seismological data in the area indicates Holocene activity on the fault (Hileman and others, 1973). The Palos Verdes Hills fault zone trends northwest, parallel to the Cabrillo fault trend, in the study area (pl. 9; area 17). A 13 km segment of the fault zone is interpretable in the sale area (pl. 9; tracts 182 and 187). This fault segment is as deep as 40 m subbottom and cuts bedrock southwest of the study area. According to Richmond and others (1981), individual faults in the offshore portion of the zone range from 3 to 15 km long, and have as much as 60 m vertical displacement downthrown on the northeast in shallow Neogene bedrock.

The Newport-Inglewood fault is a major right-lateral, strike-slip fault 1 km east of the study area (pl. 9; area 17). The fault consists of en echelon, northwest-trending faults and folds. Right-lateral strike-slip displacement on the fault ranges from 915 to 1,525 m in Pliocene strata (Yerkes and others, 1965). Vertical separation is locally 1,220 m at the basement surface, does not exceed 305 m in Pliocene strata, and is 61 m at the base of the Pleistocene (Yerkes and others, 1965). Many instrumentally determined seismic events (less than magnitude 6.0) are associated with the fault zone (Hileman and others, 1973).

At the base of the Santa Monica shelf, an 8-km-long, northwest-trending fault segment cuts the sea floor (pl. 7; tracts 147 and 152). A sea-floor bulge as high as 20 m has formed along the entire fault. The relative sense of movement could not be determined along the fault. Several recent earthquake epicenters reported by Hileman and others (1973) align with the fault.

A 6-km-long, northwest-trending fault cuts the sea floor at the base of the San Pedro Escarpment (pl. 8; tract 162). A 7-m scarp has formed along the fault trace but the relative displacement cannot be determined. The fault is located in a seismically active area but no epicenters coincide with the fault.

In the outer banks area, many faults cut the sea floor where bedrock is exposed. Few are considered active because sedimentation has not been continuous and exposure at the sea floor is probably due to erosion. Several faults cut Quaternary sediments and locally cut the sea floor (pls. 5 and 11; areas 5 and 14).

On the east flank of the northern Santa Rosa-Cortes Ridge (pl. 5; area 5), a partially exposed bedrock ridge was uplifted along a series of north-northwest-trending en echelon faults. The three major fault traces, 3-12 km long, form a zone 25 km long. The ridge has been uplifted as much as 120 m on the east side (downslope side) of the fault zone. A thin (<3 m) pocket of Holocene sediment is ponded behind the uplifted block along at least a part of the fault zone. Seismic activity is not well documented in this area so the recency of faulting is not known. The fault zone is considered potentially active.

A group of north-northwest-trending faults cuts basin sediments of probable Quaternary age on the northeast side of the southeast extension of Tanner Bank (pl. 11; tracts 213 and 219). The faults range in length from 1 to 7 km and are as much as 140 m subbottom. Fault segments cut, but do not offset, the sea floor. As much as 10 m of vertical separation has been mapped on two of these faults. The relative displacement is down on the east. The west side of the ridge appears to be fault controlled. Northwest-trending inferred faults may cut the sea floor. Basin sediments are upturned against the ridge flanks above this inferred fault zone.

## Mass Transport

Mass transport is the gravity-induced, downslope movement of unconsolidated to semiconsolidated sediments. The sediments move en masse either as individual grains or as sediment units. Mass transport of sediment occurs in response to one or more of the following: seismic shaking, overloading or oversteepening of slopes, lowered shear strength of sediments, high gas content in sediments, cyclic loading, or other causes. For a complete discussion of factors affecting slope failure refer to Edwards and others (1980). Sediment mass transport in the southern California continental borderland occurs as slides, slumps, sediment gravity flows, and sediment creep. Slides (glides) are translational movement of rigid or semiconsolidated sediments due to failure along discrete shear planes subparallel to underlying beds (Field, 1981). Slides exhibit relatively minor internal flow (Dott, 1963). Slump, a term often used synonymously with slide, refers to rotational movement of sedimentary units along a discrete, concave-up, shear surface (Dott, 1963). Sediment gravity flow is a general term for the flow of sediments or sediment-fluid mixtures in which the sediment movement is induced by gravity and the sediment motion moves the interstitial fluid (Middleton and Hampton, 1973). The original internal structure is not preserved in sediment gravity flow. 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.

The existence of mass-transport deposits indicates localities of past sediment instability and zones of possible future failure. Mass transport presents a major hazard to bottom-founded structures and facilities. Contrasts in load-bearing capacity may exist within the failure zone and between the zone and the surrounding sediment. Loss of support for structures and pipelines may result from sediment movement. The degree of hazard associated with the impact of transported material upon structures and facilities depends on the thickness and velocity of the sediment mass and the frequency of movement (Sangrey, 1981). Comprehensive geological, geophysical, and geotechnical studies are required to evaluate the possibility of slope failure.

Evidence of sediment failure resulting in downslope mass transport is relatively common in the Santa Barbara Channel and the continental borderland (see Field and Edwards, 1980). Other forms of sediment failure (for example, liquefaction) are difficult to detect and it has not been possible to determine their prevalence. In the study area, mass-transport deposits occur only along the mainland shelf and slope--Point Conception area, northern Santa Barbara Channel, Hueneme Canyon, and Santa Monica and San Pedro Basins.

In the Point Conception area (pls. 1 and 2; area 1), mass-transport deposits are associated with channel and interchannel environments on the surface of Conception Fan. Mass-transport deposits in the interchannel areas are by far the largest; three deposits covering 10, 15, and more than 65 sq km of sea floor were mapped in and adjacent to the study area (pls. 1 and 2; tracts 6, 11, 12, 14, and 36). These slides are thin (<10 m), translational features that are characterized by broad depressions or scarps, 300-1,800 m wide and 10 m deep, that are separated downslope by small, localized highs showing less than 3 m of relief. Internal reflectors in these slides appear to be conformable with underlying reflectors. The two larger slides extend upslope, beyond the study area, into tracts discussed in Richmond and others (1981).

Slumped terrace and levee deposits are common in all tracts cut by major fan channels southwest of Point Conception. These slumps are relatively small, 0.5-9.0 sq km in area, and are less than 100 m thick (pls. 1 and 2; tracts 5, 6, 11, 12, 14, 21, 22, and 33). Slump deposits are quite extensive in the upslope portion of the channels described by Richmond and others (1981).

More than 20 percent of the central Santa Barbara Channel is covered by mass-transport deposits (Richmond and others, 1981). Two slides in the north central part of the basin each cover more than 135 sq km. Each slide is well over 100 m thick and is characterized by chaotic internal bedding. The sea floor is hummocky and irregular over these features, showing as much as 25 m of relief between mounds and adjacent depressions. A ridge, 2-20 m high, has formed at the toe of these slides. Each mass appears to have had several episodes of sliding and creeping.

In Hueneme Canyon, several small slumps were mapped on the canyon walls (pl. 6; area 7). These slumps are less than 7 sq km in area and about 30 m thick, and are inferred from irregular bottom topography.

A large slide, about 40 sq km in area, was mapped at the base of the slope of Santa Monica Basin (pl. 7; area 11). This slide is more than 200 m thick at its center and thins toward its borders. Internal reflectors are chaotic. The sea floor is irregular, showing as much as 10 m of relief. A well-defined removal scar, 2,130 m long and 450 m wide, was mapped at the top of the slide. The fringes of this slide are partially buried and as much as 10 m of sediment are pooled in depressions on the surface of the slide; an indication that it is not a recent event.

Seven mass-transport deposits were mapped on the basin slope surrounding San Pedro shelf (pls. 8 and 9; areas 15 and 17). Five slides, ranging from 1 to 30 sq km in area, were mapped on and at the base of the San Pedro Escarpment (pl. 8; tracts 159, 160, 162, and 163). The largest slide (tracts 162 and 163) is 10-40 m thick and lies on a slope as steep as 10°. The remaining two slides were mapped in the interchannel area near the mouth of the San Gabriel Canyon system (pl. 9; area 17). The smaller slide is about 14 sq km in area (pl. 9; tracts 177, 178, 184, and 185). The larger slide is more than 75 sq km in extent within the area of data coverage for this study (pl. 9; tracts 174, 175, 182, and 183). Each slide is 10-40 m thick and is characterized by a fairly regular surface with relief on the order of 3-5 m.

## Slopes

Slopes 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 greater than 10° are steep. Only steep-walled canyons and steep slopes are considered to be hazards, especially those slopes with sediment cover.

Steep slopes in the Santa Barbara Channel are common along the flanks of the Channel Islands Platform and along the mainland slope. Slopes as steep as 16°-17° are identified at the northwest end of the Channel Islands Platform (pl. 2; tracts 44 and 45). Slopes average 7.5° on the mainland slope along the northern edge of Santa Barbara Channel. Slopes as steep as 10.1° locally were measured in the study area east of Goleta Point (pl. 3; tract 60).

Slopes average about 10° along the northwest-trending shelf break on the west flank of the Santa Cruz-Catalina Ridge (pl. 6; tracts 115, 125, 133, 142, and 143). Slopes range from 8.2° to as steep as 12.7° locally (tracts 142 and 143).

Steep and moderate slopes occur along the flanks of the northern Santa Rosa-Cortes Ridge (pl. 5; areas 5 and 6). Local slopes range from 10.0° to 12.5° along the east flank (pl. 5; tracts 132 and 141). Slopes on the west flank are as steep as 13.8° locally (pl. 5; tract 59).

Moderate and steep slopes are common along the mainland slope and along the flanks of the ridges in the southern California continental borderland. The basin slope along the northeast edge of Santa Monica Basin is as steep as 18.1° (pl. 7; tract 123). The basin slope averages 4° south of Point Dume (pl. 7; area 11) and ranges from 6.5° to 8.0° south of the Santa Monica shelf (pl. 7; area 12).

Moderate slopes are associated with the basin slope surrounding San Pedro shelf (pls. 8 and 9; areas 15 and 17). Local slopes of 10.0° were identified in the study area (pl. 8; tract 160).

Steep slopes are identified on a west-northwest-trending ridge across the center of the area east of San Nicolas Island (pl. 10; area 13). Slopes on the flanks of the ridge are commonly 8.7°-10.9° (pl. 10; tracts 189, 190, 191, 192, and 193) and locally as high as 13.4°-15.0° (tracts 192 and 193). Slopes of 5.9°-8.9° were measured along the flanks of a small bedrock high in the southwest portion of the study area (pl. 10; tracts 191 and 194).

The southeast extension of Tanner Bank has moderate to steep slopes along the southwest flank (pl. 11; area 14). Slopes of 7.8°-17.0° were measured along the flank of the ridge (pl. 11; tracts 217, 218, 220, and 221).

## Submarine Canyons

Submarine canyons are common along the mainland shelf and slope of the southern California continental borderland, although they are rare in the Santa Barbara Channel. Canyons in or adjacent to the tracts tentatively selected for Sale 68 include Hueneme, Mugu, Dume, Santa Monica, Redondo, San Gabriel, and Newport Canyons, and San Pedro Sea Valley. The intermittent channel fill in these canyons is highly mobile and unstable. Slump deposits are common in these canyons and form as a result of terrace and levee deposits being undercut by currents and sediment transport in the canyons.

The Conception (Pescado) submarine fan south and west of Point Conception is cut by five west-to-southwest-trending, eroding and migrating channels (pls. 1 and 2; areas 1 and 2). The abundance of shallow buried and filled channels on the fan is evidence of the constantly shifting channels and depocenters on the fan's surface. Unconsolidated channel fill is common in all of the channels. Levee deposits commonly border the channels at water depths greater than 300 m. Slumped levee deposits are common along the channels within the study area (pls. 1 and 2; tracts 6, 11, 12, 21, 22, and 23) and in Sale 68 tracts adjacent to the study area (tracts 34 and 35; Richmond and others, 1981). Wall slopes within the channels are generally less than 7°, but slopes are as high as 10.5° (tract 22), 16.2° (tract 12), and 17° (tract 6) in the channels west of the Santa Barbara Channel. Wall slopes in the channels that head in the study area southwest of Point Conception were determined to be between 5.0° to 16.7° (pl. 1; tract 9).

The south-trending Hueneme Submarine Canyon cuts the outer shelf and slope south of Port Hueneme (pl. 6; tracts 101, 102, 105, 106, and 112). The canyon shows as much as 270 m of relief. Wall slopes of 11.0°-18.2° are common near the canyon head but are usually less than 10° near the mouth of the canyon. Slump deposits are common on the slopes of the channel. The extent of the channel fill present in the canyon is difficult to define owing to the lack of coherent reflectors and to the presence of diffractions. A major distributary channel associated with the Hueneme Submarine Canyon trends southward to the east of the main canyon (pl. 6; tracts 102, 106, and 113). This distributary channel has as much as 200 m relief. Steep slopes, ranging from 10.0° to 13.4°, are restricted to the channel head. All of the channels associated with Hueneme Submarine Canyon system are asymmetrical with downslope walls steeper than upslope walls.

A channel east of the Hueneme Submarine Canyon system may be a distributary channel related to the Mugu Canyon system (pl. 6; tracts 103, 107, and 114). The channel has as much as 180 m of relief and steep wall slope of 10°-12° at the channel head.

The south-southwest-trending mouth of Santa Monica Canyon cuts the base of the slope at the east edge of Santa Monica Basin (pl. 7; tract 147). The submarine channel has a maximum of 90 m relief. Steep wall slopes with 11.0°-11.3° inclination are common.

The San Pedro Sea Valley cuts the San Pedro Escarpment south of San Pedro. The canyon heads 1 km north of the study area (pl. 8; tracts 159 and 160). Wall slopes as steep as 11° are described by Richmond and others (1981).

Three south-trending submarine channels of the Newport Canyon system incise the slope southwest of Newport Beach (pl. 9; tracts 174, 175, 176, 183, and 187). The westernmost channel (tract 174) has 40 m of relief and wall slopes as steep as 14.7°. The two channels to the east converge downslope to form one channel. Relief ranges from 60 m in the upper reaches of the separate channels to 10 m in the south part of the combined channel. Steep slopes are common along the walls of the channel system. Wall slopes of 10.6° and 7.0°-13.5° are identified in the west and east channels, respectively (tracts 175, 176, and 183). Wall slopes in the west channel are as steep as 14.0° north of the channel convergence.

## Buried and Filled Channels

Buried channels are channels cut during periods of lower sea level and subsequently buried during times of transgressing seas. Filled channels associated with modern submarine canyon systems are the result of channel migration. Buried and filled channels are identified by the irregular erosional contact between the younger infilling sediments and the surrounding sediments. The infilling sediments may also show crossbedding or unconformable bedding.

Shallow buried channels pose a hazard due to possible contrasts in load-bearing capacity within the infilling sediments and between the infilling sediments and the surrounding sediments. Contrasts in load-bearing capacity can exist over short vertical and horizontal distances within heterogeneous channel fill. Filled channels may pose a hazard in terms of foundation support for bottom-founded structures and facilities.

Within the study area, buried channels occur only in the western Santa Barbara Channel (pls. 1 and 2; area 1). The buried channels are related to the modern canyon system of the submarine fan south and west of Point Conception. A group of southwest-trending buried channels is located west of Point Conception (pl. 1; tracts 1, 2, 5, and 6) at depths of 35-55 m subbottom. A second group of buried channels trends west-northwest across the west-central part of the Santa Barbara Channel (pls. 1 and 2; tracts 14, 21, 22, 31, 32, and 33). These channels range in depth from 0 m, where modern canyons cut into the channel fill, to 75 m below the sea floor.

## Shallow Gas

Shallow gas zones are confined gas accumulations with possible abnormal pore pressures. Shallow gas may result from the decomposition of shallow-buried organic matter or may be gas from deeper reservoirs that has migrated and become trapped in near-surface reservoirs or sediments. Shallow gas zones are identified on the basis of amplitude anomalies or bright spots on relative-amplitude sections.

High-pressure gas zones can cause blowouts if not anticipated and penetrated during drilling operations. Shallow gas zones can contribute to the instability of a section by effectively lowering the shear strength of the sediment.

Shallow gas occurs within the Santa barbara Channel as rare, small (≤1 sq km), isolated pockets in the western end of the channel (pls. 1 and 2; area 1). The gas zones range in depth from 160 m to 205 m below the sea floor.

Three shallow gas zones are identified south and east of Anacapa Island in the Santa Monica Basin (pl. 6; area 7). One shallow gas zone, approximately 1 sq km in area, is located east of the island (pl. 6; tracts 112, 113, 119, and 120) at a depth of 220 m subbottom. The other shallow gas zones occur in association with a fault zone south of Anacapa Island (pl. 6; tracts 118, 119, 126, and and 127). The gas zones are 3.3 and 1.2 sq km in area and are at a depth of 100 m and 140 m subbottom, respectively. In the eastern part of the Santa Monica Basin, five small shallow gas zones are associated with faults (pl. 7; areas 11 and 12). The zones are each less than 1.4 sq km in area and range in depth from 85 to 186 m subbottom (pl. 7; tracts 128, 129, 137, 138, 146, and 151).

Shallow gas occurs on the San Pedro shelf as scattered pockets associated with faulting (pl. 8; tracts 159, 163, 180, and 181). The gas accumulations range in area from 0.2 to 1.6 sq km and range in depth from 15 m to 500 m below the sea floor. A shallow gas zone associated with an active fault zone at the base of the San Pedro Escarpment is approximately 1 sq km in area and 60-65 m below the sea floor (pl. 8; tract 163). Two small shallow gas accumulations are identified in the interchannel area between San Gabriel and Newport Canyons (pl. 9; tracts 175 and 182). Each gas pocket is less than 0.2 sq km in area, and they are at 350 m and 120 m depth below the sea floor.

Shallow gas zones on the southeast extension of Tanner Bank are sparse. The zones are less than 1.5 sq km in area at depths ranging from 160 m to 280 m subbottom (pl. 11; area 14).

## Gas-Charged Sediments

Gas-charged sediments are zones of unconsolidated to semiconsolidated sediments saturated with interstitial gas under normal to near normal pressures. The gases are normally dissolved in the pore water, but part may be in bubble phase, often under pressure (Esrig and Kirby, 1978; Whelan and others, 1978). Decay of biogenic material is the primary source of this gas.

Gas-charged sediment zones are considered hazardous because large contrasts in load-bearing capacity may exist within these zones or 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. Interstitial gas could contribute to spontaneous slope failure by effectively lowering the shear strength of the sediments. Gas-charged sediments are identified by acoustically turbid zones, opaque zones, phase changes, or wipe-out zones on seismic profiles. Such identification of gas-charged sediments is tentative, because definitive criteria for detection of gas-charged sediments on seismic profiles have not been established (Hampton and others, 1979).

Extensive gas-charged sediment zones occur along the shelf break at the northern edge of the Santa Barbara Channel (pls. 1 and 3; tracts 9, 10, and 13). Three shallow gas-charged sediment zones are located in and adjacent to the study area in the west end of Santa Barbara Channel (pl. 2; tracts 22, 32, and 33). These zones range in area from 3.7 to 25.0 sq km. One zone is associated with a pair of southwest-trending shallow faults. A gas-charged sediment zone occurs associated with faulting at the base of the Channel Islands Platform north of San Miguel Island (pl. 2; tracts 45 and 46). This zone is approximately 3.5 sq km in area.

A large zone of gas-charged sediment is identified in the central Santa Barbara Channel in Sale 68 tracts previously evaluated for Sale 48 (tracts 37, 38, 39, 47, and 52). This zone is approximately 103 sq km in extent; the north boundary underlies a slide deposit and is difficult to define. This zone was previously mapped as a zone of minor faulting (Richmond and others, 1981) but was identified as gas-charged sediments upon review of the data for the Sale 68 geohazards analysis. A smaller gas-charged sediment zone, 23.8 sq km in area, is south of and may be an extension of the larger zone (tracts 52 and 53).

Two extensive zones of gas-charged sediments occur associated with active faulting in the eastern Santa Barbara Channel (pls. 3 and 4; areas 4 and 8). A gas-charged sediment zone at least 36.5 sq km in extent is associated with the possible west end of the Pitas Point fault (pl. 3; tracts 62, 63, and 64). The zone extends 7.5 km west of the study area into a mass-transport deposit in the Sale 68 area previously evaluated for Sale 48 (Richmond and others, 1981; tracts 19, 30, and 61). The eastern extent of the zone lies outside of the surveyed area.

A gas-charged sediment zone, greater than 157 sq km in extent, is associated with the Oak Ridge fault in the eastern Santa Barbara Channel. The zone is confined to the south fault block at the west end of the mapped fault trace (pl. 4; tracts 79, 80, 81, and 82). The gas-charged sediments extend 7.6 km south of the fault in an area of little or no Holocene sediment cover (pl. 4; tracts 79-82, 92, 93, and 94). The zone is on both sides of the east extension of the fault and extends onto the mainland slope at the east end of the Channel (pl. 4; tracts 75, 85, and 96). The south and east boundaries of this gas-charged sediment zone are outside the area covered by available high-resolution geophysical data.

Isolated pockets of gas-charged sediments occur in the Santa Barbara Channel north of Santa Cruz Island (pls. 3 and 4; area 4). The pockets are commonly small ($\leq$3.2 sq km) in areal extent (pl. 3; tracts 69, 70, 76, 77, and 90). Two of these zones are associated with near-surface faults (tracts 77 and 90).

There are few gas-charged sediment zones identified in the study areas of the southern California continental borderland. East of Anacapa Island, gas-charged sediments occur on the shelf in the interchannel area between Hueneme and Mugu Canyons (pl. 6; tracts 102 and 103). Two small gas-charged sediment zones are identified in the south part of Santa Monica Basin (pl. 7; area 12). One of these zones, 3 sq km in extent, is associated with an active fault (pl. 7; tracts 147 and 152). The smaller zone is approximately 1 sq km in area.

Two gas-charged sediment zones are identified on the basin slope at the edge of San Pedro shelf. A small zone, less than 2.6 sq km, is located on the slope at the northwest edge of the shelf (pl. 8; tract 160). A larger zone of gas-charged sediments, at the southeast edge of the shelf, is at least 23 sq km in extent (pl. 9; tracts 174, 175, and 176).

## Hydrocarbon Seeps

Hydrocarbon seeps are natural phenomena that do not pose a geologic hazard but indicate weak zones that may be hazardous. Seeps occurring in association with rock outcrops, steeply-dipping beds, or faults are considered hazards. Near-surface structures may act as conduits from pressurized gas zones at depth and, if intersected during drilling, can act as escape routes for hydrocarbons. Oil and gas seeps emit intermittently. Seepage often increases in response to cyclic loading by waves, storm surges, earthquakes, or tsunamis (Bouma, 1981).

Water-column anomalies, or bubble trains in the water column, identified on high-resolution geophysical profiles indicate possible hydrocarbon seeps. Geochemical studies are necessary to document hydrocarbon seeps. The apparent alignment of water-column anomalies is artifical, inasmuch as they were identified only along survey lines. Continuous zones of water-column anomalies or anomalies identified on only one geophysical system may represent kelp or schools of fish.

Possible hydrocarbon seeps in the eastern Santa Barbara Channel are limited to shallow water areas (<350 m) with little or no sediment cover. Water-column anomalies are identified on the northwest end of the Channel Islands Platform (pl. 2; tracts 43, 44, 49, and 51) and on the shelf southwest of Point Conception (pl. 1; tract 9). Hydrocarbon seeps occur on the shelf in the northern channel west of Goleta Point (pl. 3; tracts 13 and 60). In the eastern Santa Barbara Channel, possible seeps are identified in areas with no Holocene sediment cover (pl. 4; tracts 80 and 93). Two seeps in the study area, and several seeps immediately north of the study area, are associated with the Oak Ridge fault in the central part of the east end of the channel (pl. 4; tract 82).

South of Santa Rosa Island, possible hydrocarbon seeps are sparse on the north end of the Santa Rosa-Cortes Ridge (pl. 5; areas 5 and 6). The seeps are confined to the ridge top in outcrop areas where there are no Holocene sediments. Most of the seeps are associated with mapped fault traces (pl. 5; tracts 57, 58, 59, and 153), although a few are not (pl. 5; tracts 57, 59, 130, and 149).

Very few hydrocarbon seeps are identified in the remaining southern California continental borderland study areas. Possible hydrocarbon seeps are rare on the southeast extension of Tanner Bank (pl. 11; tract 203 and 204). No water-column anomalies are identified in the San Pedro Basin study area. Richmond and others (1981) mapped hydrocarbon seeps along the northwest-trending Palos Verdes and Cabrillo fault zones (pl. 8; tracts 165, 166, 168, and 171). These seeps occur in areas of thin or no Holocene sediment cover.

### Unstable Fan Deposits

Submarine fans are associated with many of the submarine canyon systems in the Santa Barbara Channel and the southern California continental borderland. The canyons head nearshore and trap beach and nearshore sediment transported by longshore currents and funnel it into the coastal basins, forming submarine fans. The submarine fan deposits may be unstable and mobile and may constitute a hazard for bottom-founded structures and facilities. Unstable fan deposits are characterized by discontinuous reflectors indicating poorly developed bedding. Hummocky sea floor is also characteristic of fan deposits.

The submarine fan associated with Hueneme Canyon is located south and east of Anacapa Island (pl. 6; area 7). The fan deposits have poorly developed bedding and pinch out to the south and west. The thickness of the fan deposit cannot be determined from the high-resolution geophysical data. The sea floor is hummocky with 15 m maximum relief. Occasional transparent zones, or zones of no subbottom reflectors, are identified within the fan deposits. The character of these sediments is unknown. Coherent bedding, indicated by continuous reflectors, is everywhere apparent beneath the transparent zone sediments and often apparent above the zones.

The Mugu Submarine Fan (pl. 7; area 10), south of Point Mugu, is characterized by irregular, hummocky sea floor and discontinuous bedding. The fan onlaps the base of the slope to the north and northeast of the study area. Levees have formed along the banks of the channel system that crosses the surface of the fan.

## CONCLUSIONS

Geologic hazards were identified and evaluated for 221 tracts offshore southern California as a basis for recommendation of withdrawal or stipulation prior to the formal announcement of Federal Outer Continental Shelf Oil and Gas Lease Sale 68. High-resolution data were collected over 161 tracts in the sale area and previous geohazards evaluations were reviewed for the remaining tracts. The U.S. Geological Survey recommended that a stipulation for geologic hazards be applied to 83 tracts in which there is evidence of existing or potential sea-floor instability over a significant portion of the tract (table 1). High-resolution geophysical data taken within these tracts indicate areas of potential mass transport of sediment, steep slopes, steep-walled submarine canyons, and active faults. However, potential resources in these tracts can be developed from stable locations either within the tracts or in adjacent 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. In-depth engineering studies transcending usual site surveys may be required to evaluate potential geologic hazards and to provide input for engineering design. Table 1 lists all the tracts in Sale 68 and identifies the potential geologic hazards determined in this evaluation.

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Table 1.-- Tracts exhibiting potential geologic hazards

| Tract Number | Area | POTENTIAL GEOLOGIC HAZARDS | | | | | | | | | | Tracts Stipulated* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Active Faults | Faults | Mass Transport | Steep Slope (>10°) | Steep-walled Canyon | Buried Channel | Shallow Gas | Water-column Anomaly | Gas-charged Sediment | Unstable Fan Deposits | |
| 1 | 1 | | X | | | | X | | | X | | |
| 2 | 1 | | X | | | | X | | | | | |
| 3 | Sale 48 | | X | | | X | X | X | | | | |
| 4 | Sale 48 | | | | | | | X | | X | | |
| 5 | 1 | | X | X | | | X | | | | | |
| 6 | 1 | | X | X | | X | X | | | | | S |
| 7 | Sale 48 | | | X | | X | | X | | | | M |
| 8 | Sale 48 | | | X | | | | X | | | | M |
| 9 | 2 | | | X | | X | | | X | X | | M,S |
| 10 | 3 | | X | | | | | | | X | | |
| 11 | 1 | | X | X | | | | | | | | M |
| 12 | 1 | | | X | | X | | | | | | M |
| 13 | 4 | | | X | X | | | | X | X | | S |
| 14 | 1 | | | X | | | | | | | | M |
| 15 | Sale 48 | | X | X | | | X | X | | | | |
| 16 | Sale 48 | | | X | | | | | | | | |
| 17 | Sale 48 | | | | | | | | | X | | |
| 18 | Sale 48 | | | X | | | | | | X | | M |
| 19 | Sale 48 | | | X | | | | | | X | | M |

* Stipulations:
F--Active fault, M--Mass transport, S--Steep slope or steep-walled canyon

## Table 1.-- Tracts exhibiting potential geologic hazards

| Tract Number | Area | POTENTIAL GEOLOGIC HAZARDS | | | | | | | | | | Tracts Stipulated* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Active Faults | Faults | Mass Transport | Steep Slope (>10°) | Steep-walled Canyon | Buried Channel | Shallow Gas | Water-column Anomaly | Gas-charged Sediment | Unstable Fan Deposits | |
| 20 | 1 | | | | | | | | | | | |
| 21 | 1 | | X | X | | X | X | | | | | S |
| 22 | 1 | | X | X | | | X | | X | X | | |
| 23 | Sale 48 | | | | | | | | | | | |
| 24 | Sale 48 | | | | | | | | | | | |
| 25 | Sale 48 | | | X | | | | | | X | | M |
| 26 | Sale 48 | | | X | | | | | | | | M |
| 27 | Sale 48 | | X | X | | | | | | | | M |
| 28 | Sale 28 | | X | X | | | | | | | | M |
| 29 | Sale 48 | | | X | | | | | | | | M |
| 30 | Sale 48 | | | X | | | | | | | | M |
| 31 | 1 | | X | | | | X | | | | | |
| 32 | 1 | | X | | | | X | X | | X | | |
| 33 | 1 | | X | | | | X | | | X | | |
| 34 | Sale 48 | | X | X | X | | | X | | | | M |
| 35 | Sale 48 | | X | | X | | | X | X | | | M |
| 36 | 1 | | | X | | | | X | | | | M |
| 37 | Sale 48 | | | X | | | | | | X | | M |
| 38 | Sale 48 | | | X | | | | | | X | | M |

* Stipulations and withdrawals:
F--Active fault, M--Mass transport, S--Steep slope or steep-walled canyon

Table 1.-- Tracts exhibiting potential geologic hazards

| Tract number | Area | POTENTIAL GEOLOGIC HAZARDS | | | | | | | | | | Tracts Stipulated* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Active Faults | Faults | Mass Transport | Steep Slope (≥10°) | Steep-walled Canyon | Buried Channel | Shallow Gas | Water-column Anomaly | Gas-charged Sediment | Unstable Fan Deposits | |
| 39 | Sale 48 | | X | X | | | | | | X | | M |
| 40 | 1 | | X | | | | | | | | | |
| 41 | 1 | | X | | | | | | | | | |
| 42 | 1 | | X | | | | | | | | | |
| 43 | 1 | | X | | | | | | X | | | |
| 44 | 1 | | X | | X | | | | X | | | S |
| 45 | 1 | | X | | X | | | | | X | | S |
| 46 | 1 | | X | | | | | | | X | | |
| 47 | Sale 48 | | | X | | | | | | X | | |
| 48 | 1 | | X | | | | | | | | | |
| 49 | 1 | | X | | | | | | X | | | |
| 50 | 1 | | | | | | | | | | | |
| 51 | 1 | | X | | | | | | | | | |
| 52 | Sale 48 | | | X | | | | | | X | | M |
| 53 | Sale 48 | | | X | | | | | | X | | M |
| 54 | 1 | | X | | | | | | | | | |
| 55 | 1 | | X | | | | | | | | | |
| 56 | 5 | X | X | | X | | | | | | | S |
| 57 | 5 | | X | | | | | | X | | | |

* Stipulations:
F--Active fault, M--Mass transport, S--Steep slope or steep-walled canyon

Table 1.-- Tracts exhibiting potential geologic hazards

| Tract number | Area | POTENTIAL GEOLOGIC HAZARDS | | | | | | | | | | Tracts Stipulated* |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Active Faults | Faults | Mass Transport | Steep Slope (>10°) | Steep-walled Canyon | Buried Channel | Shallow Gas | Water-column Anomaly | Gas-charged Sediment | Unstable Fan Deposits | |
| 58 | 5 | | X | | | | | | X | | | |
| 59 | 6 | X | | | | | | | X | | | F |
| 60 | 4 | | | X | | | | | X | | | S |
| 61 | Sale 48 | | | X | | | | | | X | | M |
| 62 | 4 | | | X | | | | | | X | | M |
| 63 | 4 | | X | X | | | | | | X | | M |
| 64 | 4 | | X | | | | | | | X | | |
| 65 | Sale 48 | | X | | | | | | | | | F,M,S |
| 66 | Sale 48 | | X | | | | | | | | | F,M,S |
| 67 | Sale 48 | | X | | | | | | X | | | F,M,S |
| 68 | Sale 48 | X | X | | | | | | | | | F |
| 69 | 4 | | X | | | | | | | X | | |
| 70 | 4 | | X | | | | | X | | | | |
| 71 | 4 | | | | | | | | | | | |
| 72 | 4 | | | | | | | | | | | |
| 73 | Sale 48 | X | | | | | | | | X | | F |
| 74 | Sale 48 | | | | | | | | | X | | |
| 75 | 8 | | | | | | | | | X | | |
| 76 | 4 | | | | | | | | | X | | |

* Stipulations:
F--Active fault, M--Mass transport, S--Steep slope or steep-walled canyon

Table 1.-- Tracts exhibiting potential geologic hazards

| Tract number | Area | POTENTIAL GEOLOGIC HAZARDS | | | | | | | | | | Tracts Stipulated * |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Active Faults | Faults | Mass Transport | Steep Slope $(>10^{o})$ | Steep-walled Canyon | Buried Channel | Shallow Gas | Water-column Anomaly | Gas-charged Sediment | Unstable Fan Deposits | |
| 77 | 4 | | X | | | | | | | X | | |
| 78 | 4 | | | | | | | | | | | |
| 79 | 4 | | X | | | | | | | X | | |
| 80 | 4 | | X | | | | | | X | X | | |
| 81 | 4 | | | | | | | | | X | | |
| 82 | 4 | X | | | | | | | X | X | | F |
| 83 | Sale 48 | X | | | | | | | | X | | F |
| 84 | Sale 48 | X | | | | | | | | X | | F |
| 85 | 8 | X | | | | | | | | X | | F |
| 86 | 8 | X | | | | | | | | | | F |
| 87 | Sale 48 | | | | | | | | | | | |
| 88 | Sale 48 | | | | | | | | | | | |
| 89 | Sale 48 | | X | | | | | | | | | |
| 90 | 4 | | X | | | | | | | X | | |
| 91 | 4 | | | | | | | | | | | |
| 92 | 4 | | X | | | | | | | | | |
| 93 | 4 | | X | | | | | | X | X | | |
| 94 | 4 | | | | | | | | | X | | |
| 95 | 4 | | | | | | | | | X | | |

* Stipulations:
F--Active fault, M--Mass transport, S--Steep slope or steep-walled canyon

Table 1.-- Tracts exhibiting potential geologic hazards

| Tract number | Area | POTENTIAL GEOLOGIC HAZARDS | | | | | | | | | | Tracts Stipulated* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Active Faults | Faults | Mass Transport | Steep Slope $(>10^{\circ})$ | Steep-walled Canyon | Buried Channel | Shallow Gas | Water-column Anomaly | Gas-charged Sediment | Unstable Fan Deposits | |
| 96 | 9 | | | | | | | | | X | | |
| 97 | 9 | | | | | | | | | | | |
| 98 | 7 | | | | | X | | | | X | | |
| 99 | 7 | | X | | | | | | | | | F,M,S |
| 100 | 7 | | X | | | | | | | | | |
| 101 | 7 | | | X | | X | | | | | | M,S |
| 102 | 7 | | | X | | X | | | | X | | M,S |
| 103 | 7 | | | | | | | | | X | | |
| 104 | 7 | | | | | | | | | | | |
| 105 | 7 | | | X | | X | | | | | | S |
| 106 | 7 | | | X | | | | | | | | |
| 107 | 7 | | X | | | | | | | | | |
| 108 | 7 | | X | | | | | | | | | |
| 109 | 7 | | X | | | | | | | | | |
| 110 | 7 | | X | | | | | | | | | |
| 111 | 7 | X | X | | | | | | | | | |
| 112 | 7 | | | | | | | X | | | X | |
| 113 | 7 | | | | | | | X | | | X | |
| 114 | 7 | | X | | | | | | | | X | |

* Stipulations:
F--Active fault, M--Mass transport, S--Steep slope or steep-walled canyon

Table 1.-- Tracts exhibiting potential geologic hazards

| Tract number | Area | POTENTIAL GEOLOGIC HAZARDS | | | | | | | | | | Tracts Stipulated* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Active Faults | Faults | Mass Transport | Steep Slope ($>10^{\circ}$) | Steep-walled Canyon | Buried Channel | Shallow Gas | Water-column Anomaly | Gas-charged Sediment | Unstable Fan Deposits | |
| 115 | 7 | | X | | X | | | | | | | |
| 116 | 7 | | X | | | | | | | | | |
| 117 | 7 | | X | | | | | | | | | |
| 118 | 7 | | X | | | | | X | | | X | |
| 119 | 7 | | | | | | | X | | | X | |
| 120 | 7 | | | | | | | X | | | X | |
| 121 | 7 | | | | | | | | | | X | |
| 122 | 10 | | | | | | | | | | X | |
| 123 | 10 | X | | | | | | | | | X | F |
| 124 | 5 | | | | X | | | | | | | |
| 125 | 7 | | X | | X | | | | | | X | |
| 126 | 7 | | X | | | | | X | | | X | |
| 127 | 7 | | X | | | | | X | | | X | |
| 128 | 11 | | X | X | | | | X | | | | M |
| 129 | 11 | | X | X | | | | X | | | | M |
| 130 | 5 | | X | | | | | | X | | | |
| 131 | 5 | | X | | | | | | | | | |
| 132 | 5 | | X | | | | | | | | | |
| 133 | 7 | | X | | X | | | | | | X | S |

* Stipulations:
F--Active fault, M--Mass transport, S--Steep slope or steep-walled canyon

Table 1.-- Tracts exhibiting potential geologic hazards

| Tract number | Area | POTENTIAL GEOLOGIC HAZARDS | | | | | | | | | | Tracts Stipulated* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Active Faults | Faults | Mass Transport | Steep Slope ($>10^{\circ}$) | Steep-walled Canyon | Buried Channel | Shallow Gas | Water-column Anomaly | Gas-charged Sediment | Unstable Fan Deposits | |
| 134 | 7 | | X | | | | | | | | X | |
| 135 | 7 | | | | | | | | | | X | |
| 136 | 11 | | X | X | | | | | | | | |
| 137 | 11 | | X | X | | | | X | | | | M |
| 138 | 11 | | X | | | | | X | | | | |
| 139 | 5 | | X | | | | | | | | | |
| 140 | 5 | | X | | | | | | | | | |
| 141 | 5 | | X | | | | | | | | | |
| 142 | 7 | | X | | X | | | | | | | S |
| 143 | 7 | | X | | X | | | | | | X | |
| 144 | 7 | | | | | | | | | | X | |
| 145 | 11 | | | | | | | | | | | |
| 146 | 11 | | X | | | | | X | | | | |
| 147 | 12 | X | X | | | | | | | X | | F |
| 148 | 5 | | X | | | | | | X | | | |
| 149 | 5 | | X | | | | | | X | | | |
| 150 | 5 | | X | | | | | | | | | |
| 151 | 12 | X | X | | | | | X | | | | |
| 152 | 12 | X | X | | | | | | | X | | |

* Stipulations:
F--Active fault, M--Mass transport, S--Steep slope or steep-walled canyon

Table 1.-- Tracts exhibiting potential geologic hazards

| Tract number | Area | POTENTIAL GEOLOGIC HAZARDS | | | | | | | | | | Tracts Stipulated* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Active Faults | Faults | Mass Transport | Steep Slope (>10°) | Steep-walled Canyon | Buried Channel | Shallow Gas | Water-column Anomaly | Gas-charged Sediment | Unstable Fan Deposits | |
| 153 | 5 | | X | | | | | | X | | | |
| 154 | 5 | | X | | | | | | | | | |
| 155 | 5 | | X | | | | | | | | | |
| 156 | 5 | | X | | | | | | | | | |
| 157 | 5 | | X | | | | | | | | | |
| 158 | 5 | | X | | | | | | | | | |
| 159 | 15 | | X | X | | | | X | | | | M |
| 160 | 15 | X | X | X | | | | | | X | | F,M |
| 161 | 15 | | X | | | | | | | | | |
| 162 | 15 | | X | X | | | | | | | | M |
| 163 | 15 | X | X | X | | | | X | | | | F,M |
| 164 | 16 | | X | | | | | | | | | |
| 165 | Sale 48 | | X | | | | | | X | | | |
| 166 | 16 | | X | | | | | | | | | |
| 167 | Sale 48 | | X | | | | | | | | | |
| 168 | Sale 48 | X | X | X | | X | | X | X | X | | F,M |
| 169 | Sale 48 | | X | | | | | | | | | |
| 170 | Sale 48 | X | X | X | X | | | X | | | | F,M,S |
| 171 | Sale 48 | X | X | X | | | | X | X | | | F |

* Stipulations:
F--Active fault, M--Mass transport, S--Steep slope or steep-walled canyon

## Table 1.-- Tracts exhibiting potential geologic hazards

| Tract number | Area | POTENTIAL GEOLOGIC HAZARDS | | | | | | | | | | Tracts Stipulated* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Active Faults | Faults | Mass Transport | Steep Slope ($>10^{\circ}$) | Steep-walled Canyon | Buried Channel | Shallow Gas | Water-column Anomaly | Gas-charged Sediment | Unstable Fan Deposits | |
| 172 | Sale 48 | | X | X | X | | | X | | | | M |
| 173 | Sale 48 | X | X | | | | | | | | | F |
| 174 | 17 | | | X | | | | | | X | | M |
| 175 | 17 | | | X | | X | | X | | X | | M |
| 176 | Sale 48 | | X | X | | X | | | | X | | S |
| 177 | 17 | | X | X | | | | | | | | M |
| 178 | 17 | | X | X | | | | | | | | M |
| 179 | 15 | | X | | | | | | | | | |
| 180 | 15 | | X | | X | | | X | | | | |
| 181 | 15 | X | X | | X | | | X | | | | |
| 182 | 17 | | X | X | | | | X | | | | M |
| 183 | 17 | | X | X | | X | | | | | | M,S |
| 184 | Sale 48 | | | X | | | | | | | | M |
| 185 | 17 | | | X | | | | | | | | |
| 186 | 15 | | X | X | | | | X | | | | |
| 187 | 17 | | X | | | X | | | | | | F |
| 188 | 17 | | | | | | | | | | | F |
| 189 | 13 | | X | | X | | | | | | | S |
| 190 | 13 | | X | | X | | | | | | | S |

* Stipulations:
F--Active fault, M--Mass transport, S--Steep slope or steep-walled canyon

Table 1.-- Tracts exhibiting potential geologic hazards

| Tract number | Area | POTENTIAL GEOLOGIC HAZARDS | | | | | | | | | | Tracts Stipulated* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Active Faults | Faults | Mass Transport | Steep Slope ($>10^\circ$) | Steep-walled Canyon | Buried Channel | Shallow Gas | Water-column Anomaly | Gas-charged Sediment | Unstable Fan Deposits | |
| 191 | 13 | | | | | | | | | | | |
| 192 | 13 | | X | | X | | | | | | | S |
| 193 | 13 | | X | | X | | | | | | | S |
| 194 | 13 | | X | | | | | | | | | |
| 195 | Sale 48 | | X | | X | | | | | | | |
| 196 | Sale 48 | | X | | | | | | | | | |
| 197 | Sale 48 | | X | | | | | | | | | |
| 198 | Sale 48 | | | | X | | | | | | | |
| 199 | Sale 48 | X | X | | | | | | X | | | F |
| 200 | Sale 48 | | X | | | | | | X | | | |
| 201 | Sale 48 | | X | | | | | | X | | | |
| 202 | Sale 48 | | X | X | | | | X | | | | |
| 203 | Sale 48 | | X | X | | | | | | | | |
| 204 | 14 | | X | | | | | | X | | | |
| 205 | Sale 48 | | X | X | X | | | | | | | M |
| 206 | Sale 48 | | X | | | | | X | X | | | |
| 207 | 14 | | X | | | | | X | | | | |
| 208 | Sale 48 | | X | X | X | | | | | | | M,S |
| 209 | Sale 48 | | X | | X | | | X | | | | S |

* Stipulations:
F--Active fault, M--Mass transport, S--Steep slope or steep-walled canyon

Table 1.-- Tracts exhibiting potential geologic hazards

| Tract number | Area | POTENTIAL GEOLOGIC HAZARDS | | | | | | | | | | Tracts Stipulated* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Active Faults | Faults | Mass Transport | Steep Slope (>10°) | Steep-walled Canyon | Buried Channel | Shallow Gas | Water-column Anomaly | Gas-charged Sediment | Unstable Fan Deposits | |
| 210 | 14 | | X | | | | | | | | | |
| 211 | 14 | | X | | | | | | | | | |
| 212 | 14 | | X | | | | | | | | | |
| 213 | 14 | | X | | | | | X | | | | |
| 214 | 14 | | X | | | | | | | | | |
| 215 | 14 | | X | | | | | | | | | |
| 216 | 14 | | | | | | | | | | | |
| 217 | 14 | | X | | | | | | | | | |
| 218 | 14 | | X | | | | | | | | | |
| 219 | 14 | | X | | | | | | | | | |
| 220 | 14 | | X | | X | | | | | | | S |
| 221 | 14 | | X | | X | | | | | | | S |

* Stipulations:
F--Active fault, M--Mass transport, S--Steep slope or steep-walled canyon

Table 2.--Corresponding Tract Numbers for OCS Lease Sales 68 and 48

| Sale 68 Tract Number | Sale 48 Tract Number | Sale 68 Tract Number | Sale 48 Tract Number |
|---|---|---|---|
| 3 | 1 | 74 | 65[w] |
| 4 | 2 | 83[s] | 75 |
| 7[s] | 7[s] | 84[s] | 76 |
| 8[s] | 8[s] | 87 | 84 |
| 9[s] | 12[w] | 88 | 85 |
| 12[s] | 13[w] | 89 | 86 |
| 13[s] | 19[s] | 165 | 121[w] |
| 15 | 21 | 167 | 122[w] |
| 16 | 22 | 168[s] | 123 |
| 17 | 24 | 169 | 124 |
| 18[s] | 27 | 170[s] | 125[s] |
| 19[s] | 23 | 171[s] | 126 |
| 23 | 35 | 172[s] | 127[s] |
| 24 | 36 | 173[s] | 128 |
| 25[s] | 38 | 174[s] | 129[w] |
| 26[s] | 39 | 175[s] | 130[w] |
| 27[s] | 40 | 176[s] | 131[s] |
| 28[s] | 41 | 180 | 132[w] |
| 29[s] | 42 | 181 | 133[w] |
| 30[s] | 43 | 182[s] | 135[w] |
| 33 | 48[w] | 183[s] | 136[w] |
| 34[s] | 50[s] | 184[s] | 137 |
| 35[s] | 51 | 195 | 167 |
| 36[s] | 54[w] | 196 | 168 |
| 37 | 55 | 197 | 169 |
| 38 | 57 | 198 | 171 |
| 39[s] | 58 | 199[s] | 174[s] |
| 47 | 70 | 200 | 175 |
| 52[s] | 82 | 201 | 176 |
| 53[s] | 83 | 202 | 184 |
| 60[s] | 20[w] | 203 | 185 |
| 61[s] | 29 | 205[s] | 188 |
| 62[s] | 30 | 206 | 189 |
| 63[s] | 45 | 208[s] | 193 |
| 68[s] | 47[w] | 209[s] | 194 |
| 73[s] | 64[w] | | |

s--stipulation(s) applied w--withdrawn from sale