UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

# Geologic Framework, Petroleum Potential, Petroleum Resource Estimates, Environmental Hazards, and Deep-water Drilling Technology of the Maritime Boundary Region, Offshore Southern California Borderland

Edited

By

Richard B. Powers

Open-File Report 81-264



1981

Contents

Page

Summary.............................................................. 1

Introduction, by Richard B. Powers.................................... 5

Geologic framework, by John G. Vedder................................. 7

Petroleum resource potential, by Edward W. Scott, John G. Vedder,
and David Griggs...................................................... 25

Estimates of undiscovered in-place petroleum resources, by
Richard B. Powers, and Edward W. Scott................................ 39

Other mineral resources, by John G. Vedder............................ 50

Environmental and bottom hazards, by John G. Vedder................... 54

Technological feasibility of deep-water drilling and
production, by Kent Stauffer, Maurice Adams, Richard Habrat,
and Dan Bourgeois..................................................... 61

References............................................................ 89

Illustrations

Figure 1. Map of offshore Southern California Borderland showing area
of study and assessed areas........................................... 2

2. Map showing regional physiographic provinces....................... 8

3. Map of California Continental Borderland showing boundaries of
geological terranes I to IV........................................... 9

Page

4. Map showing available data within study area and locations of drill sites outside the area.................. 10
5. Map showing ship tracklines north of lat $32^{o}$ N............... 11
6. Map showing dredge sites and ship tracklines along which bedrock cores were taken north of lat $32^{o}$ N................ 12
7. Map of structural trends in the borderland south of lat $32^{o}45'$ N........................................... 14
8. Generalized stratigraphic columns for geologic terranes I through IV............................................ 16
9. Schematic cross section of terranes I through IV............. 17
10. Map showing relation of study area to terranes I through IV... 19
11. Map of faults in nearshore borderland........................ 23
12. Stratigraphic columns, Santa Barbara Channel region.......... 28
13. Stratigraphic columns, outer basins and banks................ 30
14. Stratigraphic columns, inner basins and banks................ 31
15. Isopach map of post-Eocene sediments......................... 35
16. Petroleum resource classification diagram.................... 43
17. Probability distribution curves, Areas 1 and 2a.............. 48
18. Aggregated probability distribution curves, total study area.. 49
19. Map showing locations of known and inferred faults in the coastal zone and borderland of southern California... 55
20. Map showing earthquake epicenters offshore southern California and northern Baja California, Mexico............ 57
21. Diagram of dynamically positioned drill ship................. 63

Illustrations (continued)

22. Diagram of fixed drilling platform.......................... 65

23. Diagram of guyed-tower drilling platform..................... 67

24. Diagram of tension-leg drilling platform..................... 68

25. Diagram of semisubmersible production system................. 70

26. Diagram of subsea atmospheric production system (SAS)........ 71

27. Diagram of subsea production system (SPS).................... 73

28. Diagram of one-atmosphere chamber production system.......... 74

29. Diagram of conventional pipeline lay-barge and stinger system

30. Diagram of inclined-ramp pipeline lay-method................. 76

31. Diagram of reel-barge pipeline lay-method.................... 78

32. Diagram of bottom-tow pipeline lay-method.................... 80

33. Diagram of rigid or moored single-point moorings (SPM)....... 82

34. Diagrams of manned subsea maintenance systems................ 84

35. Graph showing projection of platform installation capability.. 86

36. Graph showing projection of floating and subsea drilling facilities.................................................. 87

37. Graph showing projection pf pipeline-laying capability....... 88

Table

Table 1.--Estimates of undiscovered in-place oil and gas resources, Southern California Borderland............................. 40

## SUMMARY


This report details the findings of a study by the U.S. Geological Survey on the oil and gas potential of a designated assessment area in the offshore Southern California Borderland (fig. 1). Only limited information is publicly available to gain an understanding of the oil and gas resource potential of this region. The principal conclusions from the analysis of these data are:

1. Favorable geological conditions exist for the occurrence of crude oil and natural gas resources in an areally small part of the designated study area;
2. Estimates of undiscovered in-place resources range from 0 to 1.78 billion barrels of oil (BBO) and from 0 to 2.86 trillion cubic feet (TCF) of gas;
3. Exploration and exploitation of these deep-water estimated resources are expected to become feasible in the future.

The study area is divided into two numbered geometrical units for assessment purposes (fig. 1). Area 1 is nearer to the mainland; Area 2, farther from shore, has been divided into two parts on the basis of geology and bathymetry. Area 2a is within the California Continental Borderland, and Area 2b is seaward of the 8,200-ft (2,500-m) isobath in the Baja California Seamount Province. The total study area covers approximately 7,500 mi$^2$ (19,425 km$^2$) and contains an estimated total sediment volume of 2,347 mi$^3$ (9,785 km$^3$). Water depths range from a minimum of 295 ft (90 m) at Sixtymile Bank to a maximum of more than 12,000 ft (3,660 m) in the Baja California Seamount Province.

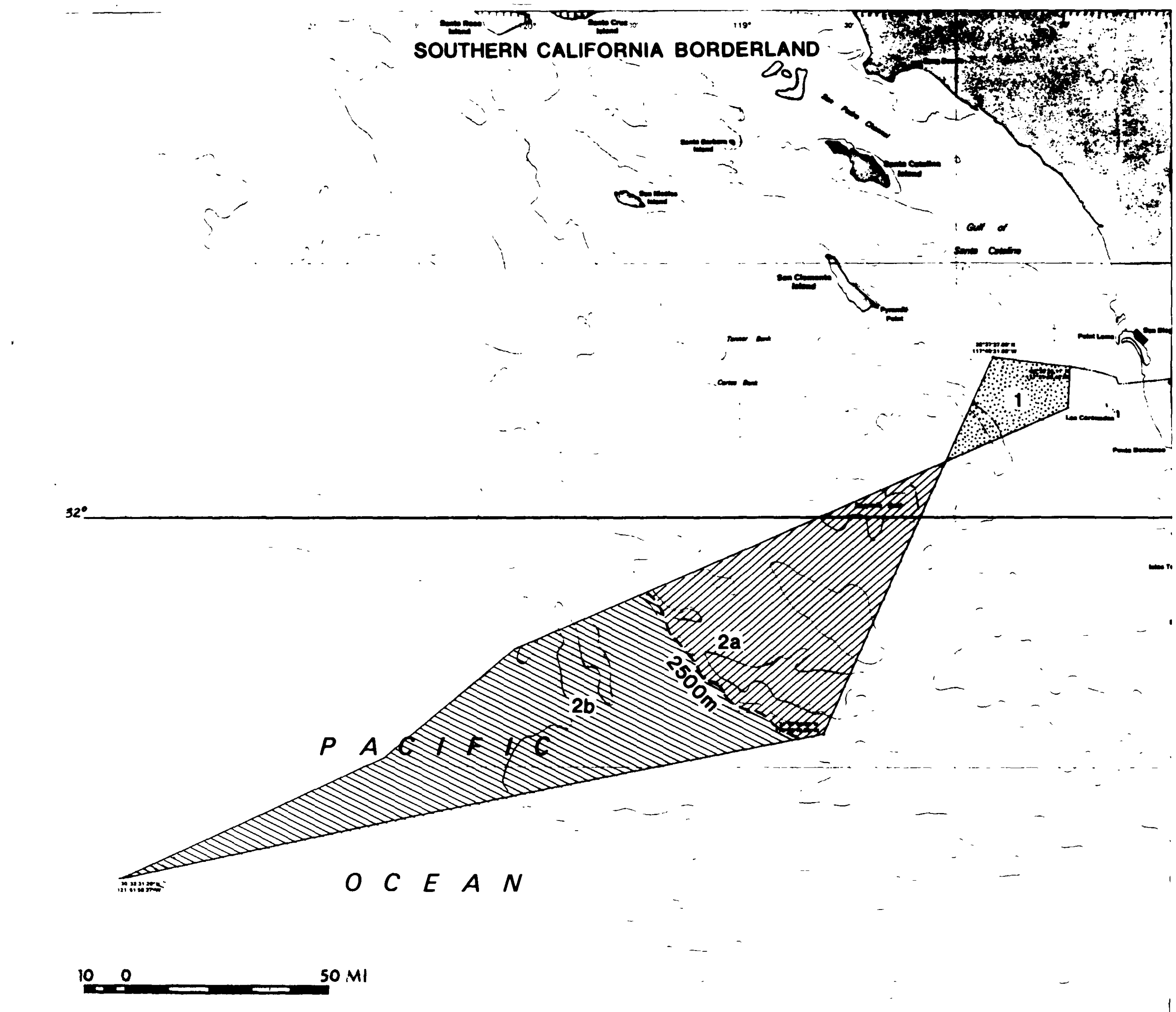



Figure 1.--Map of offshore Southern California Borderland showing area of study and areas assessed.

The study focused on factors critical to the generation, migration, and entrapment of hydrocarbons, such as: structural and stratigraphic traps, source beds and thermal maturation, reservoir rocks and seals, and timing of hydrocarbon migration relative to formation of traps.

Petroleum potential of the three assessment areas in the Southern California Borderland was analyzed by using all publicly available geophysical data recorded in the study area, supplemented by a very limited amount of geological data obtained from drilling adjacent to the area of study. Geophysical data on the study area were limited to 230 miles (370 km) of multichannel seismic-reflection profiles and 364 miles (586 km) of single-channel profiles. Geological information was limited to three sea-floor dredge samples within the study area and one stratigraphic test well, which is 38 mi (62 km) northwest of the study area. Much of the understanding of the geology and petroleum potential of the study area was gained by analogy and extrapolation of abundant geophysical and drilling data from the north (north of lat 32° N.) into the study area, rather than from direct evidence.

Evaluation of the petroleum potential and estimates of resources are related only to undiscovered in-place crude oil and natural gas, not to recoverable amounts. We do not speculate on what part of the estimated in-place resources in the assessment areas might be ultimately recoverable because not enough is known at present about petroleum-reservoir properties, economics, and the technology needed to develop these deep-water areas.

Environmental hazards that may affect drilling, production, and pipeline transportation include faults, seismicity, sediment instability, sediment erosion, and hydrocarbon seeps north of lat 32° N. Although no studies have been done south of lat 32° N. within the study area, potential problems presumably are analogous to those identified farther north. Numerous earthquake epicenters and sea-floor offsets along some of the major fault zones indicate continuing crustal activity, and many other faults that continue upward to the sea floor must be considered environmentally hazardous, as they cut beds of Holocene age. The probability of environmental hazards risk in the assessed areas, however, cannot be predicted at this time.

Exploration and production technology is not presently available to exploit any of the estimated petroleum resources in deep water in the greater part of the Southern California Borderland study area. We expect that by the year 2000, the methods and equipment required for drilling and producing in water as deep as 10,000 ft (3,048 m) will be available.

# INTRODUCTION

By

Richard B. Powers

During the past 30 or more years, drilling and production of oil and gas in offshore regions of the United States have progressed from very shallow waters to deeper water on the Outer Continental Shelf (OCS), which extends from the shore to water 656 ft (0 to 200 m) deep. Fields are now being developed in water depths exceeding 1,000 ft (305 m), beyond the shelf edge. Considerable interest and attention have been focused recently on the petroleum potential of regions at even greater water depths, where future supplies of petroleum may exist.

In response to the need for information regarding the petroleum potential of deep-water regions, the U.S. Geological Survey initiated a comprehensive study within a designated area of the Southern California Borderland (fig. 1), where very little exploration has been done, for the express purpose of defining the existing geology and assessing the undiscovered in-place resources of this deep-water area.

## Scope of the Study

This report, as its title implies, concerns mainly the petroleum potential and the geology related to its determination in three assessment areas within a part of the Southern California Borderland. The term "petroleum potential" includes the evaluation and assessment of conventional, undiscovered in-place oil and gas resources. The main objective of the work was to bring together as much publicly available information as possible that would bear on evaluation and assessment of petroleum resources. Not much information existed on this little-explored region, but by extrapolation and analogy from well-explored basins north of the study area, a good understanding of the geology of the area was achieved.

## Topical Discussions

Important main topics in the report that apply directly to oil and gas resource assessments include detailed discussions of the geologic framework and petroleum potential of the assessed areas. A comprehensive review and an analysis of the factors identified in these discussions as being significant to petroleum generation, migration, and entrapment were used in estimating volumes of undiscovered in-place resources in each of the three assessment areas. No estimates of hydrocarbon resources in this part of the deep-water area of the Southern California Borderland are known to have been published prior to this present study.

Included within the broad scope of this report are topical discussions of other, non-energy mineral resources and a detailed evaluation of environmental and sea-bottom hazards, which may affect future exploration in this deep-water region. The final topic of discussion reviews the technology presently available for offshore exploration and the technology that may be feasible for deeper water drilling and production in the future.

We wish to acknowledge the following members of the U.S. Geological Survey for their assistance in assessing the petroleum potential of the Southern California Borderland assessments: Anny Coury, Abdul Khan, and Robert Pike. Our special thanks go to Gordon Dolton and Mahlon Ball for their substantial contribution in many areas of the study, and for their thoughtful and constructive review of the manuscript.

GEOLOGIC FRAMEWORK

By

John G. Vedder

## Introduction

Assessment Areas 1 and 2 lie athwart parts of two regional physiographic provinces and three geologic terranes (figs. 2 and 3). The geologic histories and resource potentials of these provinces and terranes are different and large segments of the designated study area are characterized by geologic relations and factors affecting resources that are complex and poorly understood. Consequently, description of the regional geologic framework is treated area by area in sequence from the deep ocean to the nearshore. Because available information on the area south of lat 32° N. (fig. 4) is scant in contrast to the abundance of geophysical and core data on the region to the north (figs. 4, 5, 6), many of the correlations are made by analogy rather than by direct evidence.

The two provinces crossed by Assessment Areas 1 and 2 are the Baja California Seamount Province, which is part of the Pacific Ocean Basin, and the California Continental Borderland, which is part of the North American Continent. Abyssal depths, numerous volcanic seamounts, and thin veneers of sediment characterize the Baja California Seamount Province. South of lat 31° N., a series of narrow troughs interrupts a smooth apron of sediment along the base of the Continental Slope (Menard, 1955; Moore, 1969). The California Continental Borderland (Shepard and Emery, 1941) is an elongate, high-relief segment of the continental terrace that stretches nearly 620 mi (1,000 km) southeastward from Point Conception to Bahia Sebastian Vizcaino and that extends 62-170 mi (100-275 km) seaward from the mainland coast. The borderland includes 19 major topographic basins that are 20-35 mi

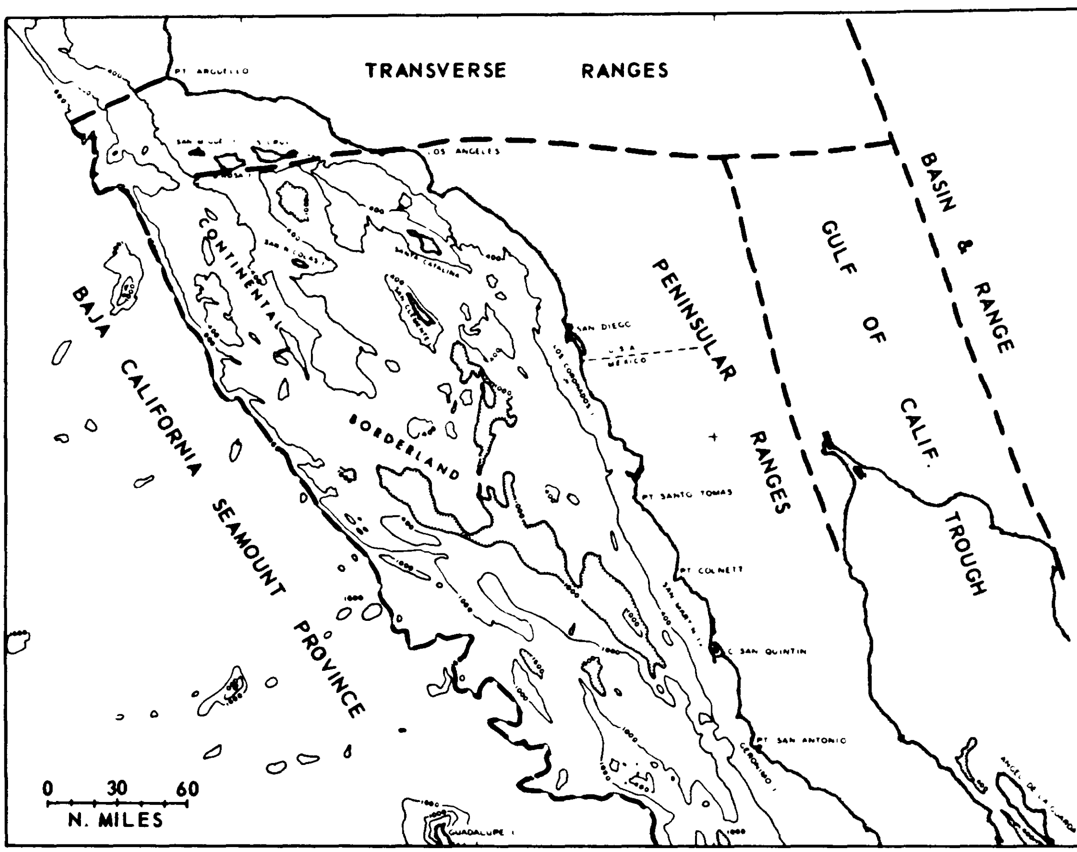



Figure 2.--Regional physiographic provinces (from Moore, 1969).

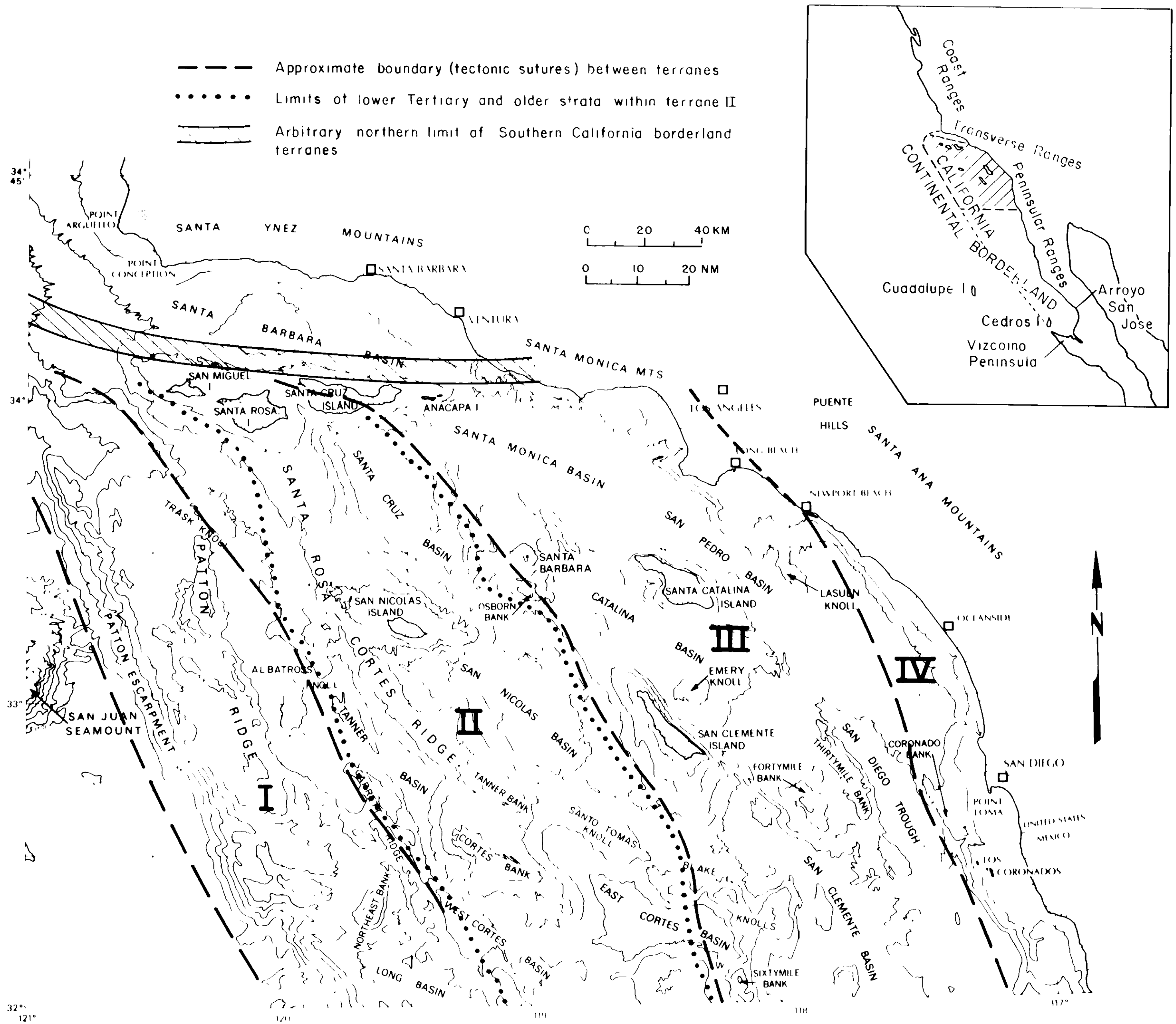



Figure 3.--Map of the northern part of the California Continental Borderland showing generalized boundaries between geologic terranes I-IV. (from Howell and Vedder, 1981). Depths in meters.

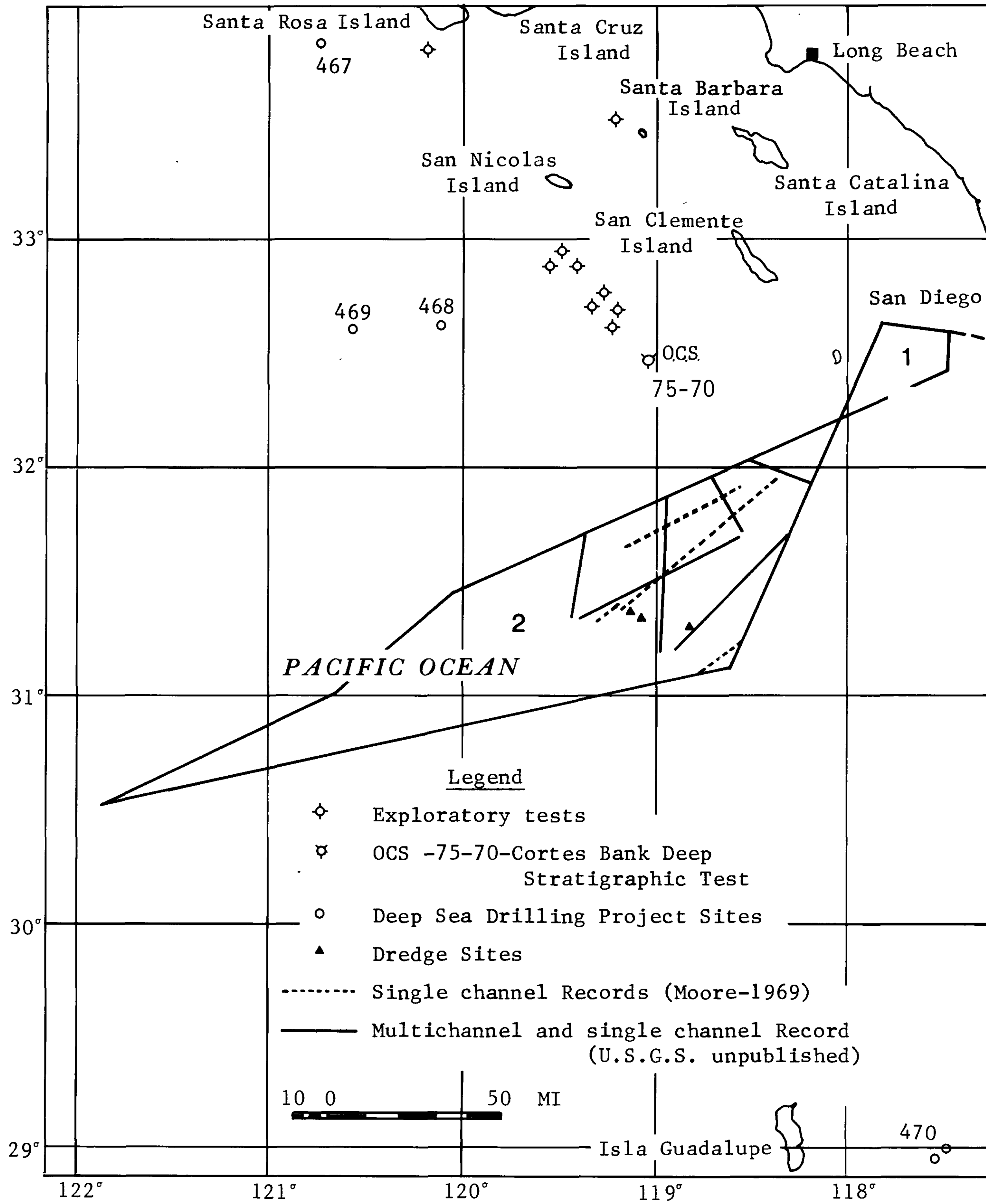



Figure 4.--Available seismic-reflection profiles and dredge sites in Assessment Area 2 and drill sites on the outer borderland. U.S.G.S.

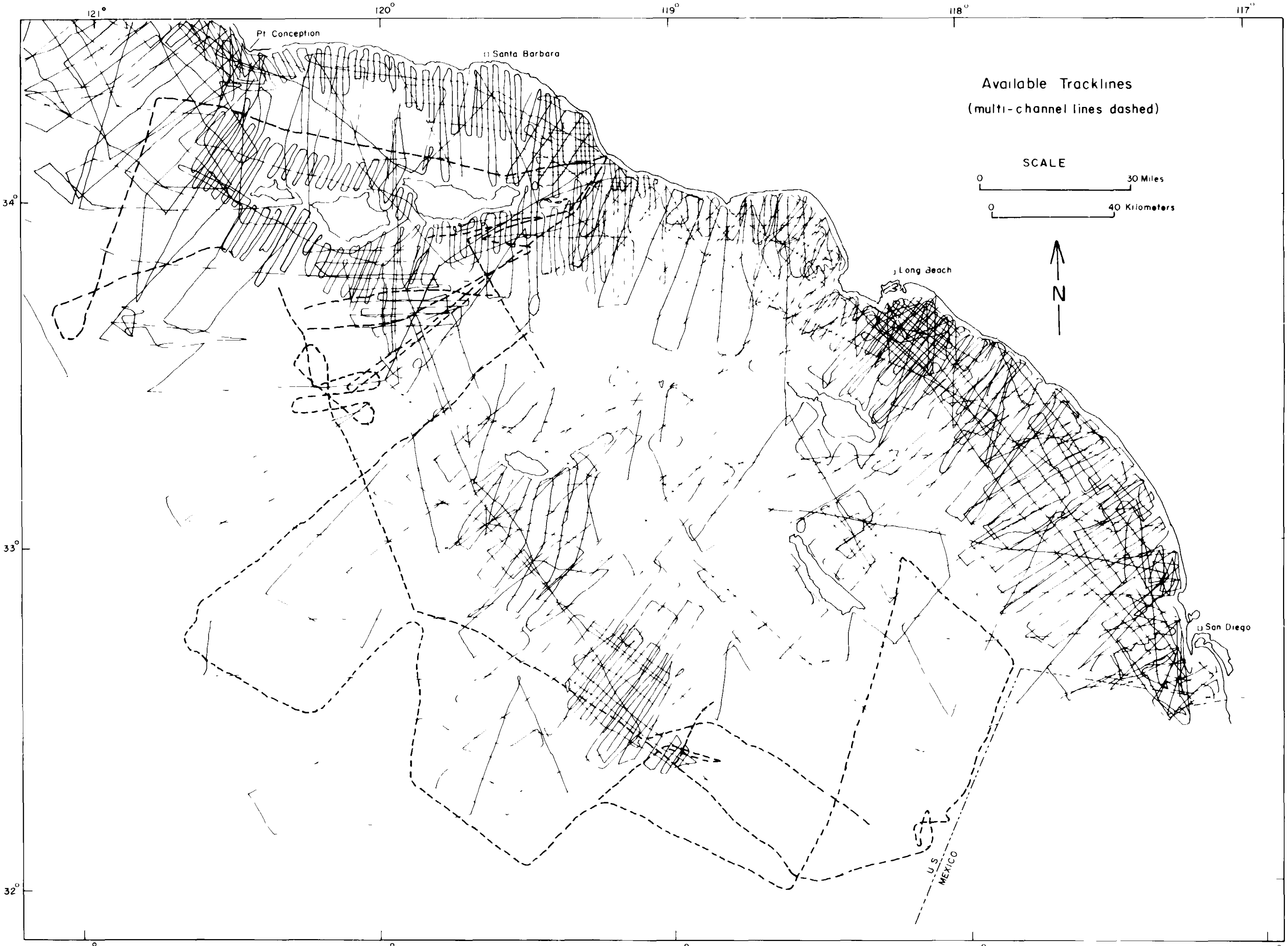



Figure 5.--Ship tracklines north of lat. 32° N. along which nonproprietary geophysical data have been acquired by the U.S. Geological Survey.

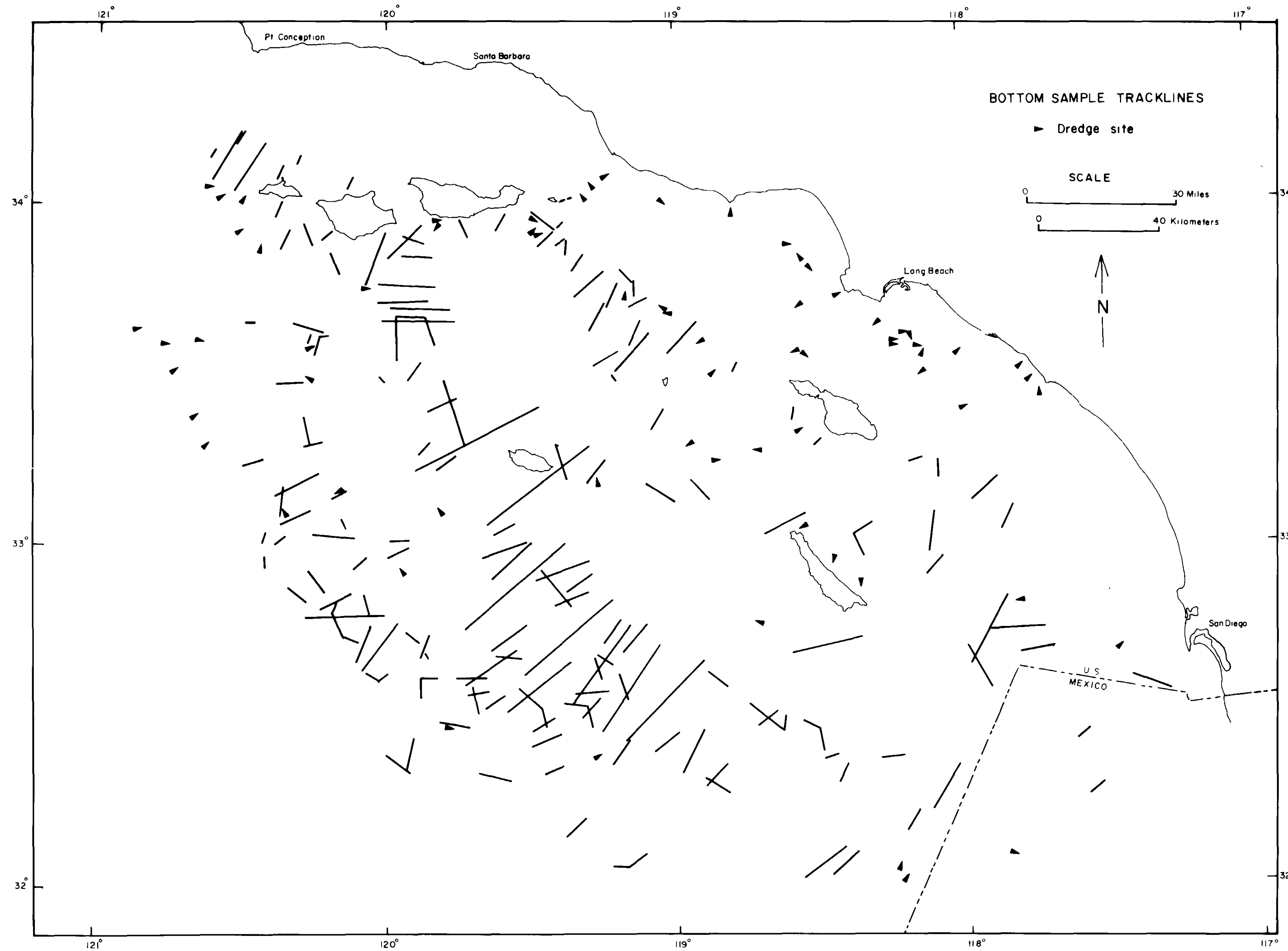



Figure 6.--Dredge sites and ship tracklines along which nonproprietary bedrock cores were taken north of lat. 32° N.

(35-60 km) long and 6-25 mi (10-40 km) wide and that have depths of 1,300 ft (400 m) to more than 6,500 ft (2,000 m). At places, the relief is comparable to that along the east face of the Sierra Nevada. South of lat 31° N., the borderland is about half as wide as it is to the north, and the regularly spaced, northwest-trending basins and ridges converge southeastward to form a large composite basin north of Isla Cedros.

According to the concept of plate tectonics, the geologic history of the California Continental Borderland and adjoining provinces has been governed largely by the interactions of crustal plates. The western margin of California and Baja California apparently has been a zone of subduction, oblique subduction, and transform tectonic activity throughout most of the late Mesozoic and early Cenozoic eras (ca. 150 to ca. 30 m.y. ago) (Howell and others, 1980), and the effects of these motions are largely responsible for the formation of the contrasting geologic terranes on the borderland. After the latest episode of subduction, which ended about 29 m.y. ago, an increasingly large part of the margin was subjected to dextral translational shear, and a profound change from convergence to transform motion began (Atwater and Molnar, 1973). It is noteworthy that more than 90 percent of the known petroleum accumulations west of the San Andreas fault are in areally restricted basins that probably formed in response to this major tectonic reorganization (Blake and others, 1978).

## Geologic Terranes

North of the Santo Tomas fault (Krause, 1965), a major feature that separates the northern and southern parts of the borderland (fig. 7), four broad belts of contrasting rock sequences trend northwest nearly parallel to the mainland coast (fig. 3). The seawardmost belt is bordered on the west by

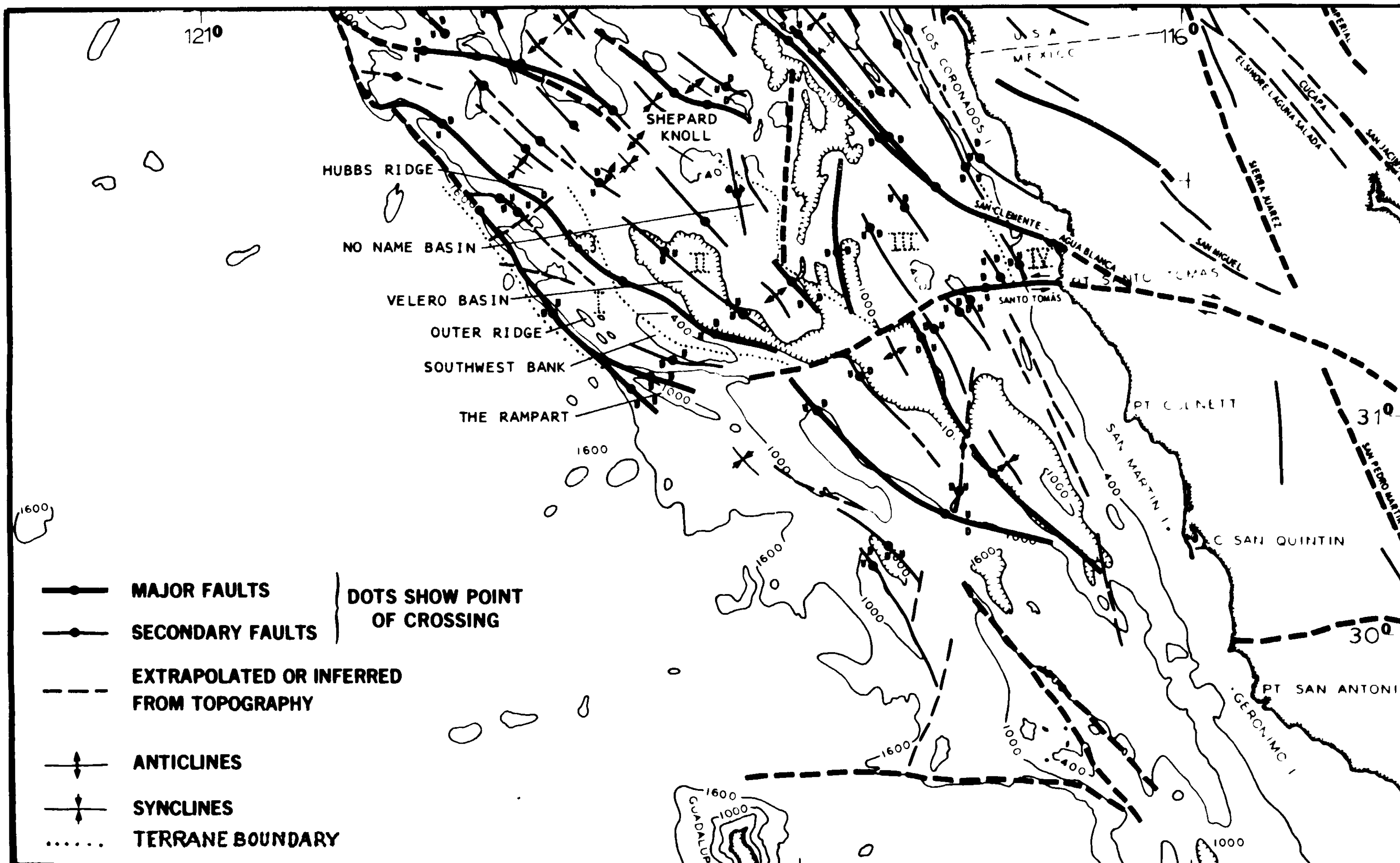



Figure 7.--Structural trends on the borderland south of lat. 32°45′ N. Approximate terrane boundaries are shown between lat. 32° N. and the Santo Tomas Fault. Map modified from Moore (1969).

the base of the Continental Slope; the others are separated from one another by major fault zones or regional stratigraphic discontinuities that presumably reflect deep-seated crustal dislocations. Because each is composed of a distinctive succession of rocks, these belts are termed geologic terranes and are informally designated by numerals I through IV (figs. 3, 8, 9). Assessment Areas 1 and 2 transect three of the four terranes, and the western part of Area 2 extends into the Baja California Seamount Province of the Pacific Ocean Basin.

Pacific Ocean Basin.--Approximately two-thirds of Area 2 is within the oceanic basin of the Pacific and is included in the Baja California Seamount Province. According to Menard (1955), widespread recent volcanism and a thin sediment cover characterize the province. Moore (1969) stated that most of the abyssal sea floor is devoid of sediment cover, and Plawman (1978) showed less than 655 ft (200 m) of Cenozoic section on the seaward end of his crustal model. An experimental corehole drilled east of Isla Cedros penetrated only 558 ft (170 m) of Miocene to Holocene sediments before reaching basalt (Riedel and others, 1961). Deep Sea Drilling Project (DSDP) Hole 470, which was close to the experimental corehole (fig. 4), bottomed in basalt after passing through 535 ft (163 m) of Miocene and younger sediments. Farther north, about 185 mi (300 km) west of San Diego and 14 mi (22 km) west of the foot of Patton Escarpment, DSDP Hole 469 drilled through 1,300 ft (396 m) of Miocene and younger section before reaching basalt (Initial Core Descriptions, Leg 63, 1979). Seismic-reflection profiles that cross the inner edge of the oceanic basin indicate that sediment thicknesses range from 0 to about 1,300 ft (400 m).

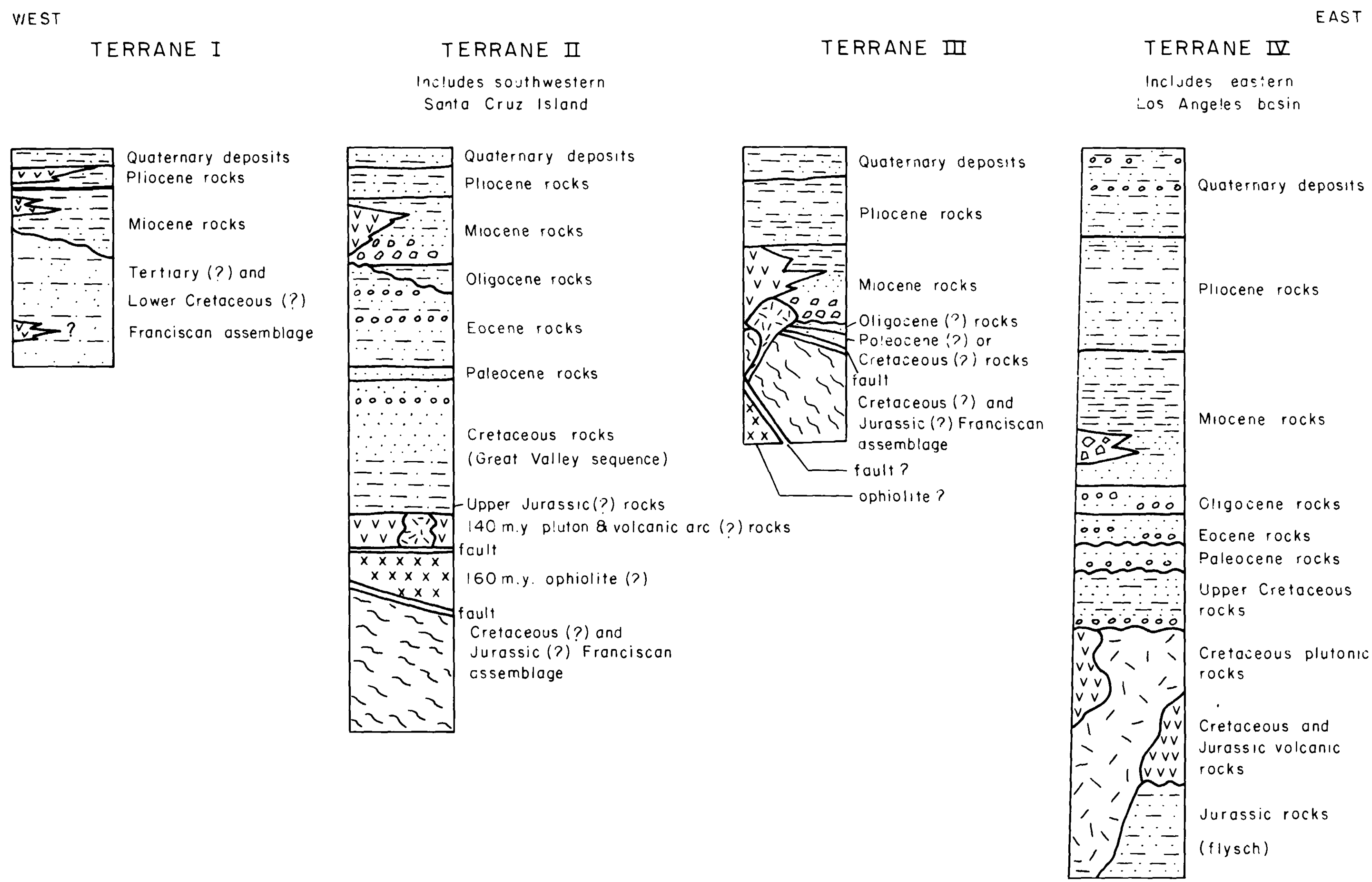



Figure 8.--Generalized stratigraphic columns for geologic terranes I through IV of the California Continental Borderland (from Howell and Vedder, 1981). Thicknesses of rock units are relative and actual scale is not intended.

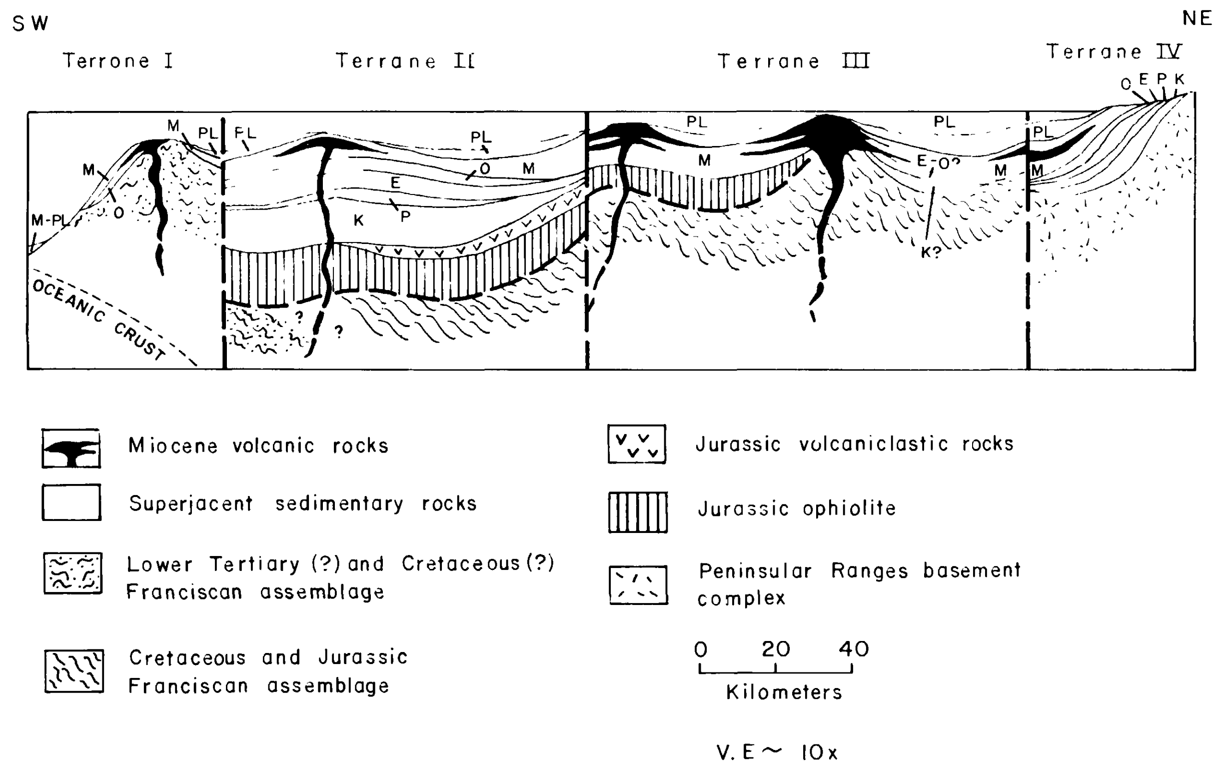



Figure 9.--Schematic east-west cross section of California Continental Borderland at approximately lat. 33°15′ N. (from Howell and Vedder, 1981). The relations shown are diagrammatic and largely speculative. Letter symbols indicate sedimentary rock sequences as follows; K - Upper Jurassic(?) and Cretaceous; K? - Cretaceous or Paleocene; P - Paleocene; E - Eocene; O - Oligocene; M - Miocene; and PL - Pliocene and younger.

Terrane I.--Rocks of the outer ridge system of the borderland north of the Santo Tomas fault constitute Terrane I (figs. 3 and 10). Named features partly or wholly within Area 2 that are underlain by this terrane are The Rampart, Outer Ridge, and Southwest Bank (fig. 7). North of lat 32° N., known basement rocks consist of zeolite-bearing arkosic and lithic arenite, argillite, and serpentinite. Schistose rocks and altered ultramafic rocks have been reported but may be erratics. Late Oligocene (ca. 24-30 m.y.) and younger clastic and volcanic rocks fill sedimentary basins and drape slopes in Terrane I, but generally are less than 3,280 ft (1,000 m) thick. North of Area 2, the thickest known section is in Patton Basin near the northern extremity of the terrane, where as much as 5,000 ft (1,525 m) of sedimentary section may be present (Vedder and others, 1980).

Estimates from a seismic-reflection profile across Long Basin near the northern edge of Area 2 suggest that between 4,400-5,250 ft (1,350-1,600 m) of Miocene and younger strata underlies the deep part of the basin. Elsewhere in the part of Area 2 within Terrane I, the sedimentary section is relatively thin on ridge slopes and is absent at places on Outer Ridge and Southwest Bank. One seismic profile across Southwest Bank indicates that as much as 2,450 to 3,770 ft (750 to 1,150 m) of post-Oligocene strata may be present on the northeast flank of the bank. Volcanic rocks, chiefly Miocene(?), are interspersed with the sedimentary rocks, but the sparseness of samples and wide spacing of seismic profiles precludes accurate mapping of their distribution.

Faults, folds, and unconformities are present in the Terrane I part of Area 2. Moore (1969) showed three major faults in the area, one of which is depicted as a northwestward continuation of the Santo Tomas fault. These faults, however, are not well defined on unpublished records and may be

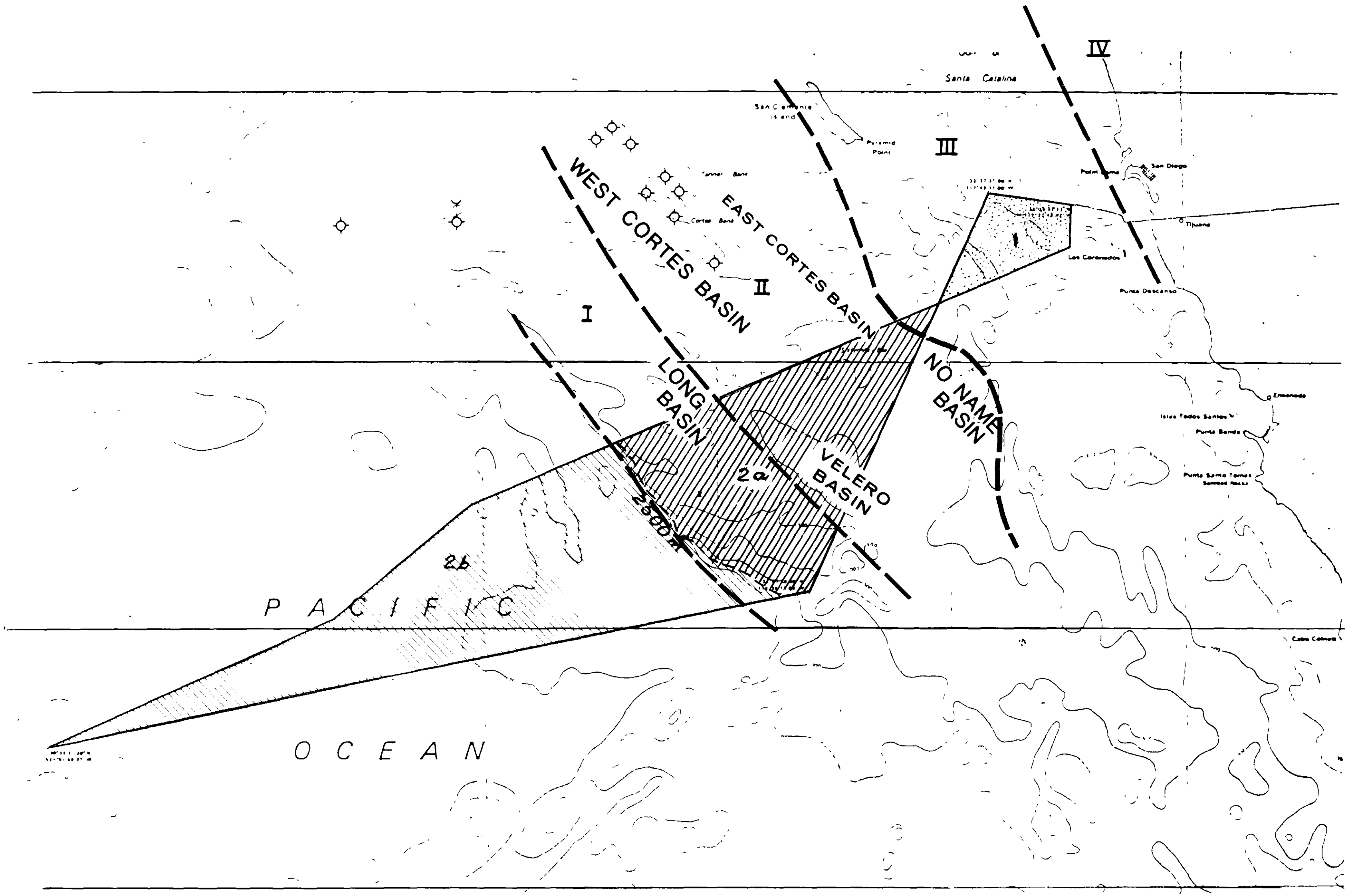



Figure 10.--Map showing positions of geologic terranes (terranes I, II, III, IV) as related to assessment areas.

smaller features than Moore indicated. Broad folds in Long Basin deform Miocene(?) strata, but younger beds apparently are draped across these structures. Unconformities of unknown age disrupt the sedimentary sequences in the basins and along the northeast flank of the Outer Ridge and its counterpart to the northwest. Possibly, the unconformity in the basins is late Miocene or early Pliocene, and the one beneath the ridge flank is Eocene or Oligocene.

Terrane II.--Velero and No Name Basins (figs. 7 and 10) and the unnamed plateau that separates them are included in the Terrane II part of Area 2. The southernmost parts of Shepard Knoll and Hubbs Ridge extend into the area. Terrane II north of lat 32° N. is underlain by a very thick succession of marine sedimentary rocks that range in age from Early(?) Cretaceous to Holocene (ca. 135± m.y. to present). Miocene volcanic rocks are present at places (Vedder and others, 1974, in press). In the extreme northern part of the terrane, as much as 19,680 ft (6,000 m) of section may overlie basement rocks of unknown composition (Vedder and others, 1980, fig. 4). Within Area 2, a presumably correlative sequence may be nearly 16,400 ft (5,000 m) thick beneath Velero Basin. The nearest known analogous section was penetrated in a deep stratigraphic test well at the southeast end of Cortes Bank, where middle and early Miocene (ca. 11-24 m.y.), Oligocene (ca. 24-38 m.y.), Eocene (ca. 38-55 m.y.), Paleocene (ca. 55-63 m.y.), and Late Cretaceous (ca. 63-96 m.y.) strata were drilled (Paul and others, 1976). The thick section in Velero Basin apparently wedges out southwestward against the crest of Southwest Bank where Miocene(?) strata lap onto basement or volcanic rocks. Pinchouts suggesting different source areas of sediment are evident in the Eocene(?) to Pliocene(?) part of the sequence. An equivalent section may be limited by fault truncation along the northeastern edge of the Long Basin. Possibly a thin sequence of volcanic or volcaniclastic rocks underlies about 1,640 ft (500 m) of Miocene(?) and younger strata on the unnamed plateau that separates Velero Basin from No Name Basin, and discontinuous, faint reflectors beneath them suggest that older layered rocks occur deeper. At least 4,100 ft (1,250 m) of post-Eocene(?) sedimentary rocks is present in No Name Basin; and older strata, unresolvable on the profiles, may underlie the well-defined reflectors. The southeastern part of Shepard Knoll apparently is underlain by volcanic rocks at shallow depth.

Structural features in the Terrane II part of Area 2 include faults, folds, and unconformities. Northwest-trending faults of unknown displacement along the southwest side of Velero Basin seem to disrupt strata as young as Pliocene and may affect younger sediments. Strata beneath the deep part of Velero Basin are relatively undeformed, although some broad downwarping is indicated. The topographic high that separates the two branches of the basin in its northwestern part apparently is a very broad anticline that is downfaulted on its flanks. On the opposite side of the basin, two smaller folds deform Miocene strata. Farther southeast, pre-Quaternary faults underlie the northeast flank of the basin. At least three minor folds deform Miocene(?) and Pliocene(?) rocks along the southwest edge of No Name Basin, and a broad, pre-Pliocene(?) anticline forms the northeast flank of the unnamed plateau south of this basin. Unconformities recognizable on seismic-reflection profiles across the Terrane II part of Area 2 include one that separates Oligocene(?) or Miocene strata from Eocene(?) or older rocks and another that separates Pliocene(?) from Miocene strata. Other unconformities undoubtedly disrupt the sequences along the margins of both Velero and No Name basins.

Terrane III.--The northeastern apex of Area 2 and all of Area 1 are underlain by rocks of Terrane III (fig. 10). North of lat 32° N., these rocks consist of schistose basement rocks that are intruded and overlain by Miocene plutonic and volcanic rocks (figs. 8 and 9). Overlying and buttressing against these metamorphic and igneous rocks are clastic rocks, most of which are late early Miocene and younger (ca. 17 m.y. and younger). Within Area 2, Sixtymile Bank and the eastern Blake Knolls area are composed largely of basement and volcanic rocks, although a thin veneer of Miocene sedimentary rocks apparently flanks the southern side of the Blake Knolls. Within Area 1, San Salvador Knoll, Boundary Bank, and the southeast end of Thirtymile Bank (fig. 11) probably consist of the same rock types although bedrock-sample data are sparse. The narrow parts of San Clemente Basin east and west of San Salvador Knoll apparently contain less than 980 ft (300 m) of sedimentary fill, all of which is Miocene and younger. In contrast, San Diego Trough in the eastern part of Area 1 may be filled by as much as 1,970 ft (600 m) of late Miocene to Holocene sediments and an additional 1,970 ft (600 m) of middle Miocene volcanic and sedimentary rocks (Vedder and others, 1980).

Structures in Area 1 are dominated by faults. A major northwest-trending wrench-fault zone called the San Diego Trough-Maximinos fault by Legg and Kennedy (1979) probably is largely responsible for the formation of the San Diego Trough (fig. 11). Another large throughgoing fault is the San Clemente fault, which parallels the northeast edge of San Clemente Basin (fig. 11). Minor folds are associated with both these major fault zones. Broad, poorly defined folds deform Miocene rocks in the southeastern part of the Thirtymile-Fortymile Banks Plateau. Boundary Bank possibly is an anticline

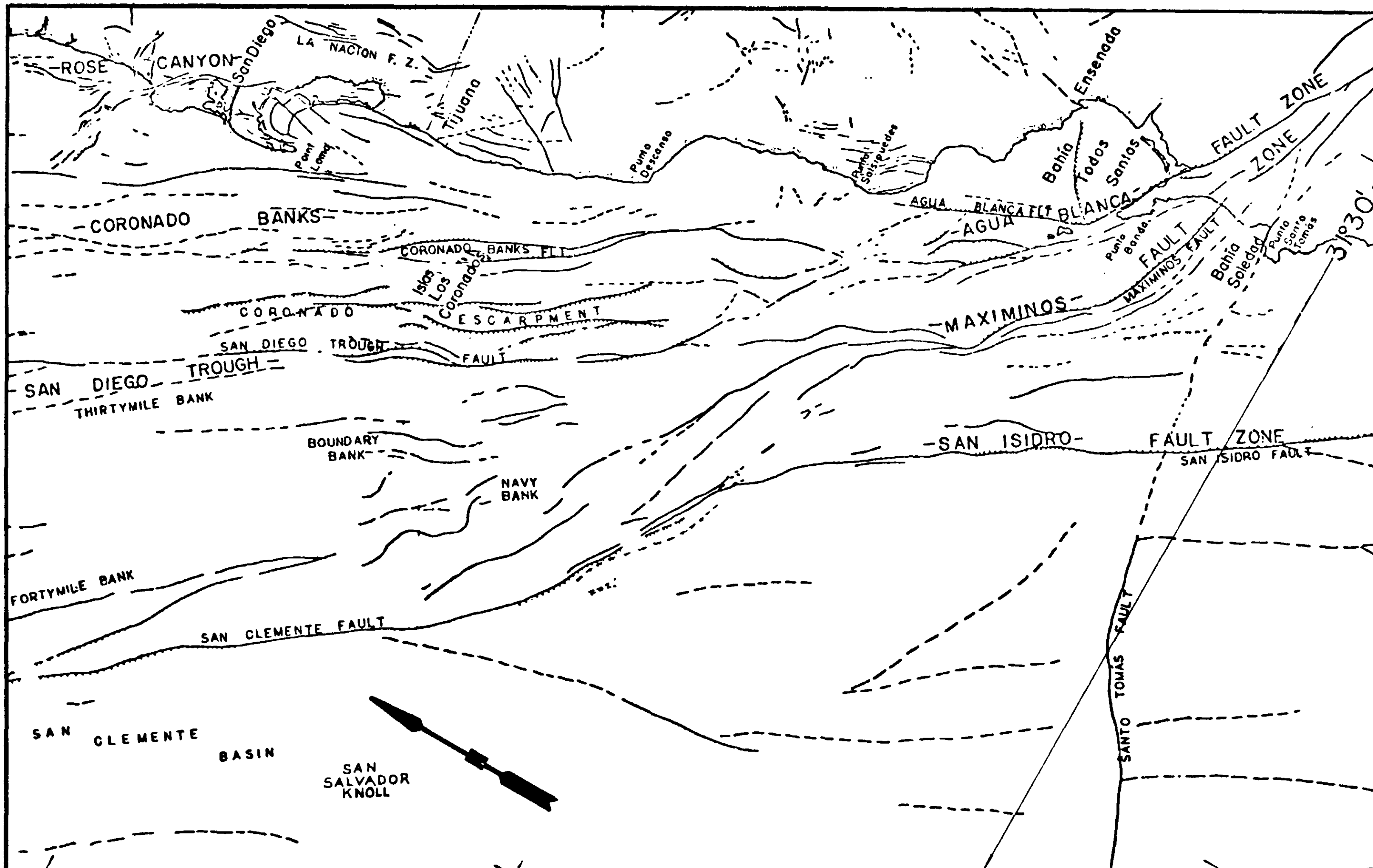



Figure 11.--Faults in the nearshore part of the borderland as interpreted by Legg and Kennedy (1979) from seismic-reflection profiles.

that contains basement and volcanic rocks in the core and Miocene strata on the flanks. Unconformities are present in the late Cenozoic section beneath San Diego Trough, but their age is uncertain.

Terrane IV.--A discussion of Terrane IV is not relative to this report because it is east of the designated study area.

# PETROLEUM RESOURCE POTENTIAL

By

Edward W. Scott, John G. Vedder, and David Griggs

Commercial accumulations of petroleum are dependent upon a combination of geological factors including; 1) suitable source beds for the generation of petroleum, 2) reservoir rocks of sufficient porosity and permeability, and 3) the presence of traps of adequate size that will permit accumulation and preservation of petroleum in commercial quantities. Coupled with these physical conditions are the requirements of burial history and time of migration that would be favorable for the generation and movement of petroleum from the source beds into reservoir rocks within the trapping features.

Deep stratigraphic information essential for determining the possible presence of source rocks and reservoir rocks within the study area is not available; thus, the petroleum potential is largely speculative. The nearest subsurface information is the deep stratigraphic test, Outer Continental Shelf (OCS) 75-70 No. 1, drilled in 1975 about 38 mi (62 km) northwest of the study area (fig. 4). The test was drilled to a total depth of 10,920 ft (3,330 m) on the southeast flank of Cortes Bank for the purpose of obtaining stratigraphic information prior to a Federal lease sale. Petroleum exploration and drilling have been limited to the region north of lat 32° N., north of the study area (figs. 4, 5, 6). Because of the sparseness of information in the study area, comparisons are made with explored and developed regions to the north. By gross analogy, stratigraphic and structural relationships are projected into the study area.

## Petroleum in Adjacent Areas

The northern part of the California Continental Borderland is contiguous to the two largest petroleum basins in the California Coastal Province west of the San Andreas fault. The borderland south of lat 34° N. has an inner basin area that is, in part, an extension of the Los Angeles Basin; the Santa Barbara Channel between lat 34° N. and 34°30′ N. is the offshore continuation of the Ventura Basin. Other borderland basins, however, have stratigraphic and structural characteristics that differ from those in the above-mentioned basins that straddle the shoreline.

As of January 1, 1978, the cumulative production from all onshore California coastal basins totaled more than 10.2 billion barrels of oil, and the remaining oil reserves in proven fields have been estimated to be 1.7 billion barrels (California Division of Oil and Gas, 1978). Production from the coastal basins is more than half of all the petroleum found in onshore California (Taylor, 1976). Petroleum is concentrated in young reservoirs, and about 87 percent is in late Miocene or younger rocks, 5.3 percent is in middle Miocene, 4.7 percent is in early Miocene, 2.8 percent is in Oligocene, and 0.2 percent is in Eocene strata.

In each of the coastal basins, most of the known petroleum occurs in a few fields. Five giant fields account for more than 52 percent of all the petroleum produced from these basins, and 24 fields, each having cumulative production greater than 75 million barrels, account for more than 86 percent (8.5 billion barrels of oil). Approximately 80 percent of the petroleum is from turbidite sandstone reservoirs, 10 percent from shallow-water sandstone, 5+ percent from fractured siliceous shale, and 5 percent from nonmarine sandstone and conglomerate beds and fractured schist basement. Most of the fields are in faulted anticlinal traps of post-Miocene age; a few are in homoclines against major faults. Only two fields (of those larger than 20 million barrels) are stratigraphic traps.

The Ventura Basin and its seaward extension, the Santa Barbara Channel, produce from reservoirs of Eocene through Pleistocene age. Total production from this basin amounts to about 2.0 billion barrels of oil. The basin differs from both the Santa Maria and Los Angeles Basins in that a thick section of Upper Cretaceous and lower Tertiary strata underlies younger strata (fig. 12). These older rocks are believed to contain the source rocks for dry gas and account for the high gas-oil ratios that are nearly twice as high in this basin as those in other California basins (Taylor, 1976). Furthermore, almost all the petroleum from Eocene to Oligocene reservoirs in the coastal basins is from the Ventura Basin but amounts to only 0.35 billion barrels. More than half of all the oil in the basin has come from a single anticlinal trend more than 25 mi (40 km) long, which produces from turbidite sandstone reservoirs of early Pliocene age.

The Los Angeles Basin has produced 66 percent of the petroleum in the California coastal basins. The source of this oil is believed to be the thick, organically rich Miocene and younger strata that extend throughout most of the basin. Eight of the ten largest fields in the coastal basins are in the Los Angeles Basin; of these, two extend offshore, and produce from deep-water turbidite sandstone sequences in which net sand thicknesses exceed 1,000 ft (305 m). All are structural traps, either anticlinal or homoclinal against major faults, and many are situated along regional structural highs such as the Newport-Inglewood trend.

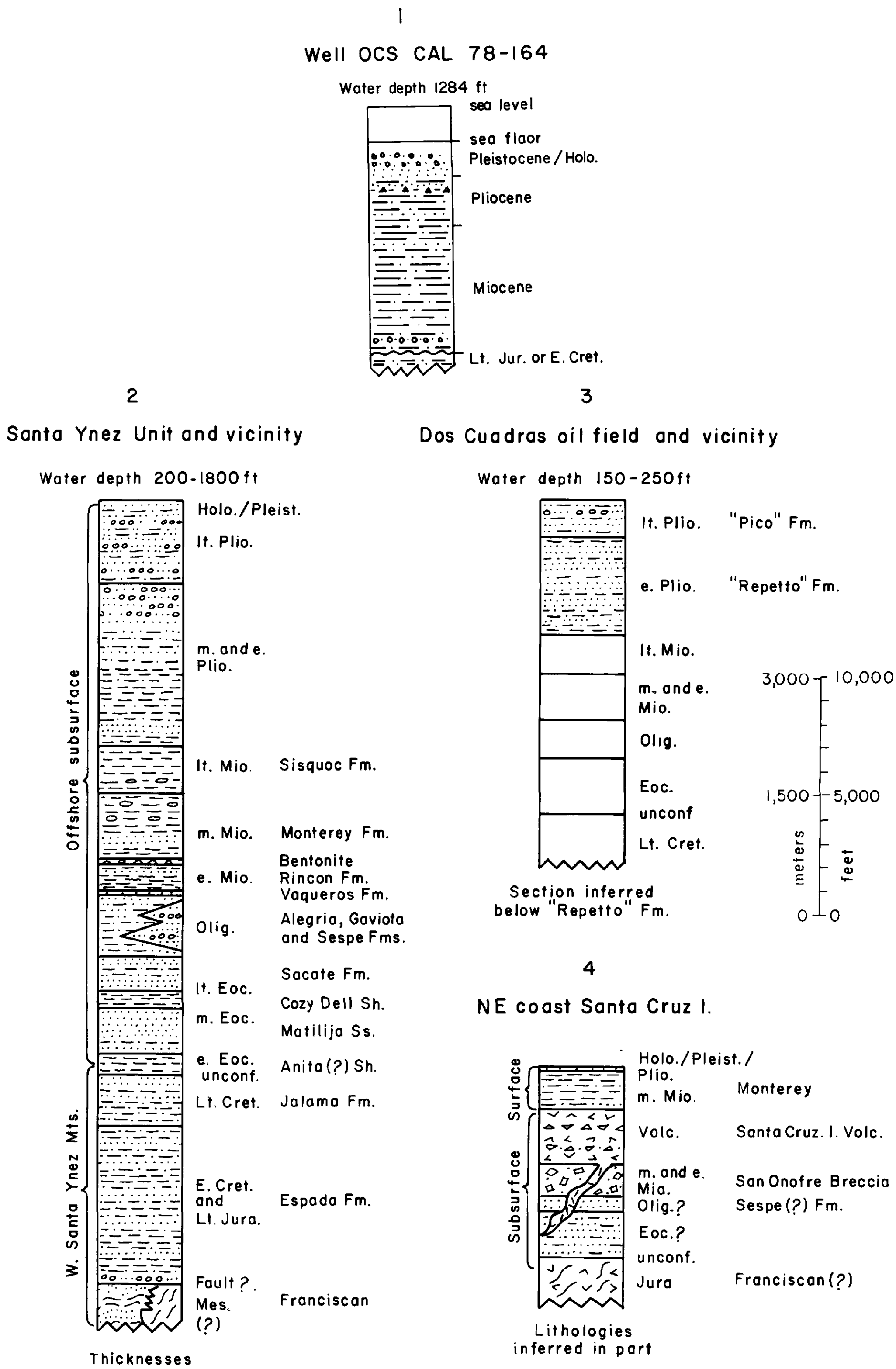



Figure 12.--Stratigraphic columns, Santa Barbara Channel region. Provincial chronologies and named stratigraphic units are shown to the right of each column. The rock types, where known, are generalized and depicted by lithologic symbols, (from Vedder and others, 1980).

## Petroleum Potential of the Study Area

Appraisals of the petroleum potential of the entire California Continental Borderland recently have been prepared (Taylor, 1976; Clifton, 1980; Vedder and others, 1980) and supplemented by information from the deep stratigraphic test wells, OCS-CAL 75-70 No. 1 (fig. 13) at Cortes Bank (Paul and others, 1976) and OCS-CAL 78-164 No. 1 (fig. 12) west of Point Conception (Cook, 1979).

Outer Continental Shelf Lease Sales 35 and 48 held in December 1975 and June 1979, respectively, together with the Call for Nominations for Lease Sale 68, 1979, included much of the available area to and beyond water depths of 2,400 ft (750 m). Much of the nearshore area adjacent to the Los Angeles Basin has been leased, with the exclusion of Santa Monica Bay. However, only one field, Beta in San Pedro Bay, has been developed. Twenty-six tracts offshore from San Diego County were eliminated from OCS Lease Sale 48 by the Secretary of the Interior, primarily because of environmental concerns. Generalized stratigraphic columns for selected areas on the inner part of the borderland are shown in figure 14.

In the area seaward of the Channel Islands, the deep stratigraphic test at Cortes Bank (fig. 13) provided data that seemed to enhance the petroleum potential of this part of the borderland, yet recent exploratory drilling at Dall Bank, Tanner Bank, and Cortes Bank has been discouraging. The distribution of potential reservoir sandstones seaward from Cortes Bank is unknown. Potential source rocks occur in strata of late Eocene and Miocene age in the test well. Organic matter in all analyzed Tertiary rocks is immature, but the same rocks might have generated petroleum in adjacent basins if sufficiently buried to have been subjected to high temperatures. Upper Cretaceous strata, known only from three widely scattered sea-floor areas of

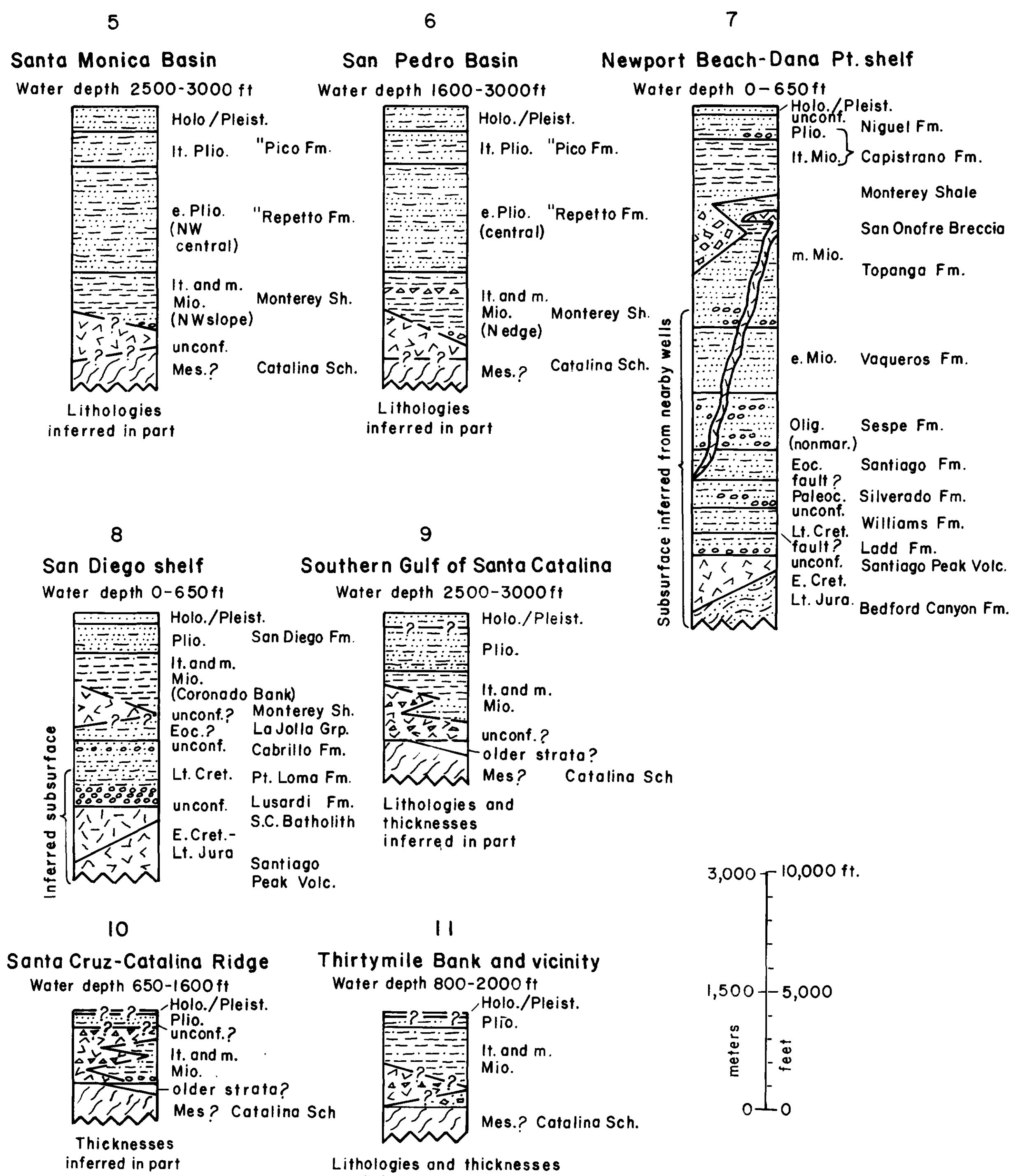


Figure 14.--Stratigraphic columns, inner basins and banks. Provincial chronologies and named stratigraphic units are shown to the right of each column. The rock types are generalized and depicted by lithologic symbols (from Vedder and others, 1980).

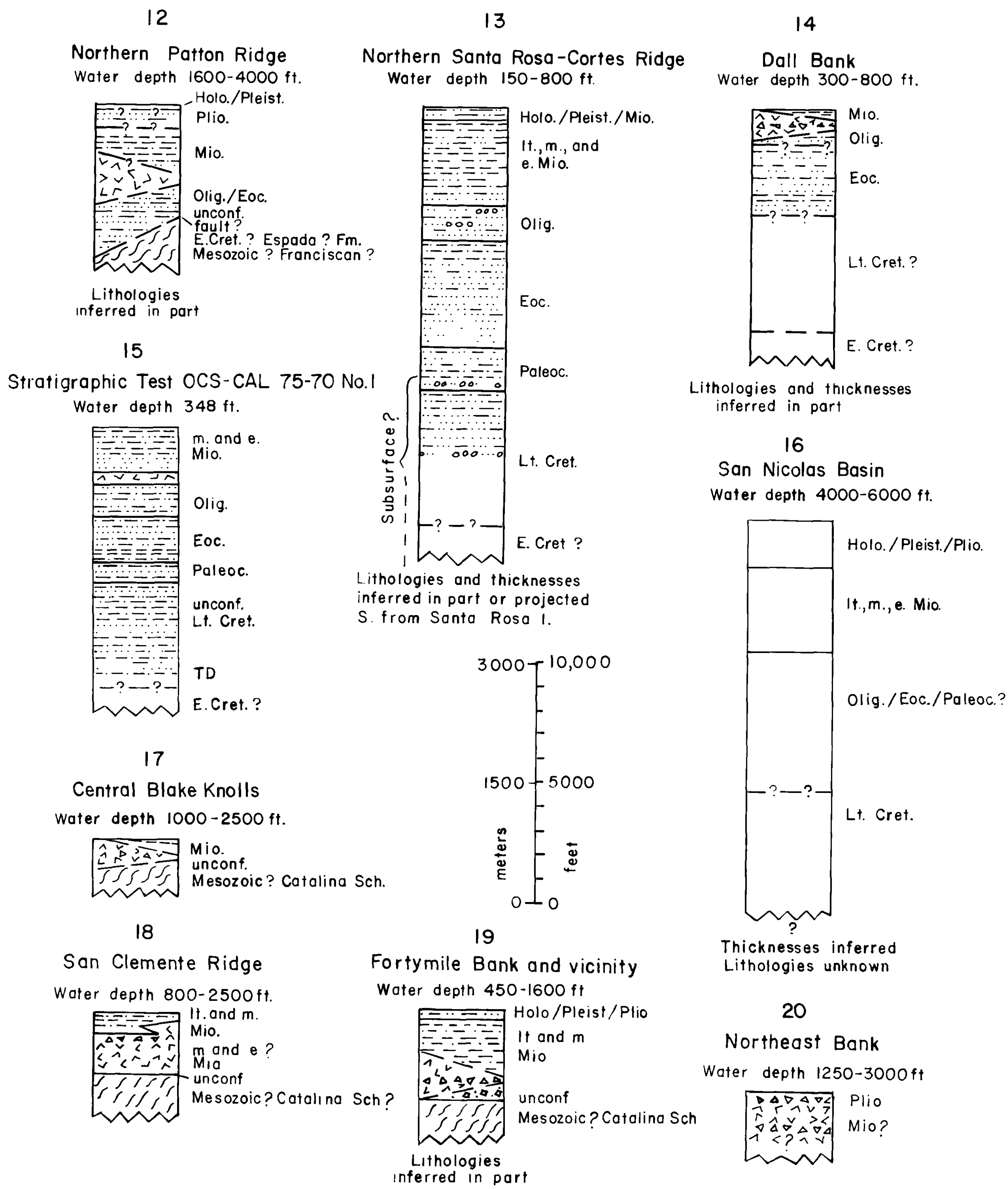



Figure 13.--Stratigraphic columns, outer basins and banks. Provisional international chronologies are shown to the right of the columns. Most stratigraphic units are unnamed. Rock types, where known, are generalized and depicted by lithologic symbols. Except for the OCS-CAL 75-70 No. 1 well, thicknesses are estimated from seismic-reflection profiles (from Vedder and others, 1980).

the borderland, are more than 5,000 ft (1,524 m) thick in the test well at Cortes Bank, but reservoir-quality rocks are present only in the upper part, and the source-rock potential is low. The lower 3,000 ft (914 m) of section in the well, below a possible unconformity within the Upper Cretaceous strata, contains small amounts of mature organic matter. An exploratory well drilled 9 mi (15 km) northwest of Santa Barbara Island proved unproductive.

Seismic-reflection profiles and sonobuoy-refraction data (Crouch and others, 1978, and unpublished data) indicate that thicknesses of Miocene strata may be 4,900-6,560 ft (1,500-2,000 m) in some of the large outer basins, and geochemical analyses of Miocene samples from scattered bottom samples (Taylor, 1976) and DSDP Hole 467 indicate that these strata may have a high source-rock potential. Moreover, middle Miocene through Plicoene strata within some of these basins may include potential reservoir rocks in the form of sandy turbidites. For example, DSDP Hole 467 in San Miguel Gap penetrated late middle Miocene and early Pliocene sands (Haq, Yeats, and others, 1979). Pliocene and younger hemipelagic strata that overlie these potential reservoir rocks are as much as 3,600 ft (1,100 m) thick at places in the outer basins. Furthermore, data from DSDP Hole 467 suggest that strata beneath the deep borderland basins have been subjected to higher temperatures than correlative, marginally mature strata on adjacent ridges (Crouch, 1980). Water depths in these basins, however, generally are more than 3,600 ft (1,100 m).

The designated area for resource evaluation is divided into two numbered geometric units (fig. 1). Area 1 is nearer to the mainland; Area 2, farther from shore, has been divided into two parts on the basis of geology and bathymetry. Area 2a is within the California Continental Borderland, and Area 2b is seaward of the 8,200-ft (2,500-m) isobath in the Baja California Seamont Province.

The presence of offshore hydrocarbon traps is ordinarily interpreted from seismic and well data. Several intermediate-penetration single-channel reflection profiles have been acquired in Area 1, but they are widely spaced and do not show deep reflectors in the basins. Geophysical data available on the designated area are limited to 230 mi (370 km) of multichannel seismic-reflection records and 364 mi (586 km) of single-channel seismic-reflection records. Thirty bedrock samples have been described for stratigraphic information within the designated area north of lat 32° N., but only three sea-floor dredge sites are reported in the southwest part of Area 2. Distribution of seismic data shows that about 4 percent of it was in Area 1, 6 percent in Area 2a, and 10 percent in Area 2b. Seven multichannel seismic profiles have been run across or adjacent to Area 2a (fig. 4). Two of these profiles extend seaward into Area 2b. The data derived from these seismic-reflection profiles show evidence for faults, folds, and unconformities, but the profiles are too far apart to determine the extent or magnitude of these structural features.

Assessment Area 1.--This small area of approximately 500 $mi^2$ (1,295 $km^2$), has a sediment volume of 120 $mi^3$ (500 $km^3$) and is wholly within Terrane III (fig. 10); its geologic setting is different from that of Areas 2a and 2b. Thus, the stratigraphic information derived from the deep stratigraphic test, OCS 75-70, cannot be applied in Area 1.

Area 1 contains a small basin underlying part of the San Diego Trough that covers about 95 $mi^2$ (245 $km^2$) and has an estimated sediment volume of about 120 $mi^3$ (500 $km^3$). The section in this basin is inferred to consist of late Cenozoic clastic sediments overlying volcanic and basement rocks and buttressing against a basement ridge on the southwest. Correlative sedimentary sequences farther north contain suitable potential source rocks and adequate reservoir units, but it is questionable whether the sediment thickness and depth of burial have been sufficient for petroleum generation in the northeast part of Area 1. Although they cannot be defined from the available seismic data, traps suitable for hydrocarbon accumulation probably are present in this small basin. For example, the buttressing relationship of the sediments to basement could provide stratigraphic traps.

Assessment Area 2a.--Area 2a covers 2,800 $mi^2$ (7,250 $km^2$) and includes parts of Terranes I, II, and III (fig. 10). The northeastern part is underlain by exposed basement rocks; hence, there is little chance for petroleum accumulation.

Approximately 42 percent of Area 2a is within Terrane II and is considered to be the most prospective part of the overall area of study. Stratigraphic information derived from the OCS-75-70 test has been projected into Area 2a, and unit thicknesses have been modified as indicated from seismic data. One conspicuous and persistent seismic reflector that apparently correlates with the top of the Eocene in the OCS 75-70 test was used to construct the isopach map shown in figure 15.

Geochemical analyses of material from OCS 75-70 indicate that good source rocks persist to a depth of 5,340 ft (1,600 m) and include beds of Miocene, Oligocene, and Eocene ages. In the test well, the mapped reflector occurs at

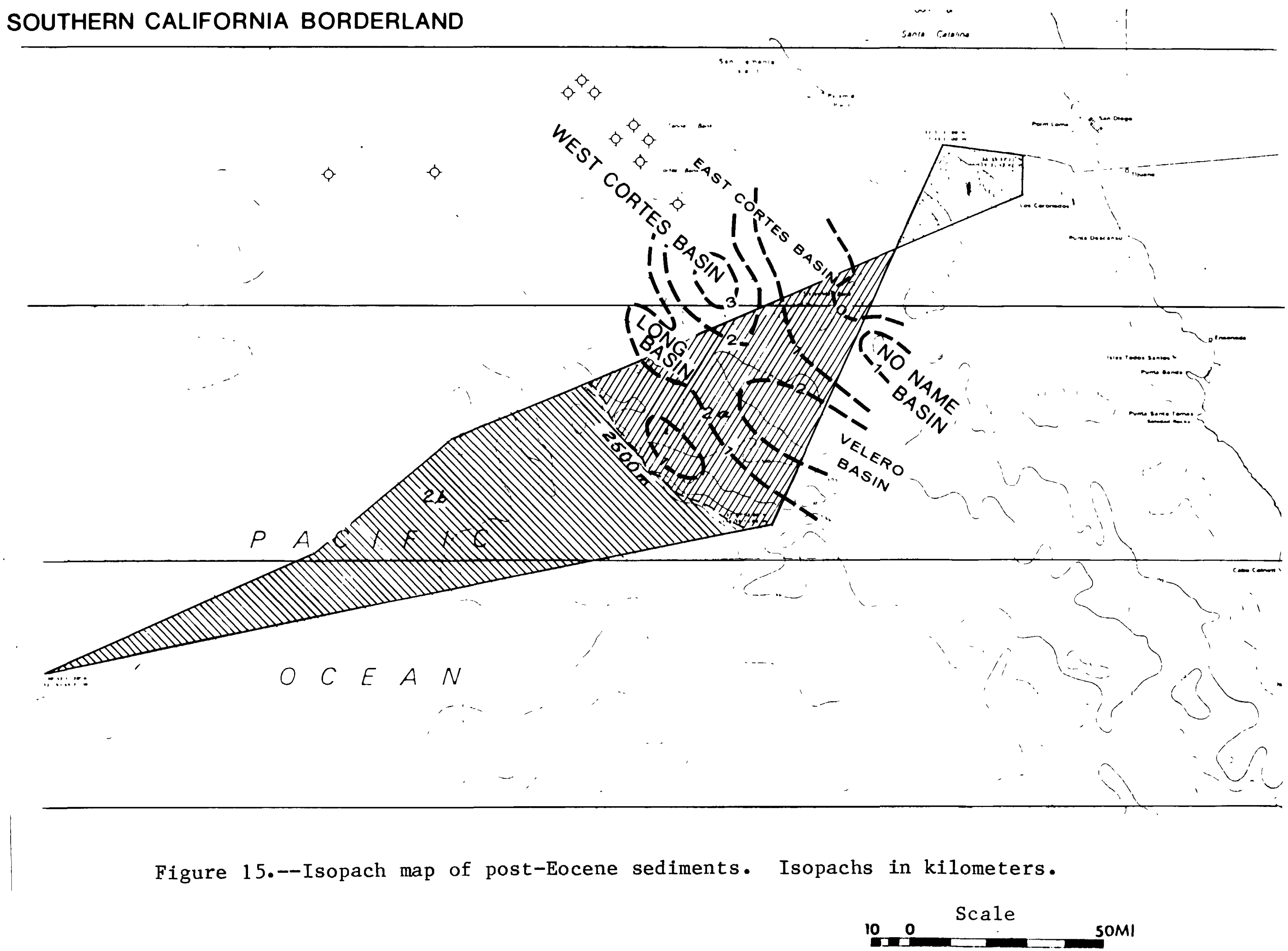



Figure 15.--Isopach map of post-Eocene sediments. Isopachs in kilometers.

a depth of 4,190 ft (1,280 m); hence, the mapped interval includes 77 percent of the well section that contains good source rocks, and we estimate that a similar ratio will hold over most of the mapped area. The post-Eocene isopach map (fig. 15) indicates that the section thickens from the OCS 75-70 test well southward into Area 2a and exceeds 6,500 ft (2,000 m) in thickness at the south end of West Cortes Basin and the northern part of Velero Basin. The same section possibly is as thick as 7,500 ft (2,300 m) in central Velero Basin along the southeast edge of Area 2a. Although much of the increase in sediment thickness occurs within the Eocene to lower Miocene section, part of the increased thickness results from an additional section of younger rocks within the basin areas. Good to excellent reservoir rocks were drilled in OCS 75-70, especially within the isopached interval. It is reasonable to expect that similar reservoir conditions extend into Area 2a and that the area may have the essential ingredients for both adequate source and reservoir rocks.

Seismic data are too limited to define specific potential traps in Area 2a. Pre-Quaternary faults are present along the edges of Velero and West Cortes Basins, and two minor, low relief folds are indicated on the southwest side of Velero Basin. A broad, fault-bounded anticline underlies the northwestern part of Velero Basin. Potential stratigraphic traps in the form of pinchouts and unconformities occur in both basins.

Assessment Area 2b.--Area 2b, which is seaward of the base of the Continental Slope, has a total area of 4,200 $mi^2$ (10,880 $km^2$) and has a sediment volume of only 520 $mi^3$ (2,170 $km^3$) The area lies almost entirely within the Pacific Ocean Basin in water depths ranging from 8,200 ft (2,500 m) to more than 12,000 ft (3,660 m). Petroleum potential is judged to be negligible.

## Summary

Assessment Area 1.--Petroleum potential presumably is limited to a small area in the northeastern part of Area 1 where a segment of the San Diego Trough covers about 95 $mi^2$ (245 $km^2$). Very little information is available here to identify any stratigraphic or structural features.

Assessment Area 2a.--Approximately 1,200 $mi^2$ (3,100 $km^2$), or about 42 percent of Area 2a, appears to have fair potential for accumulations of petroleum. This estimate of potential is based upon the presence of a thick sedimentary section that includes good source rocks and adequate reservoir rocks.

The objective section in this area ranges in age from Pliocene to Upper Cretaceous, but no hydrocarbons have been found as a result of the recent exploratory activity on Cortes and Tanner Banks to the north where middle Miocene through Upper Cretaceous strata were drilled.

Any attempt at making analog comparisons from productive basins in southern California to the study area should take into account the fact that the most attractive strata for petroleum production are in the Pliocene-upper Miocene section. These strata are absent over most of the high-standing areas of the California Continental Borderland. Even though this section is interpreted to be present within West Cortes and Velero Basins, it is relatively thin. About 87 percent of the cumulative oil production from five southern California coastal basins has been from the Pliocene-upper Miocene section (Taylor, 1976); equivalent sections in the offshore basins warrant consideration as being potentially prospective.

Assessment Area 2b.--The petroleum potential of this Area 2b is judged to be negligible because of the thinness of the sedimentary section and the nature of the sediments.

# ESTIMATES OF UNDISCOVERED IN-PLACE PETROLEUM RESOURCES

By

Richard B. Powers and Edward W. Scott

## Introduction

Undiscovered in-place resources are those resources, yet to be found, which are estimated to exist as a consequence of favorable geologic conditions. Total estimated in-place resources in the offshore southern California Borderland study area range from 0 to 1.78 billion barrels of oil (BBO) and from 0 to 2.86 trillion cubic feet (TCF) of gas. The mean estimate for oil is .41 BBO and the mean for gas is .68 TCF (table 1). The designated study area covers 7,500 $mi^2$ (19,425 $km^2$) and has a sediment volume of 2,347 $mi^3$ (9,785 $km^3$); water depths range from 295 ft (90 m) to more than 12,000 ft (3,660 m). The study area is divided into two areas defined by the intersection of an existing boundary line and a proposed line (fig. 1). The proposed line is defined by linking together the following coordinates:

1. lat 32°35′22.11" N., long 117°27′49.42" W.
2. lat 32°37′37.00" N., long 117°49′31.00" W.
3. lat 31°07′58.00" N., long 118°36′18.00" W.
4. lat 30°32′31.20" N., long 121°51′58.37" W.

Table 1.--*Summary of estimates*[1] *of undiscovered in-place oil and gas resources, areal size, and sediment volumes of assessed areas in offshore southern California Borderland*

| Assessment area | Areal size | Sediment volume | Oil in-place Billions of barrels (BBO) | | | | Total gas in-place Trillion cubic feet (TCF) | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Low [2]$F_{95}$ | High [3]$F_5$ | Mean | M.P.[1] | Low [2]$F_{95}$ | High [3]$F_5$ | Mean | M.P.[1] |
| 1 | 500 $mi^2$ (1,295 $km^2$) | 120 $mi^3$ (500 $km^3$) | 0 | .12 | .02 | .30 | 0 | .23 | .05 | .34 |
| 2a | 2,800 $mi^2$ (7,252 $km^2$) | 1,707 $mi^3$ (7,115 $km^3$) | 0 | 1.70 | .39 | .46 | 0 | 2.73 | .63 | .47 |
| 2b | 4,200 $mi^2$ (10,878 $km^2$) | 520 $mi^3$ (2,170 $km^3$) | | | | - negligible - | | | | |
| Aggregation Estimates | | | | | | | | | | |
| Total study area | 7,500 $mi^2$ (19,425 $km^2$) | 2,347 $mi^3$ (9,785 $km^3$) | 0 | 1.78 | .41 | .62 | 0 | 2.86 | .68 | .65 |

[1]The resource estimates are *unconditional*, that is, the marginal probabilities (M.P.), or risks, have been applied to the estimates.

[2]$F_{95}$ is the 95th fractile, corresponding to a 95% probability of *more than* that amount.

[3]$F_5$ is the 5th fractile, corresponding to a 5% probability of *more than* that amount.

An existing line trends due southwest starting at a point west of the Mexican Los Coronados Islands and terminating at a common point with coordinate number 4, indicated above. The study area lies between these two lines (fig. 1). Resource estimates were made for Area 1 and Area 2a, which appear to have petroleum potential. Resources for Area 2b are judged to be negligible, because stratigraphic information interpreted from seismic and drill-hole data shows that it has an extremely thin veneer of sediments, indicating very unfavorable conditions for the possible generation or accumulation of hydrocarbons.

Area 2a was divided from Area 2b on the basis of bathymetry and geology. Area 2a is on part of the Continental Slope and is bounded to the southwest by the 8,200-ft (2,500-m) bathymetric line. Area 2b lies almost entirely within the Pacific Ocean Basin, seaward of the Continental Slope in water depths ranging from 8,200 ft (2,500 m) to more than 12,000 ft (3,660 m). Area 1 lies outside of (south of) the proposed line, only the northeastern part of which is estimated to contain an adequate thickness of sediments sufficient for petroleum potential.

## Resources Assessed

All amounts of oil and natural gas estimated in the southern California Borderland Maritime Boundary region are of *undiscovered* petroleum resources in-place (not an estimate of recoverable quantities). Oil and gas *in-place* refers to petroleum in-place in reservoirs, without qualification as to what part may be considered either currently or potentially producible and without regard to any economic or technological limitations. In-place hydrocarbons are considered to be accumulations in discrete trapping features, not simply disseminated at random throughout the sedimentary rock system within a geologic basin. They are further defined to exclude accumulations of less than 1 million barrels of oil in-place and 2.5 billion cubic feet of gas in-place, respectively. The estimated amounts of undiscovered oil and gas in-place fall in the right-hand hachured column of the resource diagram shown in figure 16. Resources are defined as "...concentrations of naturally occurring solid, liquid, or gaseous materials in or on the Earth's crust in such form that economic extraction of a commodity is currently or potentially feasible" (U.S. Bureau of Mines and U.S. Geological Survey, 1976). In-place quantities, however, may include accumulations that are too small, dispersed, or remote to be recoverable, or portions of economic deposits which are potentially or actually non-extractable in an economic or technologic sense (Dolton and others, 1979). Amounts of *known* oil or gas in-place are defined as the estimated number of stock tank barrels of crude oil (42 gallons per barrel) or standard cubic feet of gas (14.73 PSI atmosphere, and $60^{o}$ F) in subsurface reservoirs prior to any production (API, 1970).

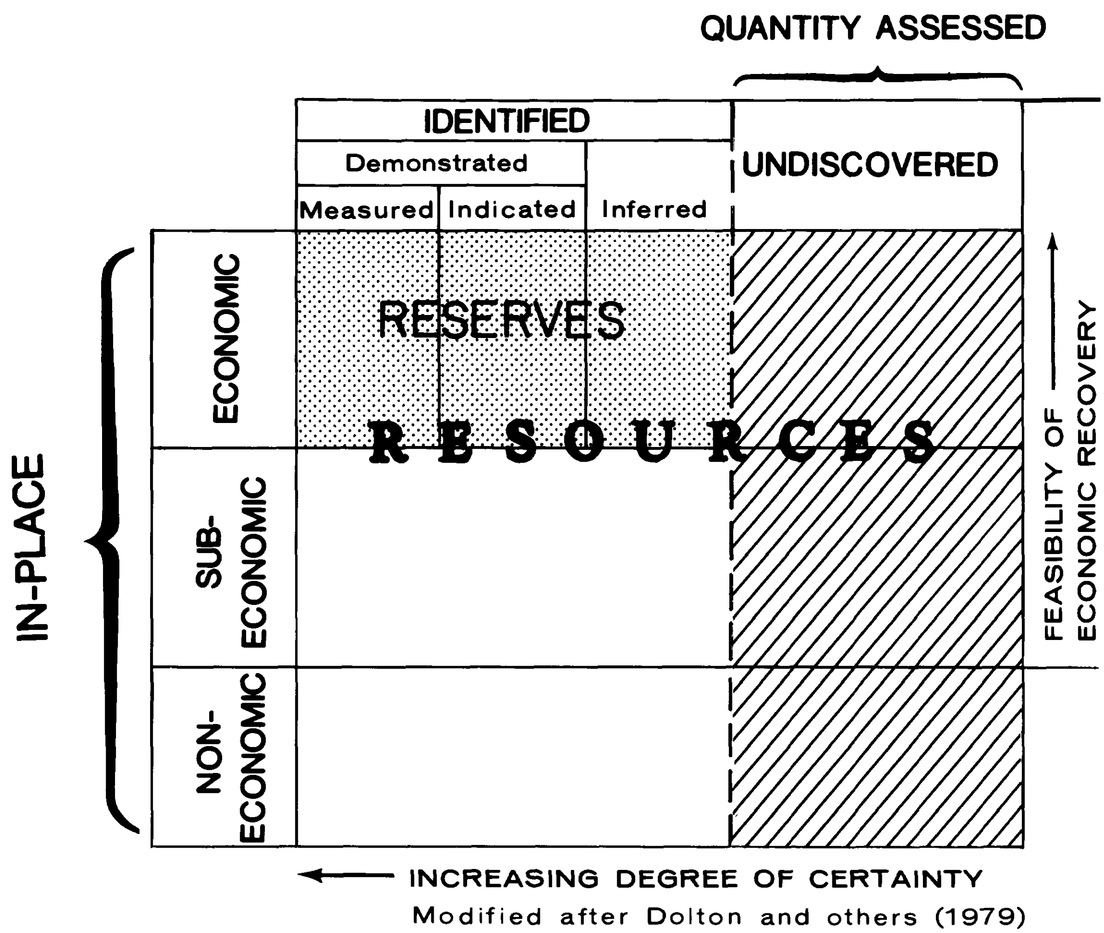



Figure 16.--Petroleum resource classification diagram; estimates of undiscovered in-place oil and gas resources in the offshore Southern California Borderland lie within the hachured column on the right.

## Speculative Recoverability of In-place Oil and Gas

Scott, Vedder, and Griggs' discussion of the petroleum potential in the offshore southern California assessment areas (this report) indicates that hydrocarbons might be contained in continuous blanket-type sandstone reservoirs where natural water encroachment might enhance primary oil recoveries. In these sandstone reservoirs, an average recovery of 30 percent of the oil in-place and 65 percent of the gas in-place may be probable. If tertiary recovery methods could be applied in these deep-water areas, we speculate that total oil recovery may be as much as 50 percent of the oil in-place.

However, the oil and gas recovery factors cited here cannot be applied directly to the gross amounts of undiscovered in-place oil and gas resources estimated. Because of the great uncertainties of reservoir properties, economics, and technology, no one knows what percent of the estimated in-place resources in the study area might ultimately be recoverable (R. F. Mast, written commun., 1981).

## Resource Assessment Procedures

Procedures for estimating volumes of undiscovered in-place oil and gas in the study area by an appraisal committee involved: 1) a comprehensive analysis of all available geological, geophysical, and petroleum-geology data; 2) analysis of the factors known to be significant to petroleum generation, migration, and entrapment; and 3) by group appraisals using, as a "scaling factor," calculated volumetric-hydrocarbon yields per cubic mile of sediment from national (U.S.) yields and from basin-type yields of Klemme (1975). Ordinarily, calculated hydrocarbon yields per cubic mile of sediment from several analogous, *known* producing basins are applied to the sediment volume in a province being assessed, such as the Southern California Borderland. These calculated yields are important in the assessment process because they provide the assessor with high, low, and average yields that serve as scaling factors in making subjective probability estimates. However, essentially all exploration is limited to the region north of lat 32° N., north of the study area, resulting in a lack of basic, subsurface information. In addition, no appropriate productive analog province was known from which hydrocarbon yield values could be applied.

Following the analysis of data, each member of the appraisal committee individually made subjective probability estimates of undiscovered oil and total gas resources in-place. The estimates were arithmetically averaged and then processed using probabilistic methodology.

## Methods Used in Processing Estimates[1]

Because of the uncertainty involved in estimating undiscovered in-place resources, estimates of their quantities include a range of values corresponding to different probability levels. Initial estimates were made conditional upon the event "in-place oil (or gas) is present" for each assessment area as follows:

1. A *low* resource estimate corresponding to a 95 percent probability of *more than* that amount; this is the 95th fractile ($F_{95}$).
2. A *high* resource estimate corresponding to a 5 percent probability of *more than* that amount; this is the 5th fractile ($F_5$).

---

[1]The authors wish to gratefully acknowledge the assistance of Robert A. Crovelli, who developed probabilistic methodology, for processing the estimates in this report.

3. A *modal* ("most likely") estimate of the quantity of resource associated with the greatest likelihood of occurrence.

These conditional estimates determined for each assessed area a conditional probability distribution of the quantity of undiscovered oil (or gas) in-place. The conditional probability distribution is the probability distribution of the quantity of undiscovered in-place resource *conditioned* on the in-place resource being present. A lognormal distribution was used as a probability model for the conditional probability distribution.

In the initial resource estimate of the assessed areas, a condition was made that the defined resource occurs in "some" quantity. This condition cannot be made with certainty in frontier areas, such as the Southern California Borderland study area, in which no oil or gas, other than shows and seeps, has been discovered to date. Therefore, a probability had to be assigned to the condition that the resource occurs in some quantity; this probability, or risk, is called the *marginal probability* (M.P.). For the estimates in each assessed area, a marginal probability was assigned by the assessors to the event "in-place oil is present" and to the event "in-place gas is present." The marginal probabilities are shown in table 1.

The marginal probability for each assessed area was applied to the corresponding conditional probability distribution to produce the probability distribution of the quantity of undiscovered in-place resource. For distinguishing purposes, this distribution is informally referred to as the *"unconditional"* probability distribution. Each probability distribution was described by means of a *more than* cumulative distribution function, which gives the probability of *more than* a specific amount. From this function, the low ($F_{95}$), high ($F_5$), and mean estimates for each assessed area were obtained; they are given in table 1.

To arrive at total resource estimates for the entire study area, an aggregation of the assessment areas was done by a Monte Carlo technique. The resulting aggregate probability distribution represents the probability distribution of the *total* quantity of undiscovered oil (or gas) in-place. From this distribution, the low ($F_{95}$), high ($F_5$), and mean estimates for the total study area were obtained (table 1). The probability curves for these in-place oil and gas estimates for each of the assessment areas are shown in figure 17, and the aggregation estimates for the total area of study are shown in figure 18.

## Summary

The overall study area of the Southern California Borderland contains a small volume of sediments, and the thick, hydrocarbon-rich Pliocene-Upper Miocene section present in the productive nearshore basins to the north is relatively thin or absent. The sparseness of subsurface geologic information south of lat 32° N., where the study area is located, affects the degree of certainty in making resource estimates. Three separate assessment areas have been evaluated in the study, only two of which (Areas 1 and 2a), appear to have any petroleum potential; the estimate of total undiscovered in-place resources for the study area, therefore, are of resources within Assessment Areas 1 and 2a (table 1).

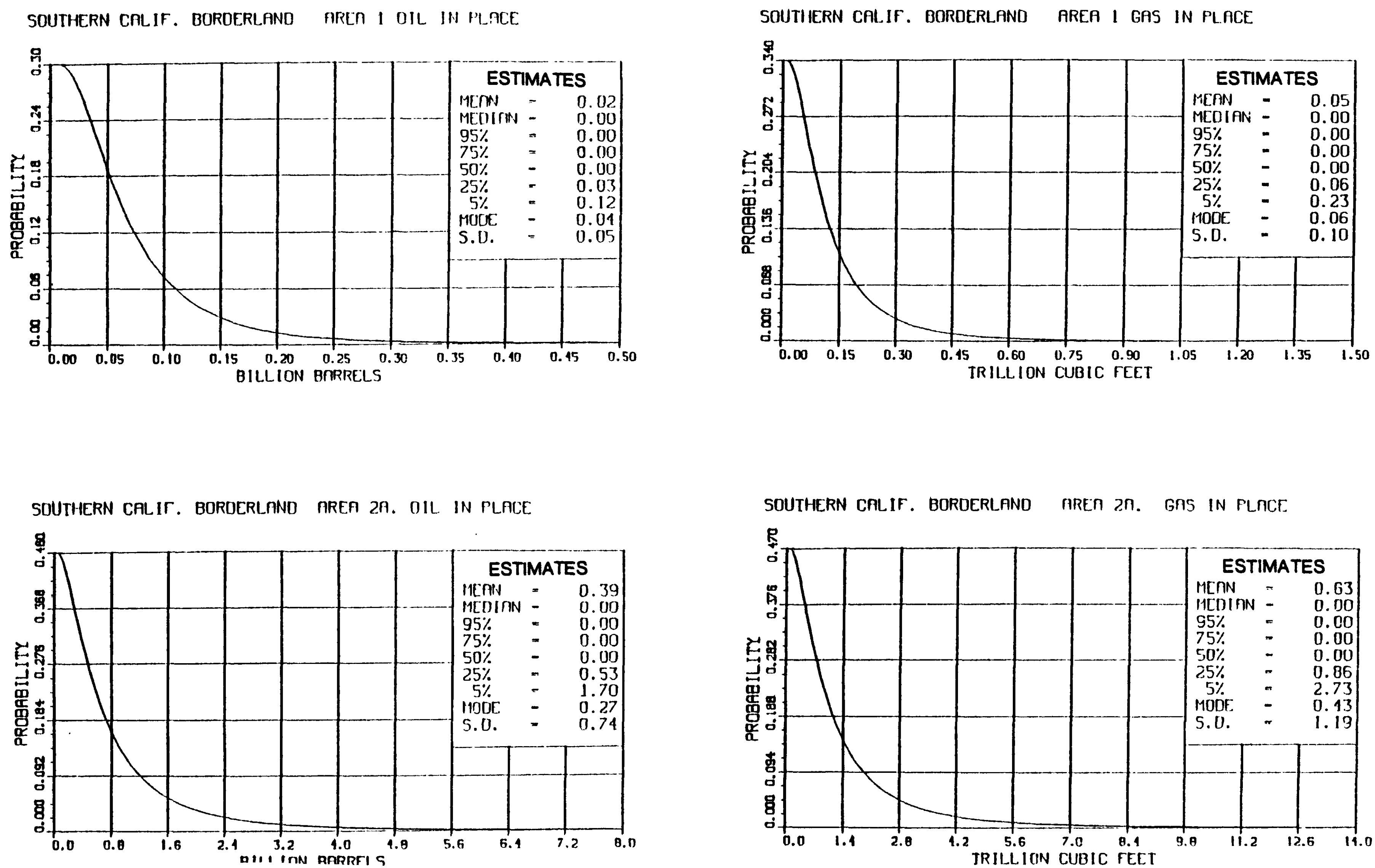
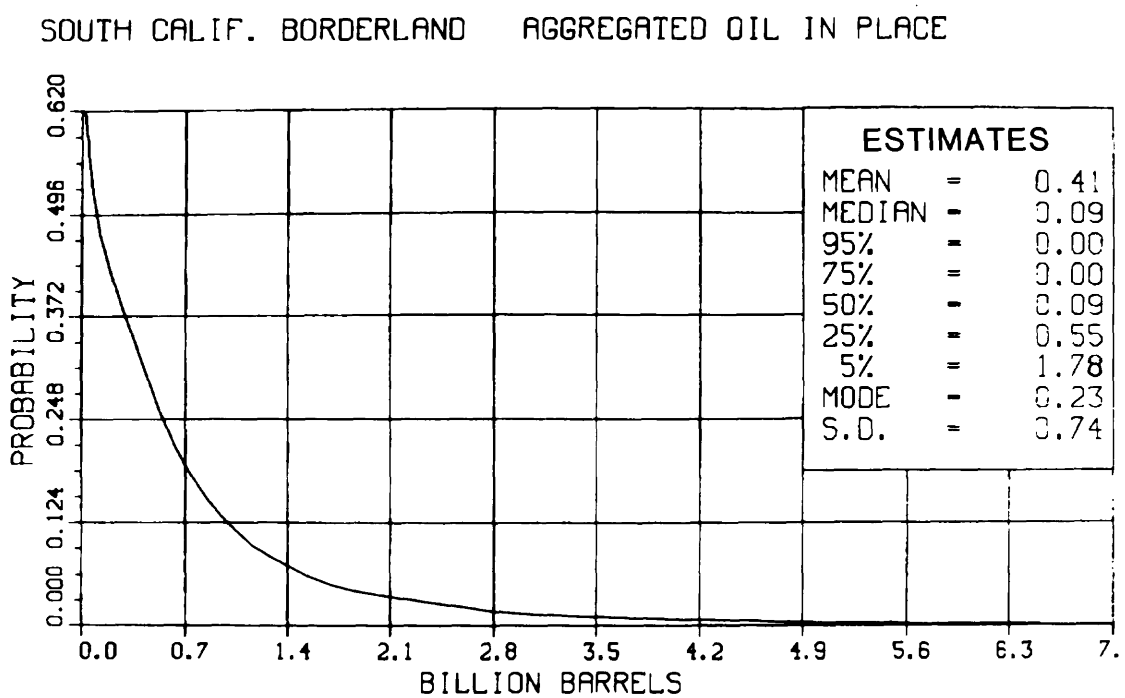



Figure 17.--Probability distribution curves for undiscovered in-place oil and gas resources for Assessment Areas 1 and 2a, offshore Southern California Borderland study area.



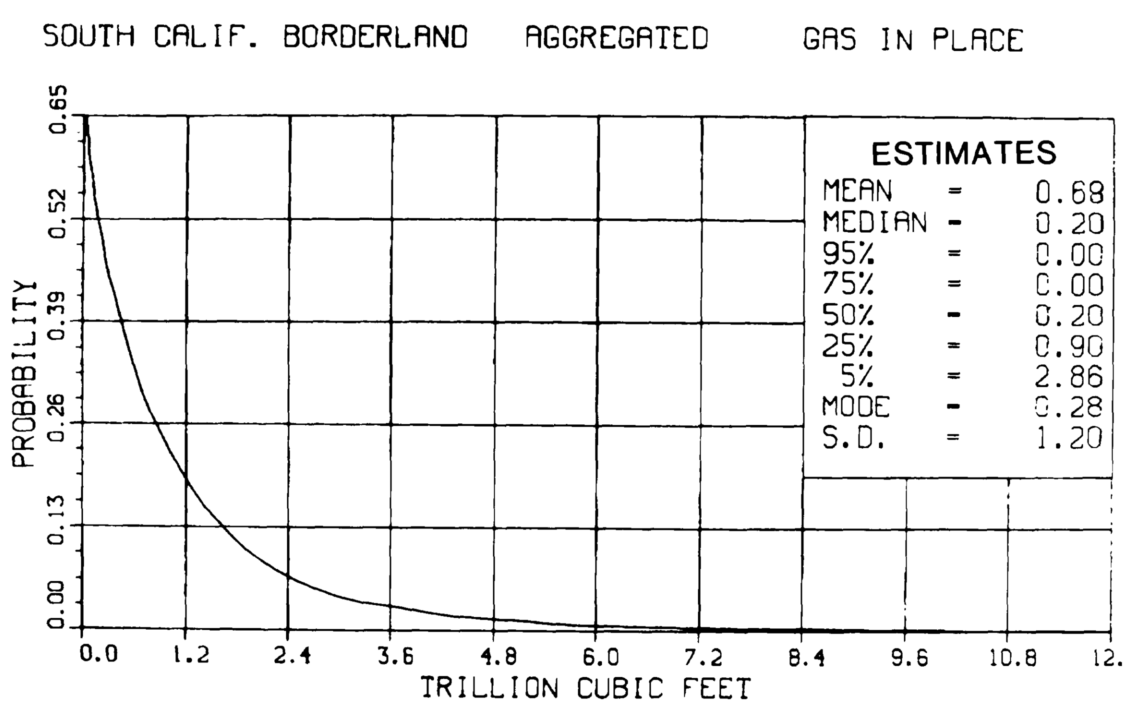




Figure 18.--Aggregated probability distribution curves for undiscovered in-place oil and gas resources for total area of study, offshore Southern California Borderland.

## OTHER MINERAL RESOURCES

By

John G. Vedder

Phosphate.--Phosphorite-rich material is abundantly distributed in the borderland but varies widely in concentration and quality. Mero (1967) estimated that more than 900 million metric tons of phosphatic nodules are present on the sea floor off southern California. Of these, he stated that 90 million metric tons may be of commercial interest. A more recent estimate (Inderbitzen and others, 1970) indicates only about 45 million metric tons of phosphatic nodules and 11 million metric tons of phosphatic pellets of marginal grade. The remainder of the phosphatic material probably consists of thinly scattered nodules too sparse for economic recovery. The $P_2O_5$ content of 53 selected phosphate-rich nodules, as reported by Pasho (1972) and Barnes (1970), showed that in a few areas, phosphorite samples contained as much as 29 and 25 percent $P_2O_5$, respectively. These samples compare favorably with the average onshore minable $P_2O_5$ content of 31 to 36 percent. However, the average $P_2O_5$ content of nodules dredged off southern California is actually much lower grade, as demonstrated by Barnes (1970) in the Coronado Bank area, where 85 percent of the samples had less than 1.0 percent $P_2O_5$, and the average content of all the samples was only 3.3 percent. Thirtymile and Fortymile Banks as well as Coronado Bank were prospected by the ocean-mining industry in the mid-1960's at depths of 262 to 1,197 ft (80 to 365 m). The results were disappointing, and a later economic analysis (Sorensen and Mead, 1969) concluded that both the quality and quantity of phosphorite off southern California are too low to warrant exploitation in the foreseeable future.

Phosphate-rich rocks off southern California are present in many geologic environments ranging from bank tops to the outer shelf and upper slope. Holocene accumulations, which are very widely distributed, generally occur as nodules and pellets, largely in areas of spring and summer upwelling of cold waters. Offshore phosphorites were first recognized in 1937 among samples dredged from bank tops (Dietz and others, 1942). Subsequent sampling has extended the range of known occurrence in the California Borderland to the outer shelf, upper slope, flanks of banks, and tops of ridges and seamount areas. Water depth seems to exert little, if any, control on nodule or pellet formation and they are found at depths greater than 10,940 ft (3,335 m). Radiometric dating suggests that most of the phosphatic nodules dredged off California were derived from underlying bedrock of Miocene age. Outcrops of this mainly low-grade phosphatic shale are scattered across large tracts of sea floor; fragments are eroded and dislodged by wave and current action, and these then serve as nuclei for intermittent addition of phosphatic coatings, which commonly contain ferromanganese oxides and other materials. Many nodules are apparently the result of direct erosion and reworking of Miocene phosphatic and nodular shales, but other conglomeratic nodules from Coronado, Tanner, Fortymile, and Thirtymile Banks may be mostly Miocene phosphatic clasts cemented within a younger matrix of phosphatic and other materials (Pasho, 1972; Barnes, 1970).

Manganese.--Manganese nodules occur predominantly on the abyssal ocean floor and submarine ridges, and sporadically on the lower parts of the Continental Slope. On the borderland, manganese dioxide is sparsely distributed as nodules and commonly as micronodules or grains and coatings on rocks. On the slopes of Northeast Bank, volcanic blocks of probable Pliocene age are coated by manganese crusts as much as 0.4 in. (1 cm) thick (Hawkins and others, 1971). The U.S. Geological Survey has dredged manganese-rich slabs and nodules more than 2 in. (5 cm) in diameter from the west slope of La Victoria Knoll 22 mi (35 km) east of Sixtymile Bank. The nodules from the shallower nearshore localities contain more iron and less manganese than those from abyssal depths (Manheim, 1965). Cronan (1972) studied three samples from an average depth of 3,760 ft (1,146 m) on the borderland; these suggest that iron forms 80 to 85 percent of offshore California nodules and that manganese forms 15 to 20 percent. Nodules having these compositions are not of significant commercial interest. Rawson and Ryan (1978) showed nodule areas on the borderland and in the adjoining ocean basin; they reported high percentages of manganese and iron and very low percentages of cobalt, nickel, and copper indicated by 14 analyses.

Barite.--Barite has been described from steep basin slopes east of San Clemente Island (Emery, 1960) and has been noted more recently from widely spaced localities 19 mi (30 km) southwest of San Nicolas Island, on the steep southwest slope of Cortes Bank, on Patton Escarpment, and on a fault scarp 9 mi (15 km) southwest of Navy Bank (Vedder and others, 1974; Lonsdale, 1980, in press). The barite southwest of Cortes Bank was dredged as freshly broken blocks as much as 12 in. (30 cm) across. Most blocks are composed of a porous mesh of crystals containing veinlets and concretionary growths of dense barite. In others, the barite cements glauconitic and foraminiferal sand, in which some fossil assemblages are as old as middle Miocene. The barium sulfate solutions may have originated from volcanic magma as suggested by high barium concentrations in nearby late Tertiary volcanic rocks (Hawkins and others, 1971) or from interstitial solutions in deep-sea sediments (Church and

Wolgemuth, 1972). Whatever their source, the solutions probably have been expelled and precipitated along fault zones, similar to the emplacement of a barite vein 3.28 ft (1 m) thick along a fault on the south side of the Palos Verdes Hills (Emery, 1960). The Holocene barite deposits southwest of Navy Bank are attributed to precipitation around submarine thermal springs (Lonsdale, 1980, in press).

## ENVIRONMENTAL AND BOTTOM HAZARDS

By

John G. Vedder

Several parts of the borderland north of lat $32^{\circ}$ N. have been investigated specifically for the delineation of potential environmental problems. Among these areas are the Santa Rosa-Cortes Ridge, the Gulf of Santa Catalina, and the San Diego Trough. The environmental phenomena assessed include faults, seismicity, sediment instability, sediment erosion, and hydrocarbon seeps. Although environmental studies have not been done south of lat $32^{\circ}$ N., potential problems presumably are analogous to those identified farther north.

Borderland, Inner Part.--Two major northwest-trending fault zones transect the inner basins and banks area; they are the Palos Verdes Hills-Coronado Bank and Newport-Inglewood-Rose Canyon fault zones (figs. 11, 19). Offsets of the sea floor and disrupted young (Holocene) sediments suggest that many faults associated with these zones may be active (Ziony and others, 1974; Jennings, 1975; Greene and others, 1979). In the San Pedro shelf area, active faults seem to be a major geologic hazard. Probably the most important is the offshore extension of the Palos Verdes Hills-Coronado Bank fault zone, branches of which extend for 110 mi (177 km) across the Palos Verdes Peninsula, San Pedro Shelf and Gulf of Santa Catalina. Earthquake epicenters and sea-floor offsets along this zone verify its continuing activity. A similar zone, called the San Diego Trough-Maximinos fault zone (fig. 11), extends from the north end of San Diego Trough nearly to lat $31^{\circ} 30'$ N. before passing onshore (Legg and Kennedy, 1979).

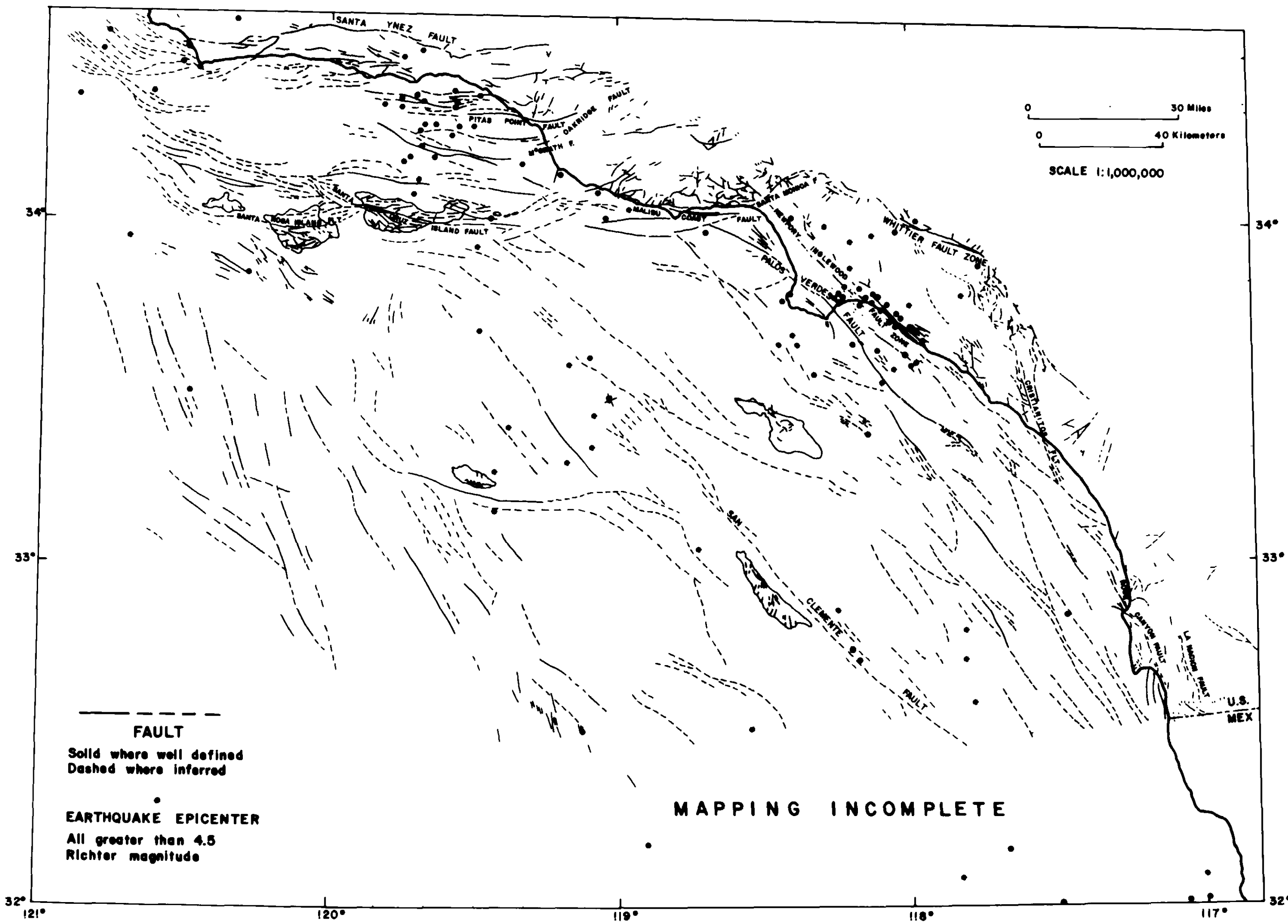



Figure 19.--Map showing locations of known and inferred faults in the coastal zone and borderland of southern California. Epicenters of earthquakes greater than the Richter magnitude 4.5 are shown by solid circles for the period 1932-1973.
Sources: Vedder and others, 1969; Hileman and others, 1973; Campbell and others, 1975; Greene and others, 1975; Jennings, 1975; Yerkes and Lee, 1979a; Lee and others, 1979; U.S. Geological Survey, unpublished data.

Many other faults that continue upward to the sea floor must be considered environmentally hazardous, as they cut beds of Holocene age (Junger and Wagner, 1977; Greene and others, 1975, plate 13; Greene and others, 1979, fig. 1).

Areas known to be prone to submarine sliding occur in the submarine canyons and on the mainland slope of the entire coast from Point Conception to San Diego. Large zones of mass movement have been mapped in detail on the slopes of the Hueneme-Mugu shelf (Greene and others, 1978), Santa Monica Bay (Haner and Gorsline, 1978), off Point Fermin (Greene and others, 1975), and off Dana Point (Field and Edwards, 1980).

The inner borderland is moderately active seismically (figs. 19 and 20), but maximum credible earthquakes and their recurrence intervals have not been predicted. Only a few locally generated tsunamis have been recorded along the coast between Santa Monica Bay and the Mexican border, and none of these caused major damage; one was noted in 1879 at Santa Monica, two others were reported in 1925 (uncertain) and 1933 at Long Beach (Iida and others, 1967), and several have been recorded at San Diego (Agnew, 1979). The 1933 seismic seawave resulted from the March 10, 1933, Long Beach earthquake.

Oil and gas seeps have been reported in the northern part of Santa Monica Bay along the probable extension of the Malibu Coast fault, in southern Santa Monica Bay along the probable extension of the Palos Verdes fault, and offshore between Point Vicente and Point Fermin (Greene and others, 1975, plates 10, 13). Wilkinson (1971) showed two oil seeps and one gas seep in the San Pedro shelf area. Other seeps presumably occur farther south, but their locations have not been documented.

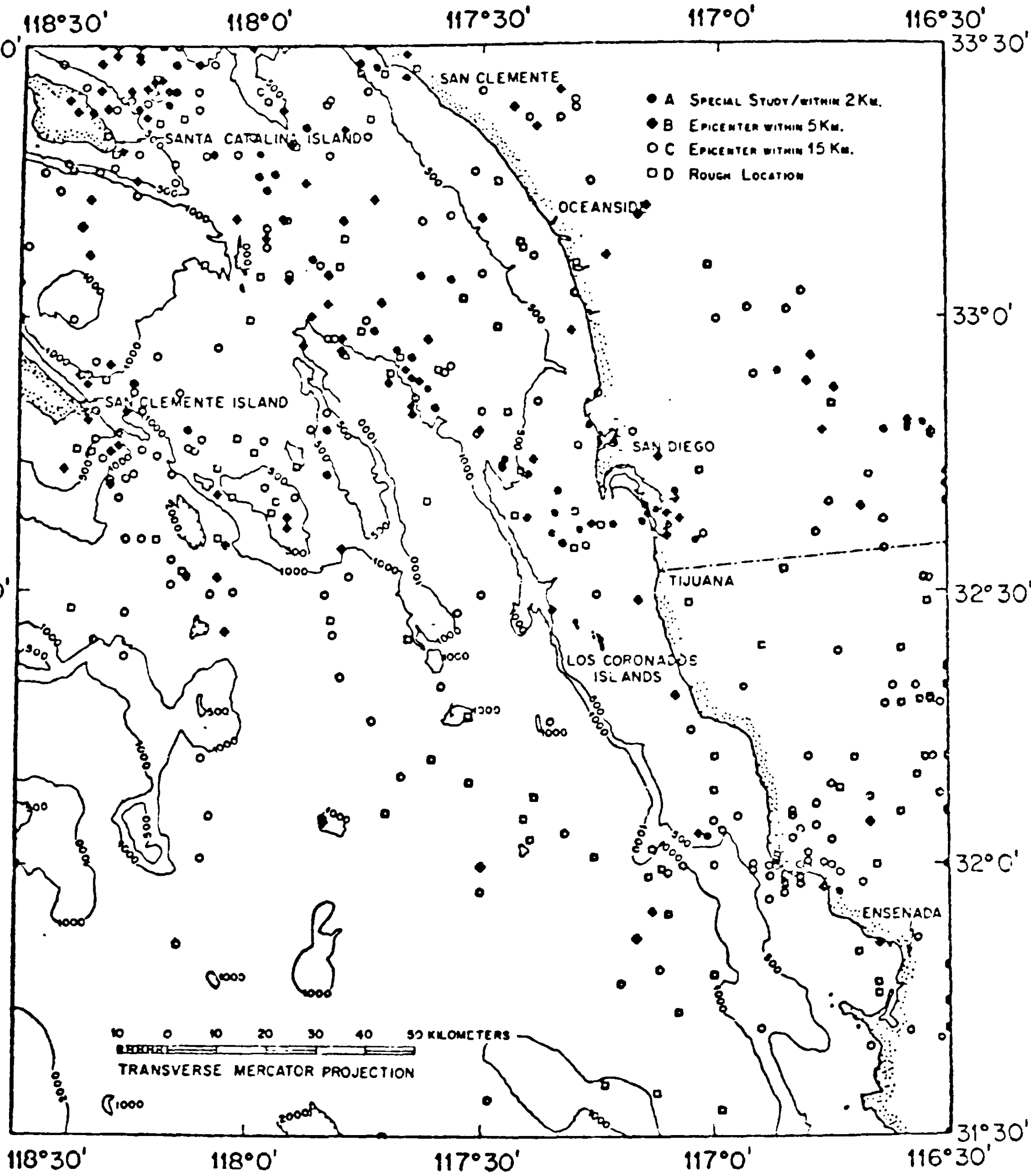



Figure 20.--Epicenters of earthquakes offshore of southern California and northern Baja California, Mexico, during the period 1 January, 1932 - 30 September, 1976 (Legg and Kennedy, 1979).

Borderland, Outer Part.--Few reports have been published on geologic environmental problems on the outer part of the borderland, and the area south of lat 32° N. is largely unsurveyed. Geological hazards on the northern part of the Santa Rosa-Cortes Ridge and Tanner-Cortes Banks were described by Greene and others (1975), Field and Clarke (1979), Field and Richmond (in press), and Nardin and others (1979).

The longest Quaternary fault mapped in the outer basins and banks area is the San Clemente fault (figs. 7 and 11); the northwestern segment is 50 mi (80 km) long, and the southeastern segment, more than 15 mi (24 km) long (Jennings, 1975; Legg and Kennedy, 1979). Many other smaller faults transect the area, and some apparently are active. The Santa Rosa-Cortes Ridge in particular seems to be tectonically unstable. Faults are common along the ridge crest where relatively small apparent vertical separations are characteristic (Greene and others, 1975, plate 5; Field and Richmond, in press). Beneath the flanks of the ridge, faults are less numerous but are longer and have greater apparent vertical separations than those on the crest. Sea-floor offsets above displaced seismic reflectors suggest that some faults are active. At Tanner and Cortes Banks, faults are concentrated along the northern flank of Cortes Bank and along the southern edge of the ridges and troughs between the two banks (Greene and others, 1975, plate 2). Many of these faults displace either Holocene sediments or the sea floor.

Numerous submarine slumps and sediment slides have taken place along the flanks of the Santa Rosa-Cortes Ridge from Santa Rosa Island to Tanner and Cortes Banks. Recurrent slumping is likely because slopes are relatively steep ($4^{\circ}$-$7^{\circ}$), and unconsolidated Holocene sediments are locally thick. The failure zones vary in size from large slumps measuring several square miles (kilometers) (Field and Richmond, in press) to small features measuring hundreds of square feet (meters) (Field and Clarke, 1979).

The Santa Rosa-Cortes Ridge area is moderately active seismically, and most of the earthquakes have been estimated to to be between 2.5 and 4.5 Richter magnitude (Hileman and others, 1973; Greene and others, 1975, plate 5). During a 4-year period between 1970 and 1973, the USGS (U.S. Geological Survey) seismic network recorded 11 earthquakes beneath the northern ridge ranging from less than 2.5 to greater than 3.5 Richter magnitude (Greene and others, 1975). Several earthquakes have been reported in the vicinity of San Clemente fault. In 1941, a Richter magnitude of 5.9 to 6.0 earthquake was recorded from an area near the southeastern extension of the San Clemente fault (Lamar and others, 1973). Significant earthquakes also have been reported from the vicinity of San Nicolas Island. Because Tanner and Cortes Banks are beyond the limits of the seismographic network, no reliable epicenter data exist for the area, and thus, no estimates can be made of maximum credible earthquakes and recurrence intervals. Tsunamis have not been reported in the outer part of the borderland. However, some of the ridges, banks, and island platforms are in shallow water, and the generation of seismic seawaves in this region could pose a hazard to engineering structures of coastal facilities.

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

Distribution of sediment types on the northern part of the Santa Rosa-Cortes Ridge (clastic sands on the edges, foraminiferal sands in the center) suggests that bottom currents may be strong on the perimeter and weaker in the center. Both the sparse sediment cover on the ridge top, due to the isolation from sediment sources, and the abundance of rocky outcrops devoid of sediment along the axis of the ridge suggest the influence of strong current activity (Greene and others, 1975, plates 8, 9; Field and Richmond, in press). On Tanner and Cortes Banks, strong current activity is suggested by areas of exposed bedrock and by the thinness of the sediment cover over much of the nearby area (Greene and others, 1975, plates 1, 2, 4).

# TECHNOLOGICAL FEASIBILITY OF DEEP-WATER DRILLING AND PRODUCTION

by

Kent Stauffer, Maurice Adams,

Richard Habrat, and Dan Bourgeois

## Introduction

This discussion summarizes what is known about the technological feasibility of drilling for and producing hydrocarbons in the parts of the study area that have been identified as having petroleum-resource potential (Assessement Areas 1, 2a, fig. 1). The discussion consists of a summary of current petroleum-industry technology and projected time frames for new techniques and equipment that will be required for drilling and producing hydrocarbons in remote deep-water locations. The assessment areas that have been identified as having petroleum resource potential are in water depths ranging from 295 to 12,000 ft (90 to 3,660 m). Current drilling technology would allow for exploratory operations in the areas under as much as 5,000 ft (1,525 m) of water at the present time, but production operations would require additional time. However, for most of the area, exploration and production technology is not presently available to exploit most of these estimated petroleum resources.

## Deep-water Drilling

Exploratory-drilling technology has progressed well in advance of the technology for development drilling, producing, storage, and loading facilities in deep water. Exploratory wells have been drilled in depths approaching 5,000 ft (1,525 m) whereas the deepest water where production has been established is slightly deeper than 1,000 ft (305 m).

The U.S. petroleum industry has several drilling vessels that can drill as much as 6,000 ft (1,830 m) of water (fig. 21). The water-depth capacity of some of these vessels could be extended to 8,000 ft (2,440 m) with a few modifications. However, only one or two of these vessels have adequate space to store more than 6,000 ft (1,830 m) of riser; therefore, larger vessels will be required.

Drilling technology is sufficiently advanced to support the engineering requirements of continuing to extend the water-depth capability of drilling units, but almost every single element of the entire drilling system will have to have more capability and greater reliability than now available. The main extensions of technology needed are:

A. Further refinement of dynamic positioning, which replaces conventional mooring systems.

B. Further refinement of remote-controlled reentry and sea-floor manipulation systems, which replace conventional guideline systems.

C. Development of larger and stronger blowout preventors and further refinement of electro-hydraulic control systems.

D. Improvement of marine risers, including their buoyancy and disconnect systems, and strengthening of couplings to withstand high tension and pressure.

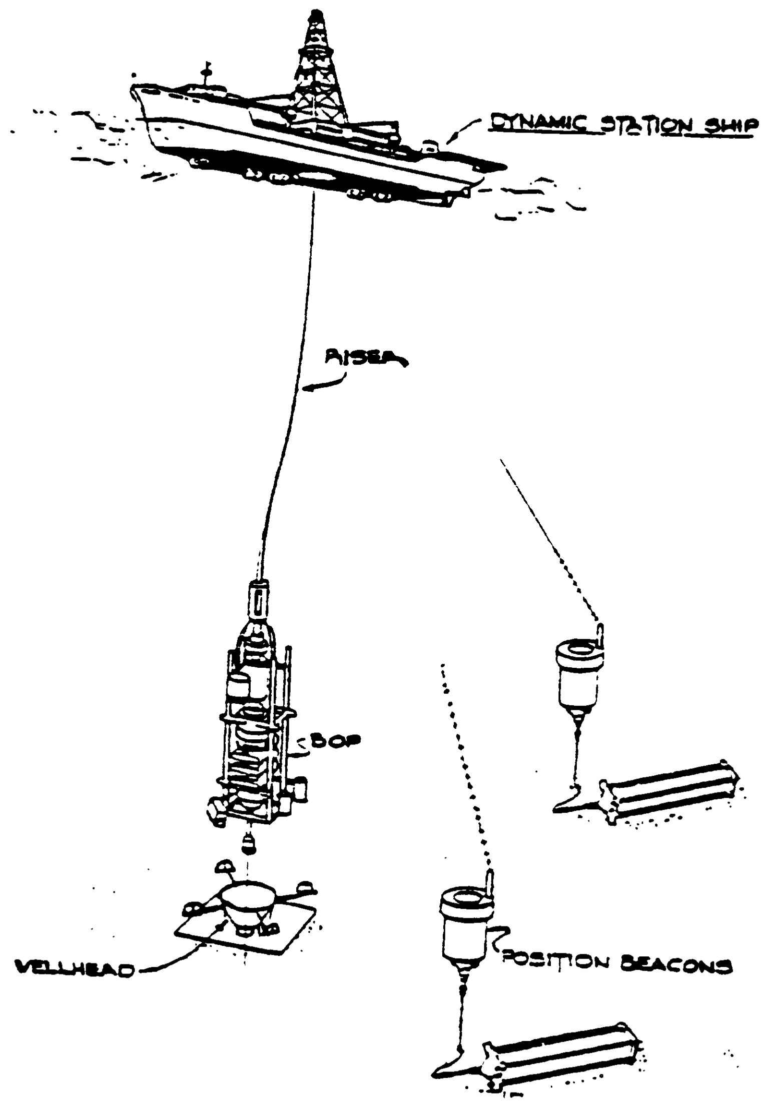



Figure 21.--Diagram of dynamically positioned drill ship.

The National Science Foundation, with the technical and financial assistance of several U.S. petroleum companies, has a project under study that relates to conversion of the Glomar Explorer to a drilling vessel in an attempt to extend some of these technologies. If this project is carried out as planned, the capacity for drilling exploratory wells in water depths as great as 13,000 ft (3,962 m) could be available by 1984.

Technology is currently being devised to provide the methods and equipment for drilling in such deep-water locations. The extent to which this technology will be used off the coast of California will be mainly a function of the amount of petroleum resources, production capability (i.e. bbl. of oil per day), and favorable economic incentives, rather than of technological impossibility.

## Deep-water Production Systems

Deep-water production technology is lagging behind deep-water exploratory-drilling technology. However, during the last several years, the oil industry has begun an intensive program to design equipment and analytical tools, perform model tests, and conduct full-scale tests in preparation for drilling development wells and producing oil and gas in deep water. The following is a discussion of the major types of production systems being considered and their feasibility for use in deep water:

Fixed platform.--Nearly all offshore fields have been developed with bottom-founded, fixed-leg platforms (fig. 22). The present water depth record for a fixed-leg platform is 1,025 ft (312 m) (Shell's Cognac Platform in the Gulf of Mexico). The size of these platforms is approaching the economic limit for fixed-leg structures because of to the very large amount of steel required and

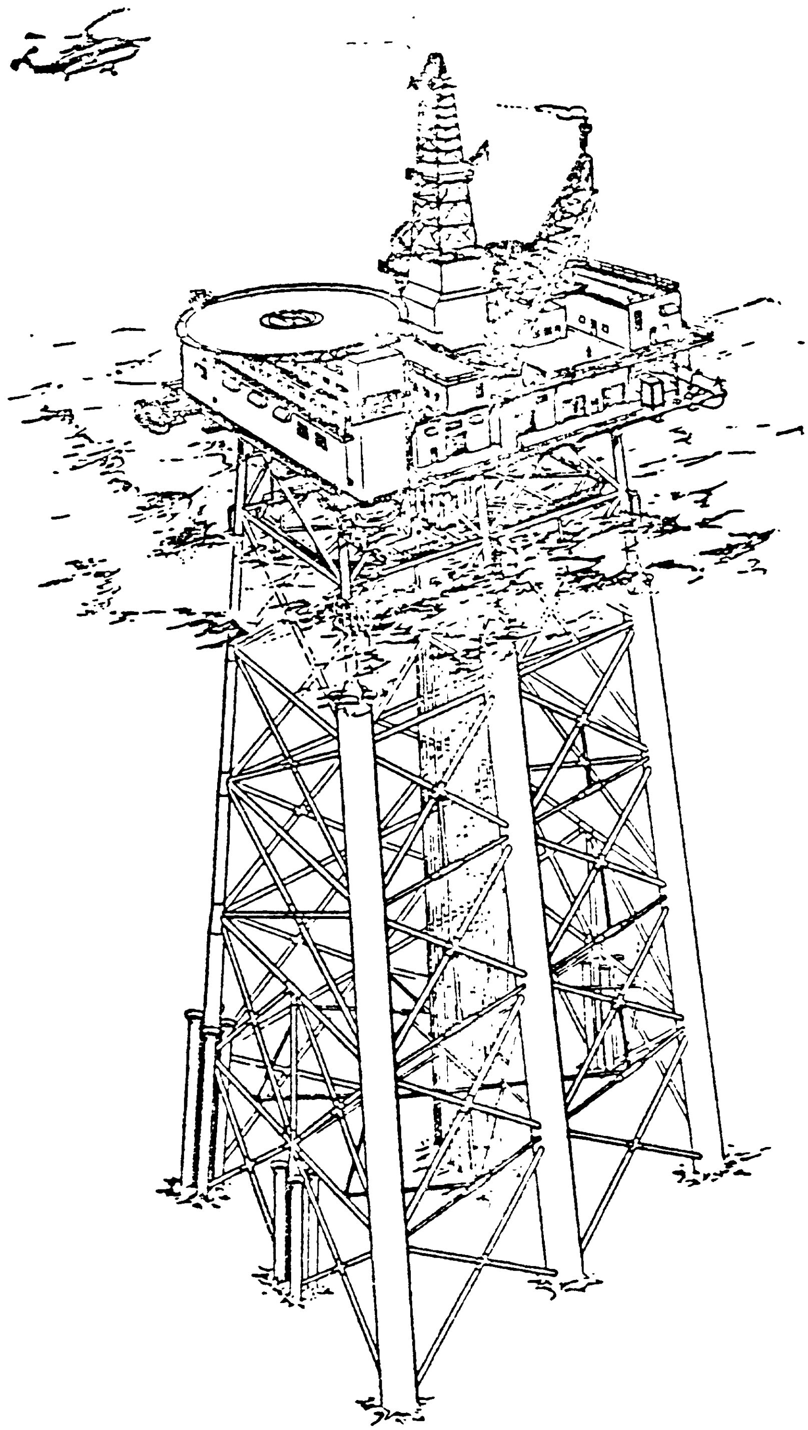


Figure 22.--Diagram of fixed drilling platform.

limitations of fabrication and installation methods. Several concepts have been proposed for modifying platforms to be placed in water deeper than 1,025 ft (312 m).

Guyed towers.--A guyed tower is a compliant structure, which is designed to move with environmental forces rather than to resist them rigidly (fig. 23). Guy lines are used to hold the tower in a vertical configuration. A scale model of this tower has been successfully tested in 300 ft (91 m) of water, and industry is planning to use a guyed tower to develop a Gulf of Mexico field in 1,000 ft (305 m) of water. This type of structure may be applicable in 2,000-2,500 ft (610-762 m) of water, but too much steel is required for these towers to be used in deeper water.

Tension-leg platforms.--A tension-leg platform is also a compliant structure (fig. 24). It is a large floating platform, similar to a semisubmersible drilling rig, connected to the sea floor by vertical tension members. A scale model of this type has been successfully tested in 200 ft (61 m) of water. Plans have been announced by some companies to use a tension-leg platform in the North Sea in 485 ft (148 m) of water. Various studies indicate that this type of structure may be used in 2,500-3,000 ft (762-914 m) of water, and predictions have been made which forecast future applicability of tension-leg platforms in 8,000 ft (2,438 m) of water and more.

Subsea production systems.--All three platform concepts discussed above offer the important advantages of drilling, maintaining, and repairing wells in a conventional manner from a platform deck. The other major type of deep-water production technology involves subsea production systems, which consist of

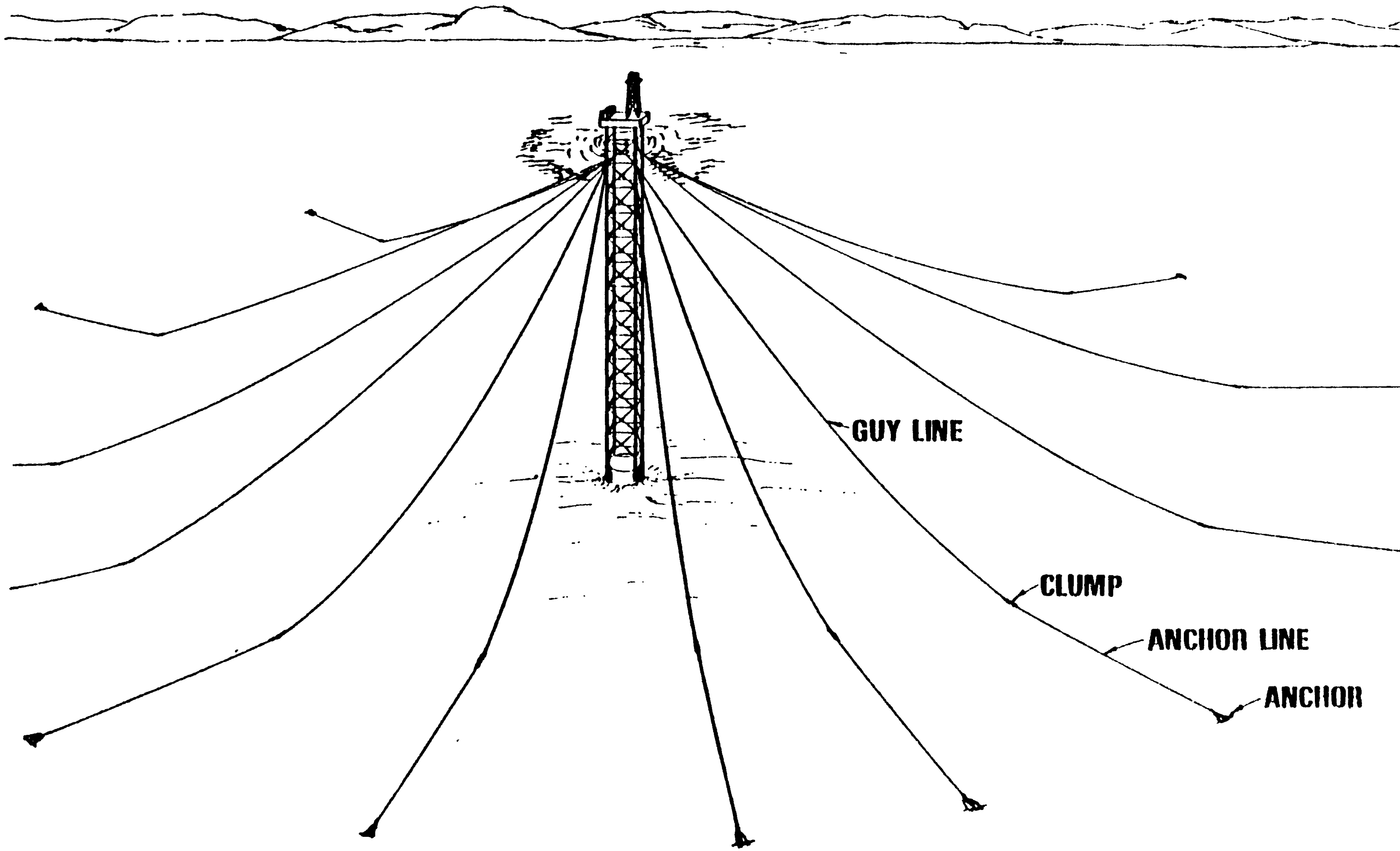



Figure 23.--Diagram of guyed-tower drilling platform.

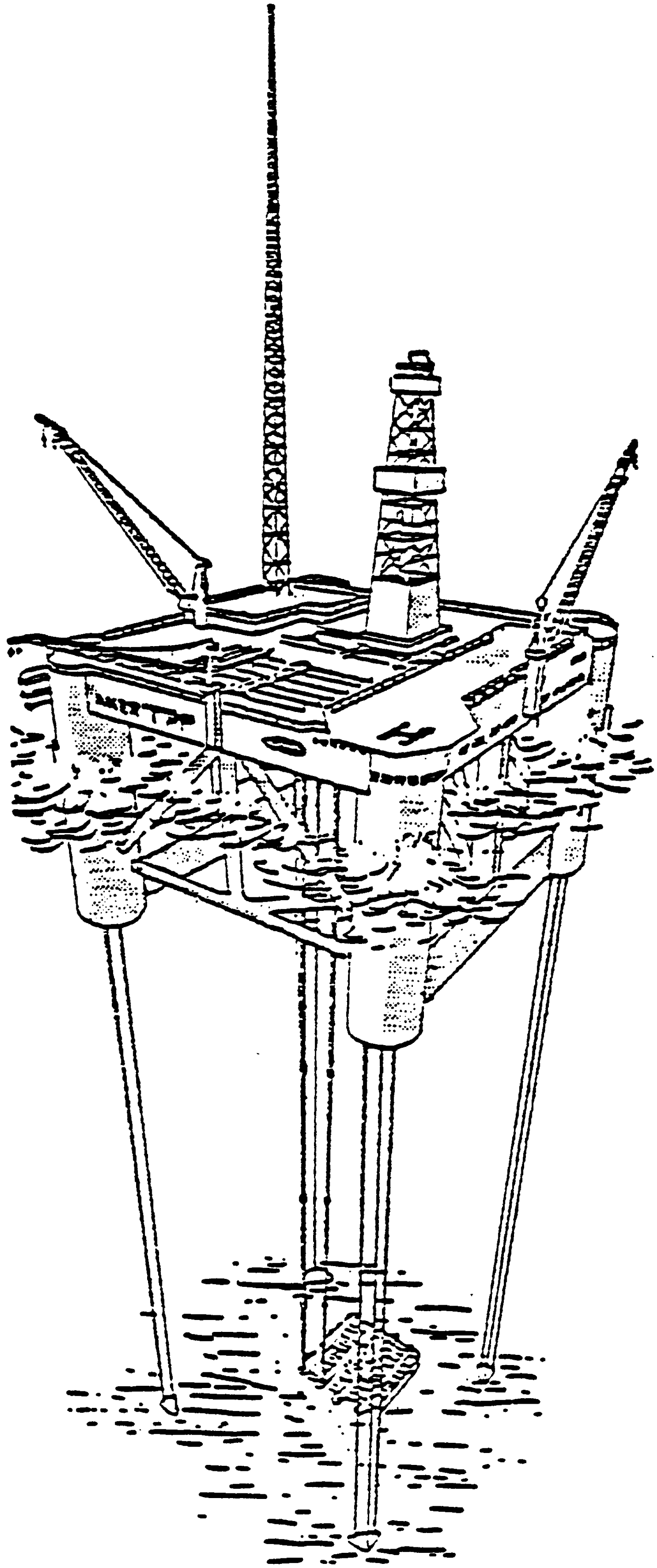


Figure 24.--Diagram of tension-leg drilling platform

wells completed at the sea floor and connected by flowlines and controls back to a surface facility. These systems would be used where platform installation is prohibited by cost or water depth. In recent years, several systems using subsea wells producing to floating facilities have been installed and these systems offer potential for application in deep water. A few of these systems are briefly described below.

Semisubmersible production system.--This system consists of subsea satellite wells completed as "wet trees" and connected by flowlines to a subsea base (fig. 25). A production riser carries fluid to a semisubmersible vessel kept on station by conventional mooring which contains process facilities. All sea-floor equipment is remotely controlled from the surface. Separated oil is pumped down the riser, through a sea-floor pipeline, up a single point mooring facility, to a shuttle tanker. Systems of this type have been installed in 300 ft (91 m) of water, proven for 1,000 ft (305 m) of water, designed for water depths beyond 1,000 ft (305 m), and considered feasible for water depths as great as 8,000 ft (2,438 m).

Subsea atmospheric system.--This system consists of wells drilled through a template and completed as "wet trees" (fig. 26). The wells are connected to a manifold center housed in a large chamber which contains breathable air at one atmosphere. Workers may be transferred to this chamber in a tethered bell of a submersible to conduct various routine maintenance operations. The manifold is connected by pipeline to a production riser, then to production facilities on a floating surface vessel. This system has been installed in 225 ft (83 m) of water, proven to 1,500 ft (457 m) of water, and considered feasible for water depths as great as 8,000 ft (2,438 m).

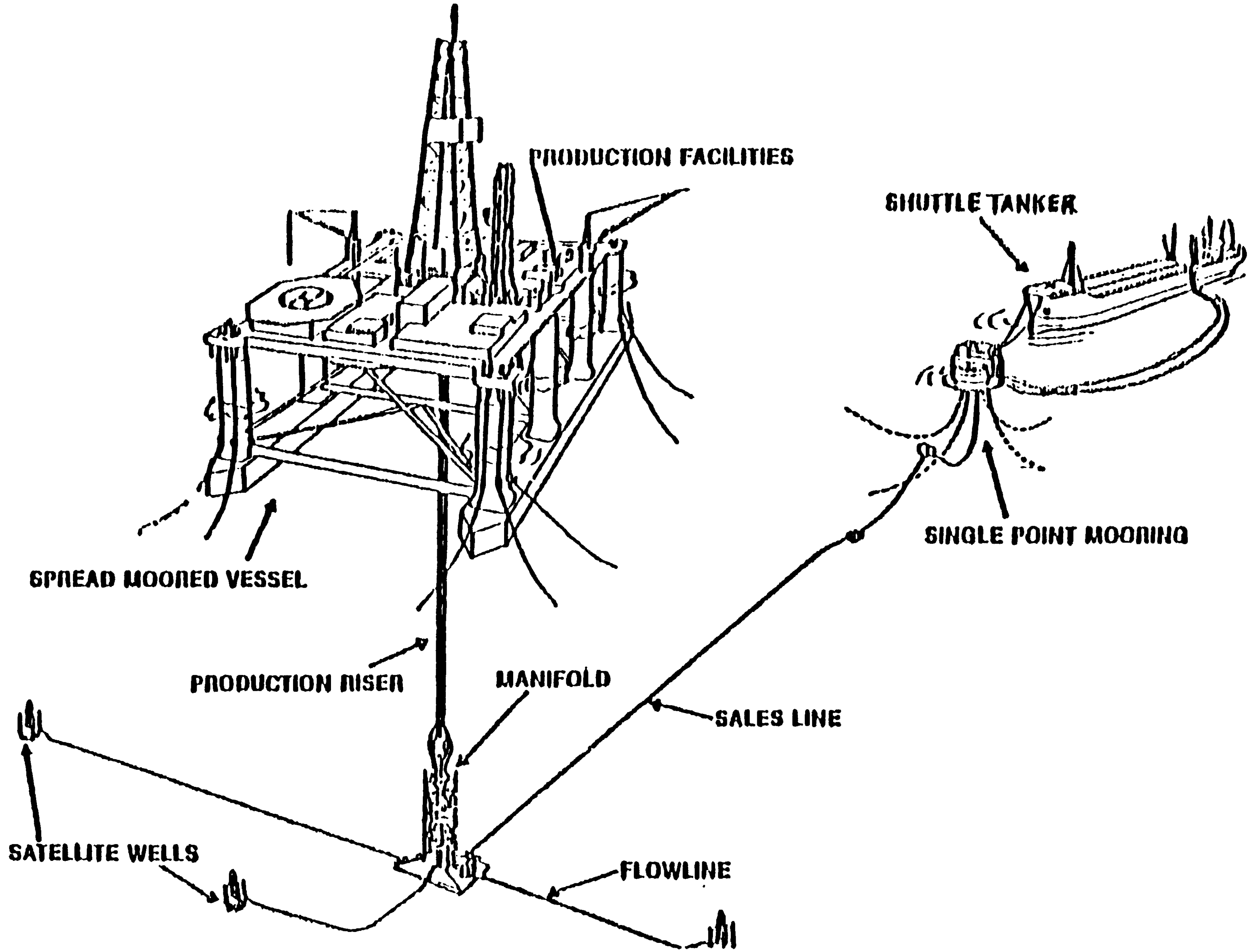



Figure 25.--Diagram of semi-submersible production system.

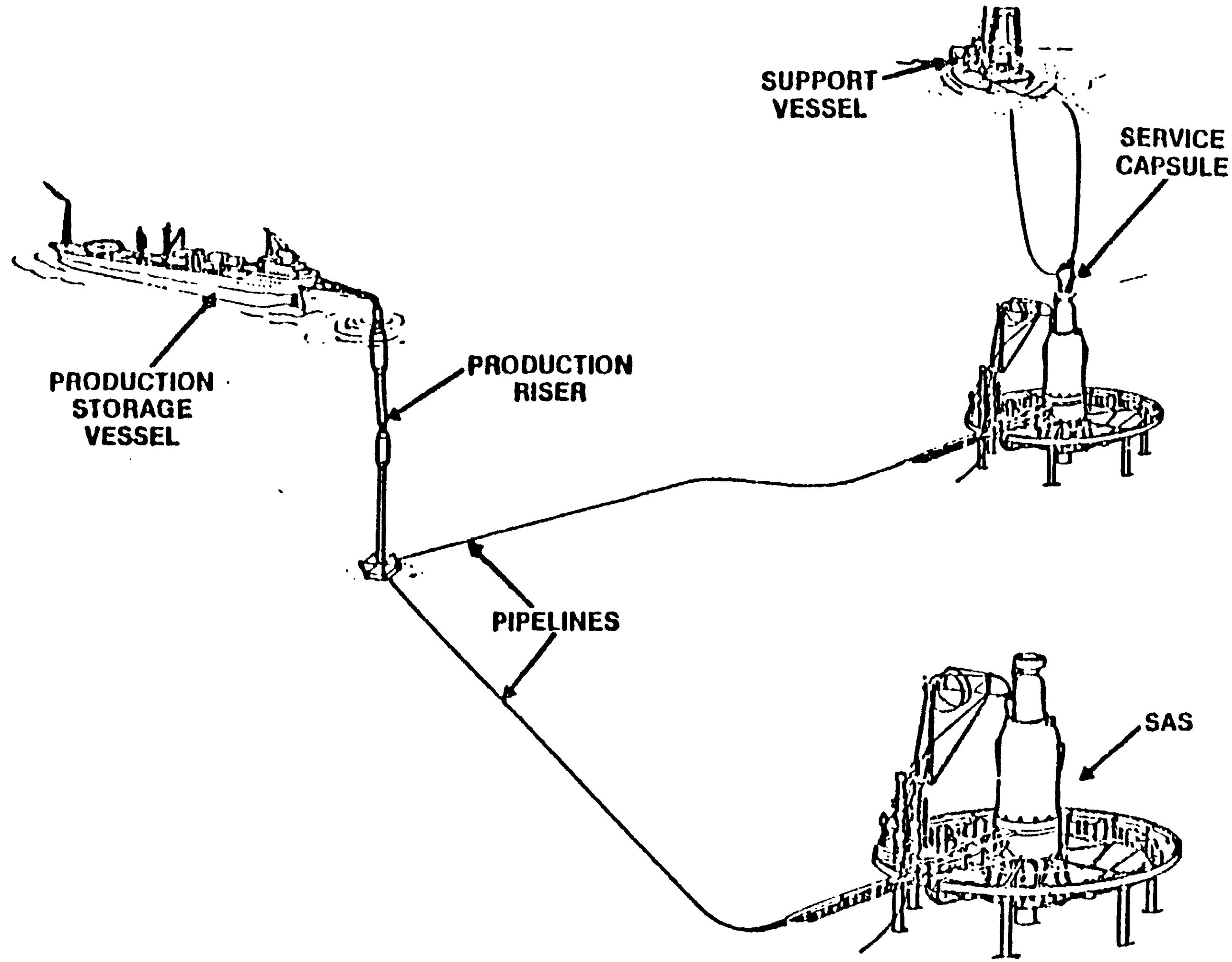



Figure 26.--Diagram of subsea atmospheric production system (SAS).

Subsea production system.--This system consists of wells drilled through an on-bottom template and completed as special subsea trees that connect to a manifold circling the bay area (fig. 27). The manifold is connected by pipeline to a production riser and then to production facilities on a floating vessel. Wells are maintained by use of "through flowline" tools from the surface. Sea-floor equipment is maintained by a special-purpose manipulator operated from the surface which runs on a track around the well bay area. This system has been installed in 270 ft (81 m) of water, and tests indicate that the system can function in water as deep as 2,000 ft (610 m) and deeper.

One-atmosphere system.--This system consists of subsea satellite wells and a manifold center housed in dry chambers (fig. 28). Workers can enter the chambers from a manned, tethered bell to conduct routine maintenance on sea-floor equipment. Wells are maintained by use of "through flowline" tools from the surface. The manifold center is connected by pipeline to the base of a single-point-mooring production riser, which is connected to production facilities installed on a tanker. Oil is transported to market by shuttle tankers, which dock periodically, depending upon production storage capacity. This system has been installed in 450 ft (137 m) of water and has been designed for application in 3,000 ft (914 m) of water.

Although deep-water production technology is lagging behind deep-water drilling technology, subsea facilities probably and platforms possibly can eventually be installed in water depths comparable to those achieved by floating drilling. The main extensions of technology needed are:

1. For subsea systems, improvement of technology to allow subsea power generation, shore-based submarine servicing of underwater installations, and sea-floor storage and pumping facilities.

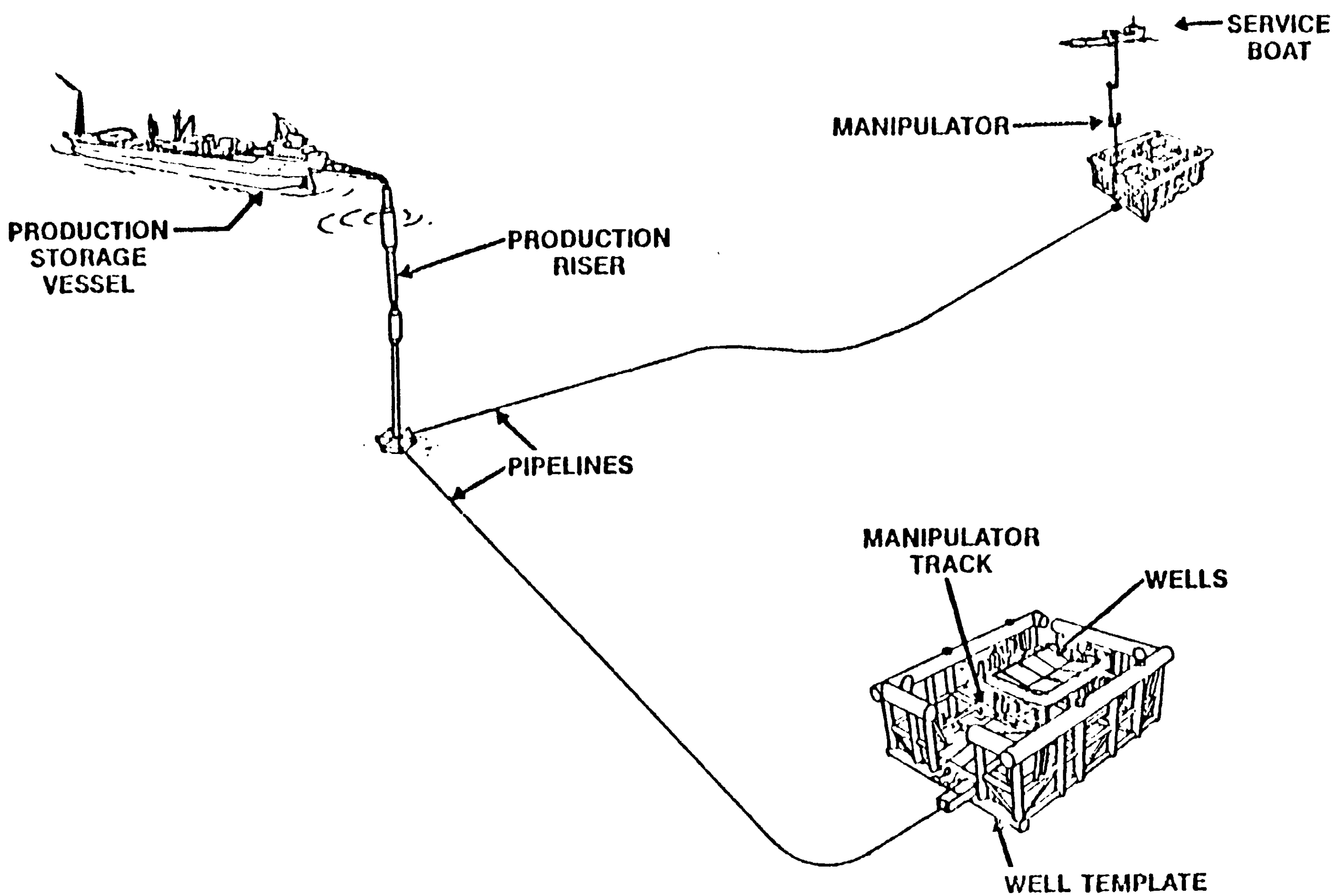



Figure 27.--Diagram of subsea production system (SPS).

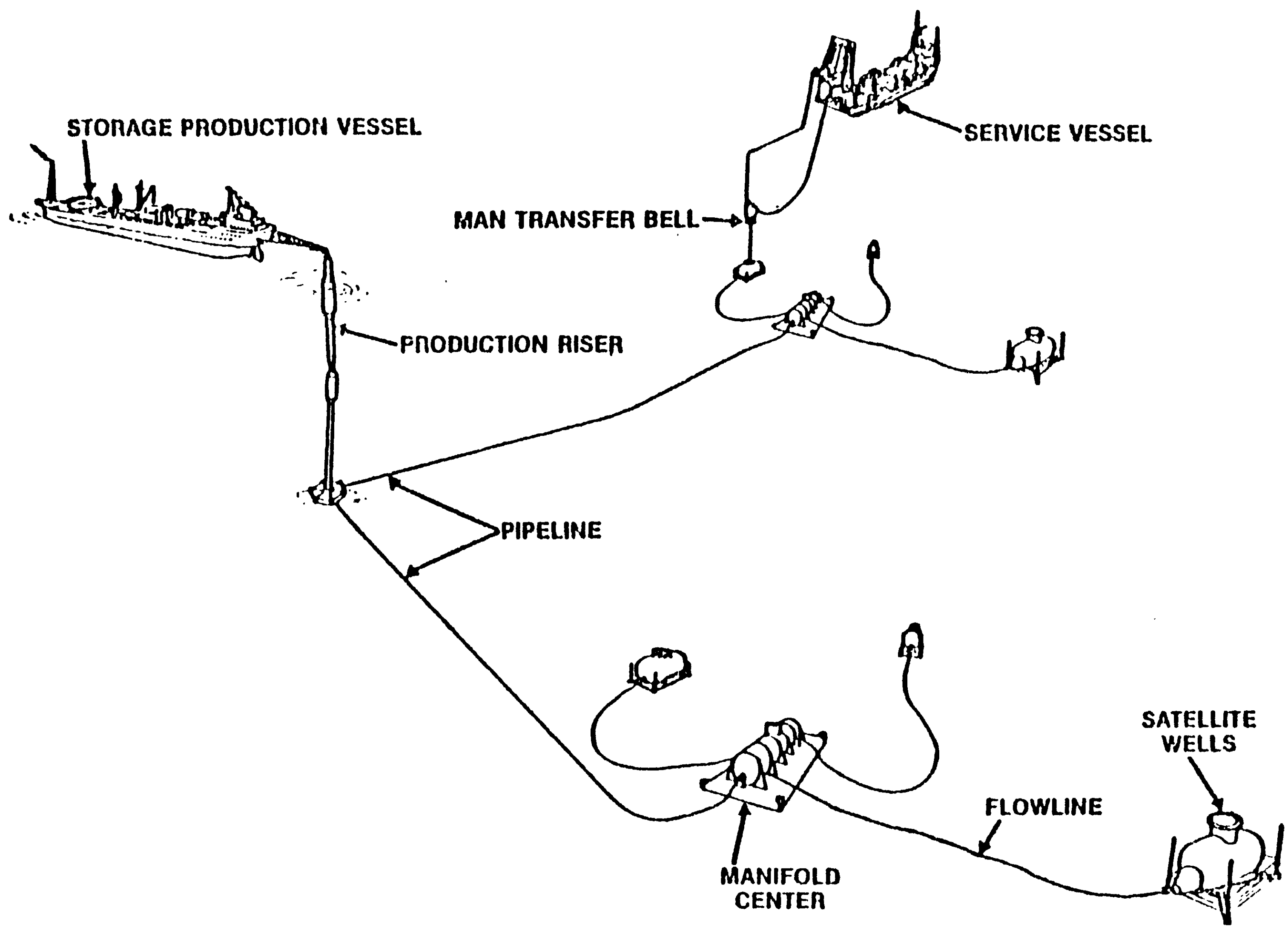



Figure 28.--Diagram of one-atmosphere chamber production system.

2. Production risers able to withstand high tension and pressure.

3. Further refinement of dynamic positioning techniques for surface vessels.

Technology is currently being devised to provide the methods and equipment for oil and gas production in deep-water locations. Drilling and production technology ase expected to be adequate to exploit petroleum resources off the coast of southern California in deep water; petroleum exploitation there is more likely to be hampered by unfavorable economics and lack of petroleum resources than by inadequate technology.

## Deep-water Pipelines

Pipelines are an integral part of any large-scale production operation. During the past several years, the petroleum industry has focused a considerable amount of attention on the subject of deep-water pipelines. Equipment capable of installing deep-water pipelines has been designed, built, and tested, and several deep-water pipelines have been installed. The present water depth record for pipeline installation is 2,000 ft (610 m). Some pipeline-installation methods are reviewed below.

Conventional lay method.--In this method, pipe joints are welded together on a lay barge and then lowered to the seabed in a controlled configuration (fig. 29). The main limitation of this method is the stress that occurs in the bending areas of the suspended pipe. As water depth increases, more tension and mooring system capacity is required to control bending of the pipe.

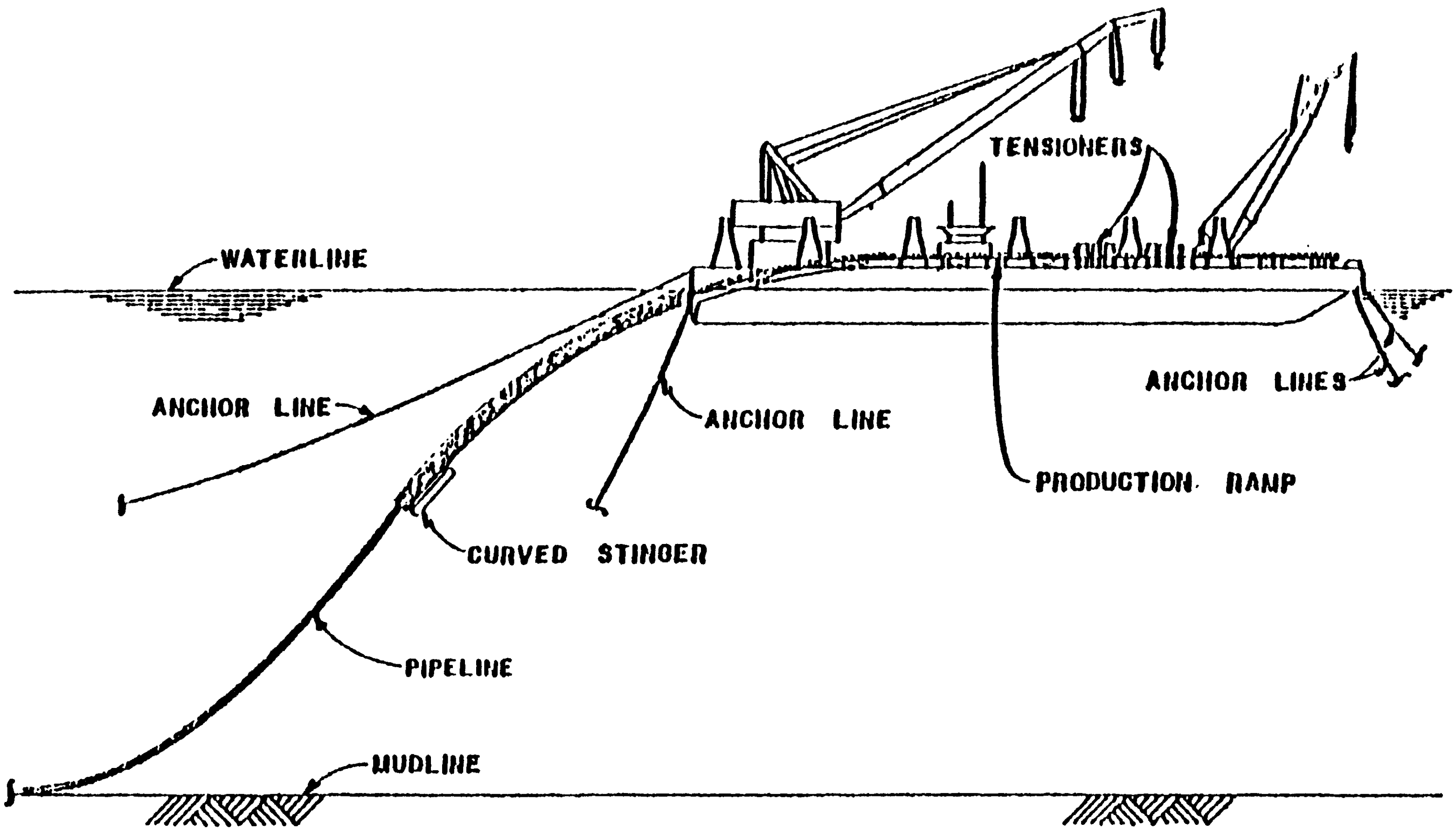



Figure 29.--Diagram of conventional pipeline lay-barge and stinger system.

Inclined-ramp method.--An inclined-ramp method has been devised to eliminate the bending stress in pipe as it leaves the barge (fig. 30). Rapid welding techniques, currently being devised, are required to make this system economical. A project that is in the planning stage would use this method to lay a pipeline in 6,000 ft (1,829 m) of water.

Reel method.--This method uses a continuous pipe string assembled onshore and coiled onto a reel (fig. 31). During laying operations, the pipe is pulled off the reel and straightened as it leaves the ship. The main limitations of the reel method are due to the consequences of coiling and uncoiling the pipe. By use of this method, large-diameter pipe (having a diameter as big as 16 in (41 cm)) can be laid in water as deep as 3,000 ft (914 m), of water and smaller diameter pipe can be laid in even deeper water.

Bottom-tow method.--In this method, pipe is fabricated onshore and fitted with buoyancy and compensation weights, which hold the pipe just off the sea floor during the tow (fig. 32). When in place, the weights are removed to settle the pipe to the sea floor. The major limitations of this method are the vulnerability of the pipe to environmental conditions during the tow and the difficulty in maneuvering long strings of pipe. Feasibility studies indicate that this method can be extended to a water depth of at least 8,000 ft (2,438 m).

The major extensions of technology needed to continue to increase the water depth capacity of pipeline installation and operation are:

1. Practical single-station pipe-joining techniques.
2. Improved barge-mooring systems.
3. Reliable mechanical pipe connectors to replace welding.

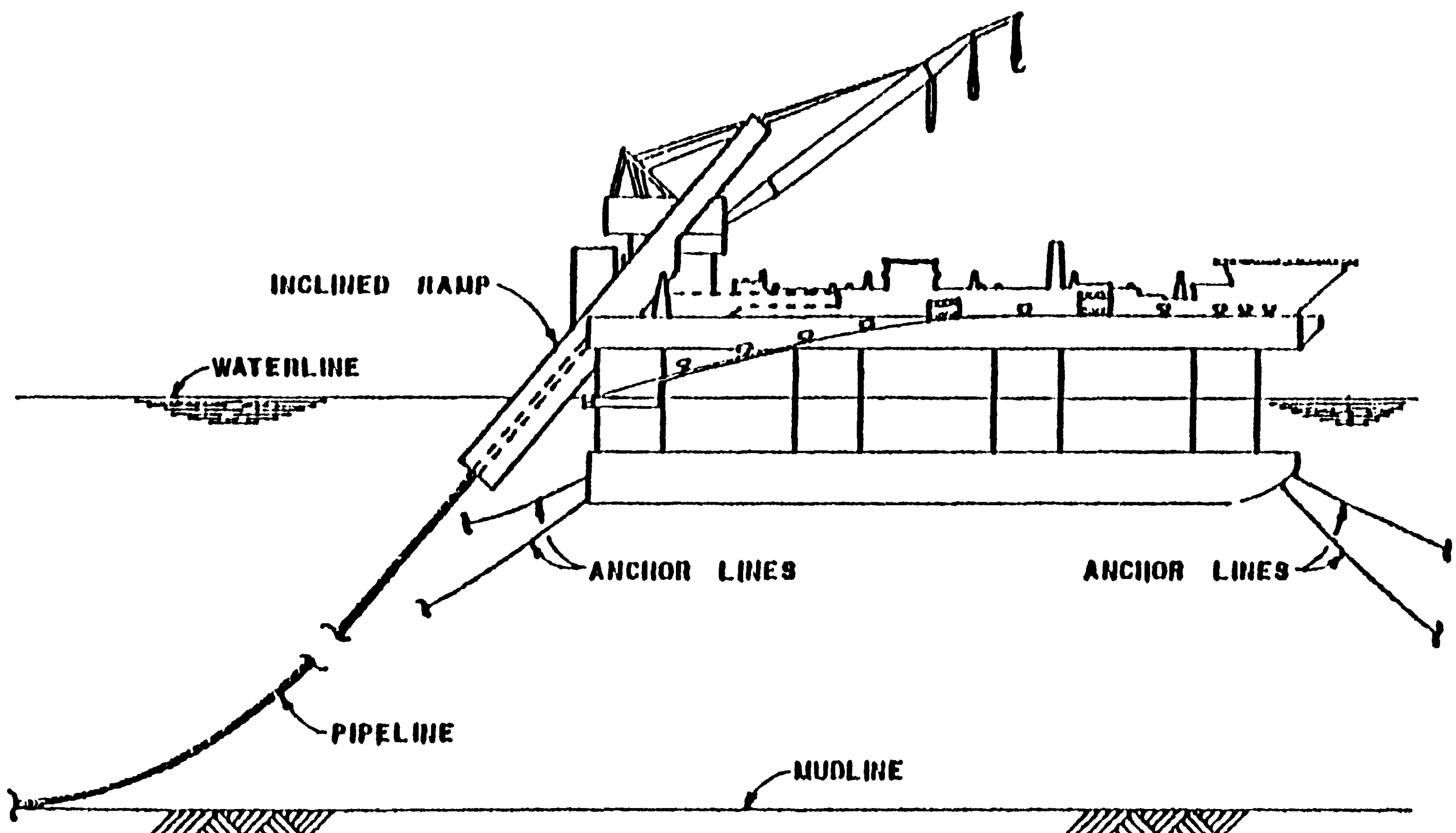



Figure 30.--Diagram of inclined ramp pipeline lay-method.

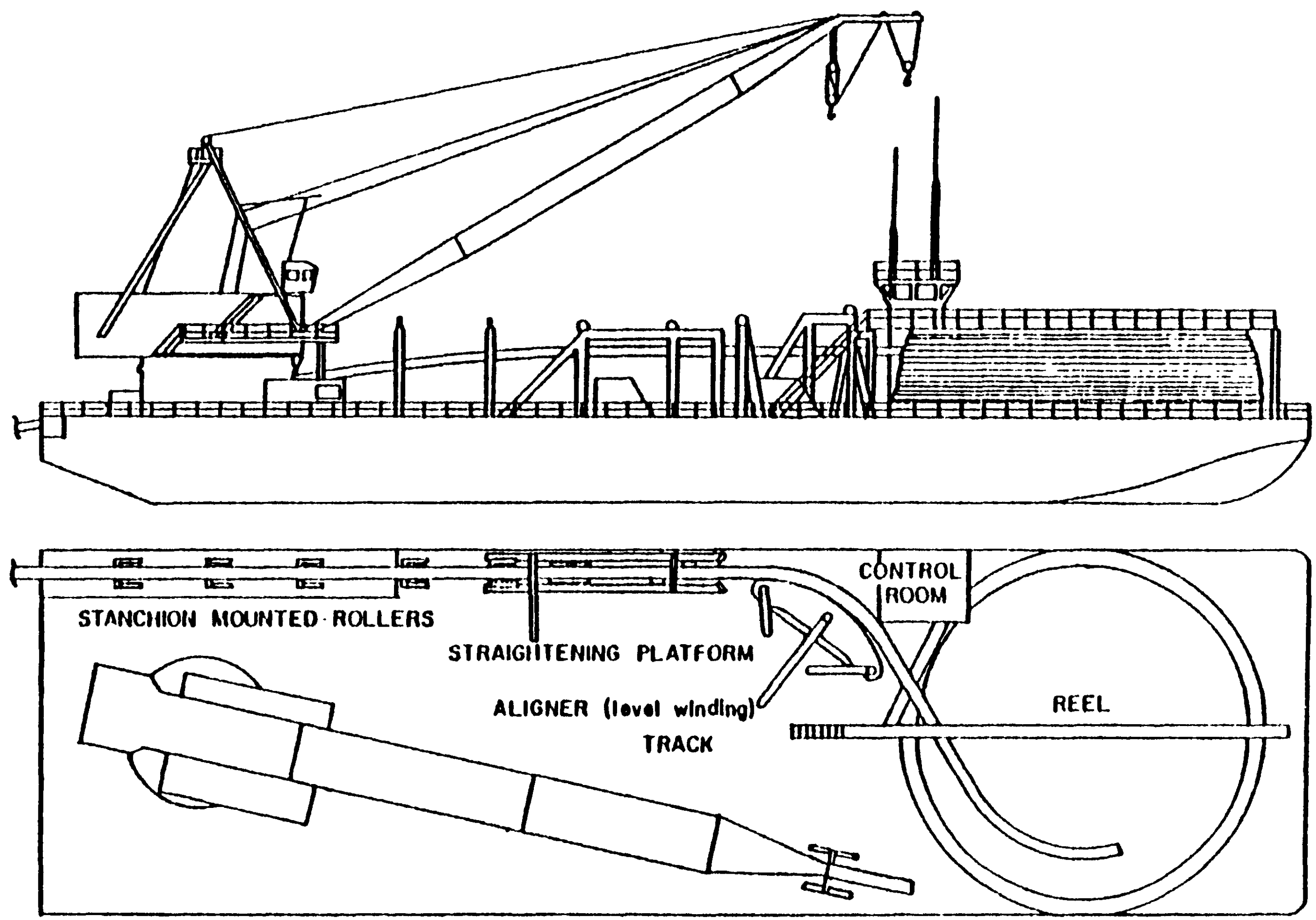



Figure 31.--Diagram of reel-barge pipeline lay-method.

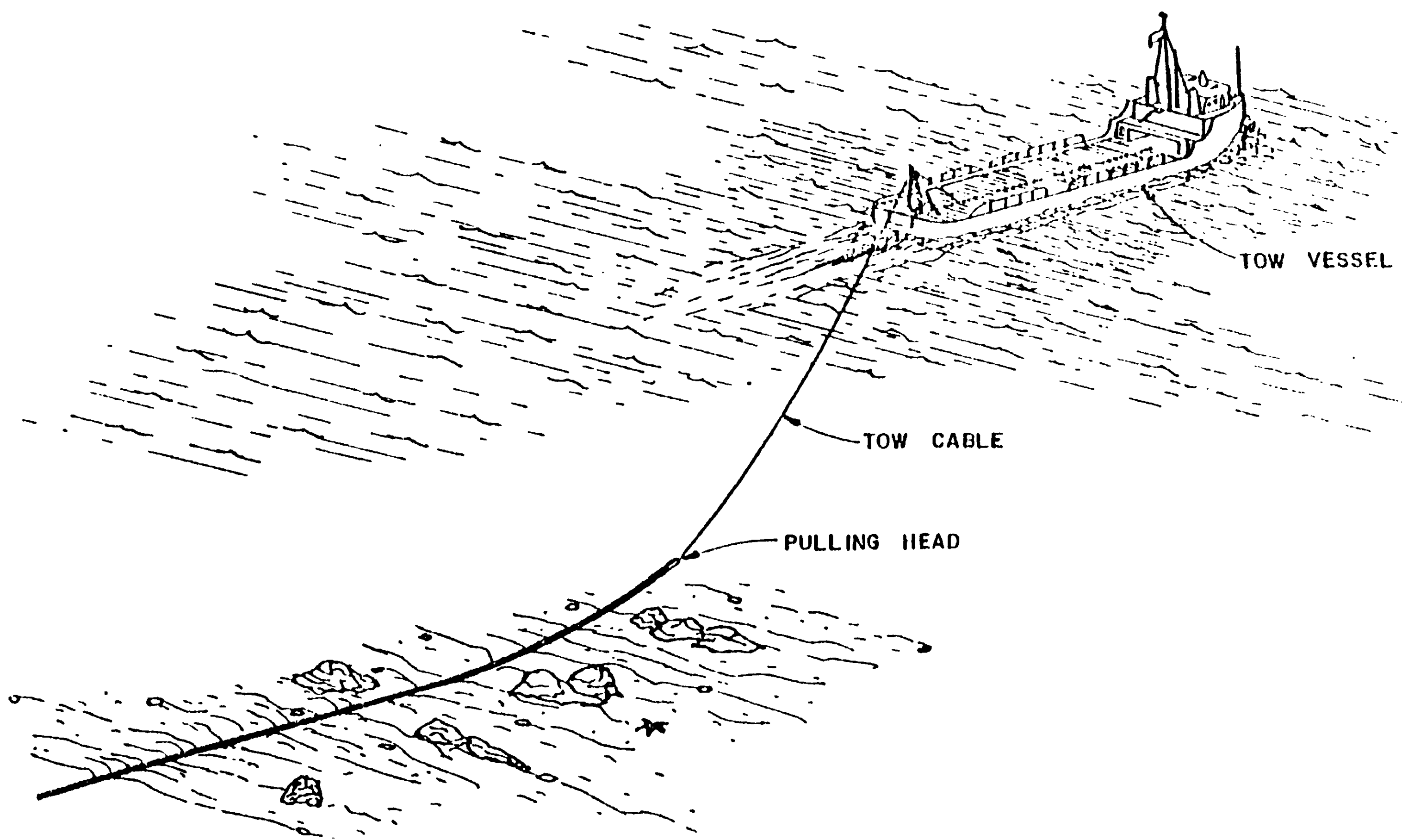



Figure 32.--Diagram of bottom-tow pipeline lay-method.

4. Unmanned systems for inspection, repair, and other activities required to suport offshore pipeline installation and maintenance.

The pipeline industry currently has the capability to lay large-diameter pipe in water depths exceeding 1,000 ft (305 m). Studies indicate that pipe at least 20 in. (51 cm) in diameter can be laid in depths of 3,000 ft (914 m) by existing techniques. Pipe 30 in. (76 cm) in diameter is now available for 3,000 ft (914 m) of water. Like drilling and production technology, pipeline-installation technology is expected to be adequate for exploiting petroleum resources off the coast of southern California in deep water. If economic conditions are favorable and petroleum resources are adequate, deep-water pipeline technology can be devised as an extension of existing conventional techniques.

## Offshore Loading Terminals

In the event that transportation of production from a deep-water location cannot be accomplished through a pipeline, some form of offshore loading terminal will be required instead. Three loading systems that are potentially applicable for use in deep water are the SALM (single anchor leg mooring), the ALP (articulated loading platform), and the SPAR (fig. 33).

The SALM system consists of a buoy at the surface, which is attached to a base on the sea floor by a single anchor chain or leg. Oil is pumped through a flexible hose from the sea floor to a tanker at the surface. The deepest SALM presently installed is in 530 ft (161 m) of water.

The ALP system consists of a base structure and a universal joint connected to a vertical articulated column. At the top of the column is a structure having a rotating head and a flow boom to support a loading hose.

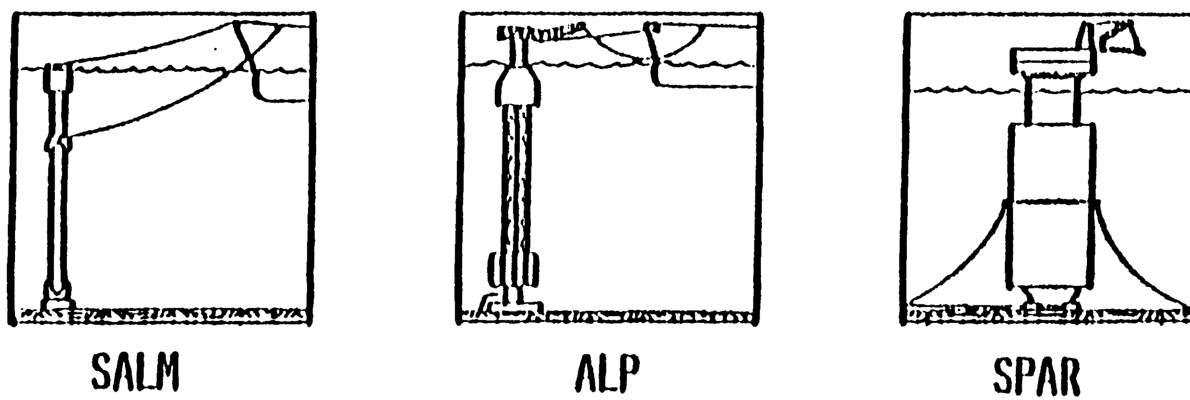



Figure 33.--Diagram of rigid or moored single point moorings (SPM).

This system is designed for uninterrupted loading operations in high winds and rough seas. The deepest ALP presently installed is in 475 ft (145 m) of water.

The SPAR system consists of a vertical floating storage tank. It is stationed in the water by a multileg catenary mooring. Off-loading is accomplished by a retractable boom mounted on a turntable. The deepest SPAR presently installed is in 460 ft (140 m) of water.

Experts on offshore loading believe that present technology will allow existing SALM and ALP systems to be used in water as deep as 2,000 ft (610 m). Studies indicate that terminals for water depths greater than 2,000 ft (610 m) may utilize a combination of various concepts known today. It is likely that in very deep water, pipelines will carry oil to loading terminals in shallower water.

## Supporting Systems for Installation, Inspection, and Repair

Because most water depths in the study area exceed the range in which divers can work effectively, inspection, maintenance, and repair of underwater installations will have to be accomplished by alternative methods that extend work capabilities beyond the range of conventional diving. Two major categories of underwater work systems exist - manned maintenance systems and remotely controlled maintenance systems.

Figure 34 shows some examples of manned systems. The suits have depth capabilities of 2,000 ft (610 m) and can be built for 3,000 ft (914 m). The manipulator bell has a depth capability of 4,500 ft (1,372 m). Some untethered submersibles can be operated in 8,300 ft (2,530 m) of water.

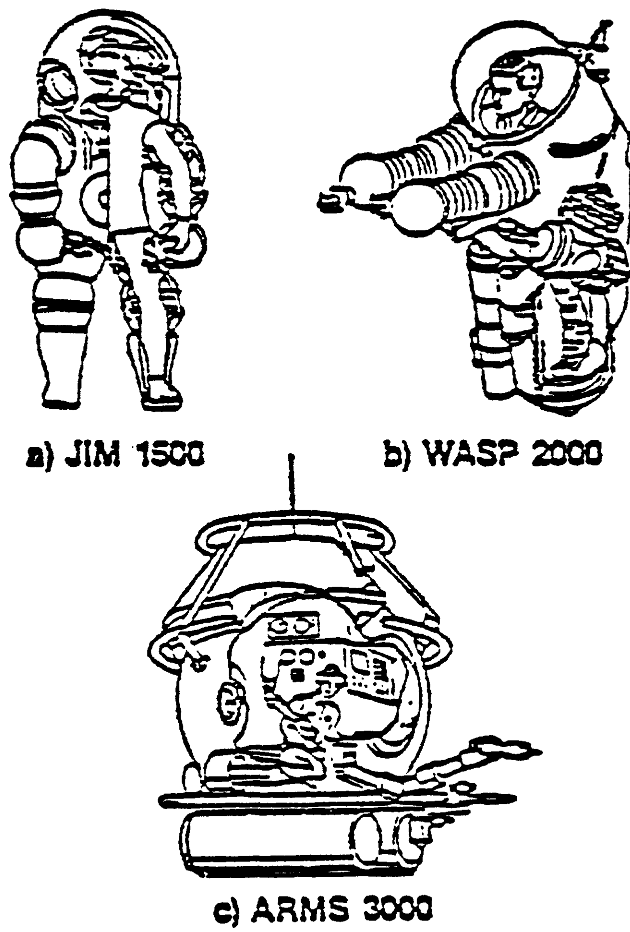



Figure 34.--Diagrams of manned subsea maintenance systems.

Remotely-controlled vehicles totally eliminate risks to human life, while providing many of the capabilities of the manned systems. Engineering and development of these systems are integral parts of any deep-water production system or pipeline.

The capability exists today to provide underwater inspection, maintenance, and repair services safely and efficiently in water as deep as 3,000 ft (914 m). No major technological problems are known that would not extend this capability should the need arise.

## Summary

If oil and gas are found in commercial quantities in the assessment areas of the offshore California Borderland, the resources will probably be exploited by use of extensions and refinements of current techniques and equipment. Breakthroughs in technology or radical changes in concepts will probably not be required.

Knowledgeable observers predict that, by the year 2000, the methods and equipment for drilling and production operations in water as deep as 10,000 ft (3,048 m) will be available (figs. 35, 36, and 37). However, many factors, including the political climate, leasing programs, lag times of 6 to 10 years from inception to completion of projects, and producing wells of low volume would tend to delay actual production from these areas by several years. Although developing and producing oil and gas in deep water will be extremely expensive, the findings of this study indicate that no insurmountable barriers will exist that would prevent petroleum from being exploited in the study area in the southern California Borderland within the next 20 to 30 years. The petroleum industry is confident that existing technology can be extended to develop oil and gas fields in deep water.

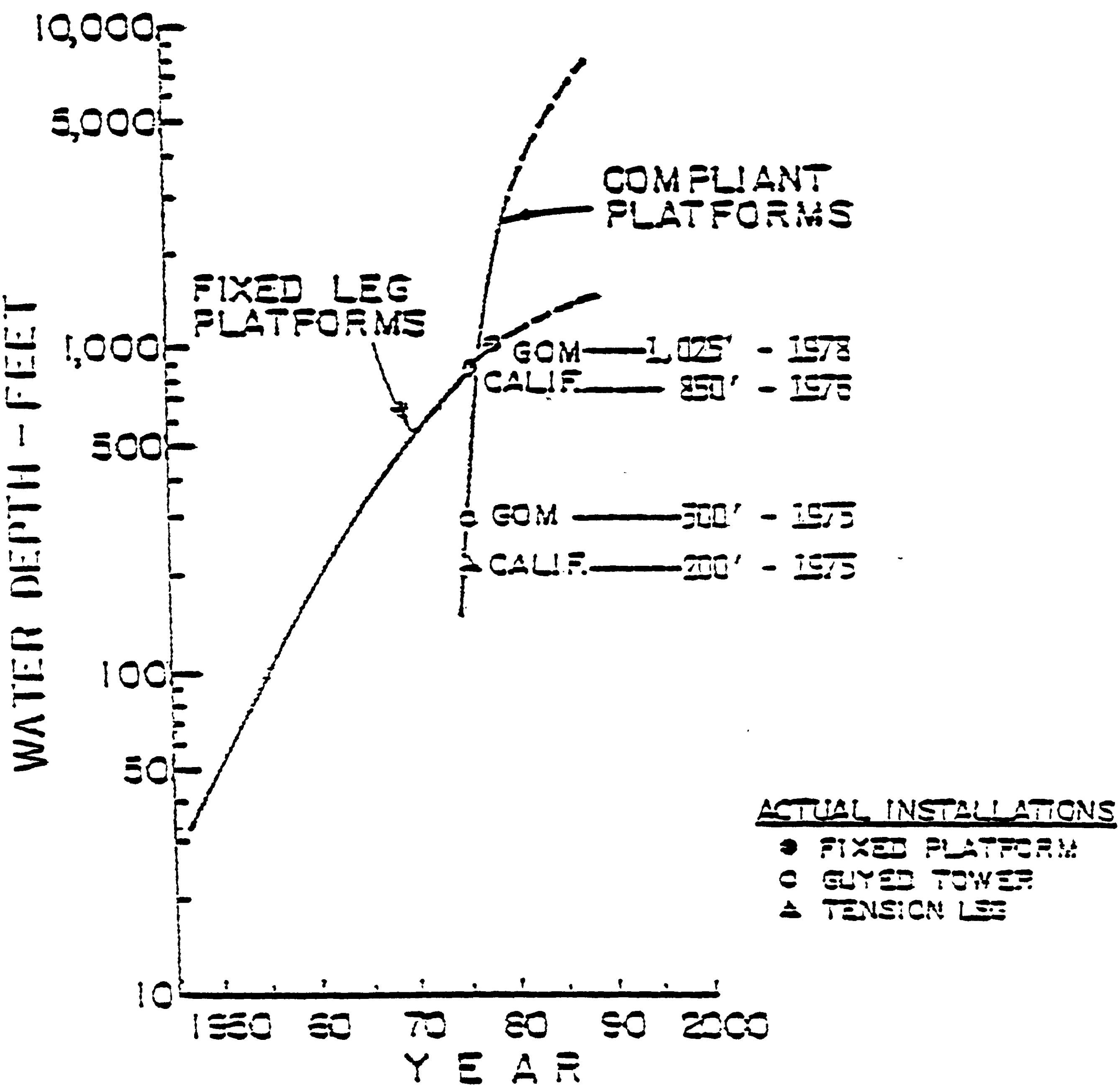



Figure 35.--Graph showing projection of platform installation capability.

GOM, Gulf of Mexico.

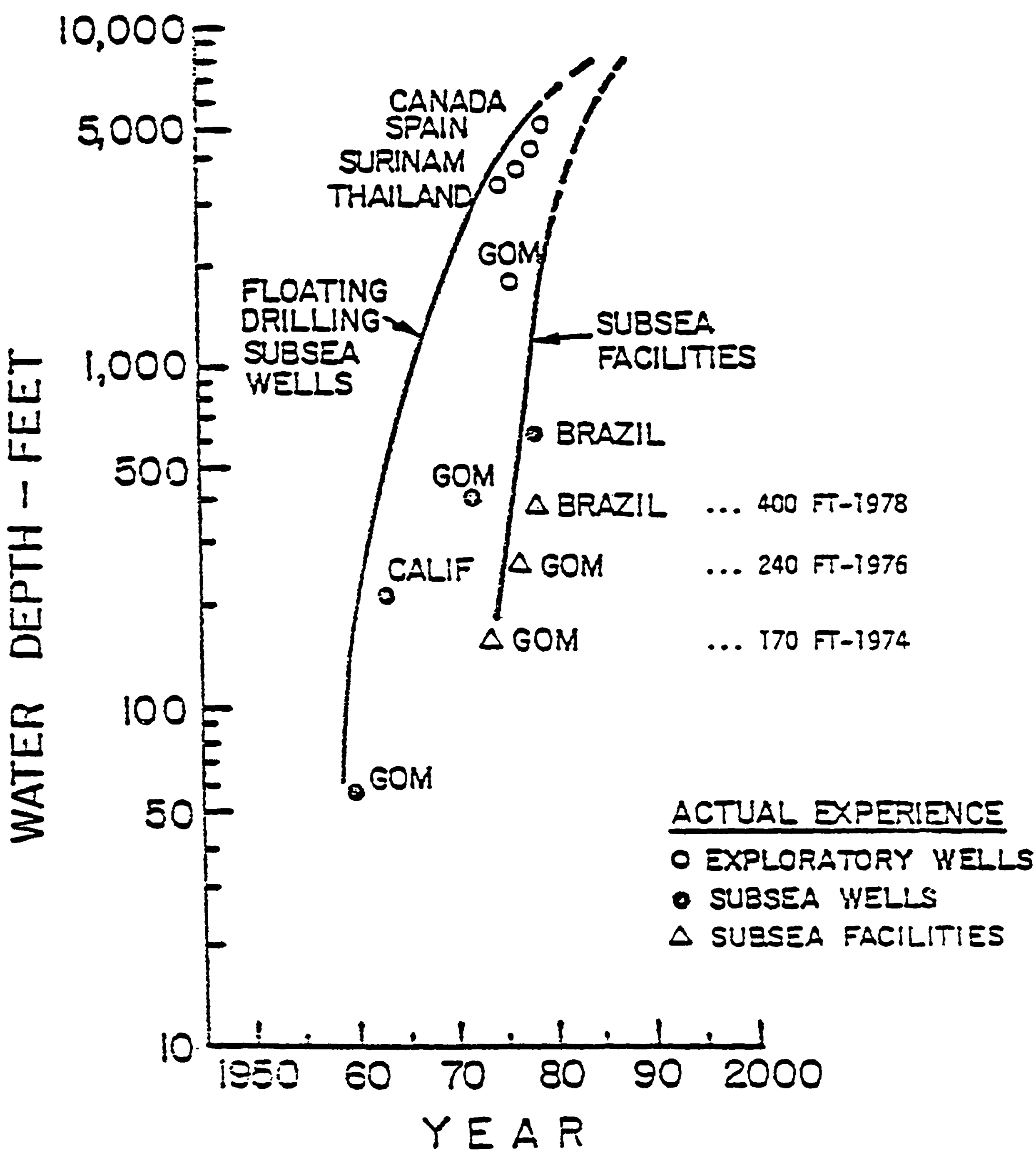



Figure 36.--Graph showing projection of floating and subsea drilling facilities. GOM, Gulf of Mexico.

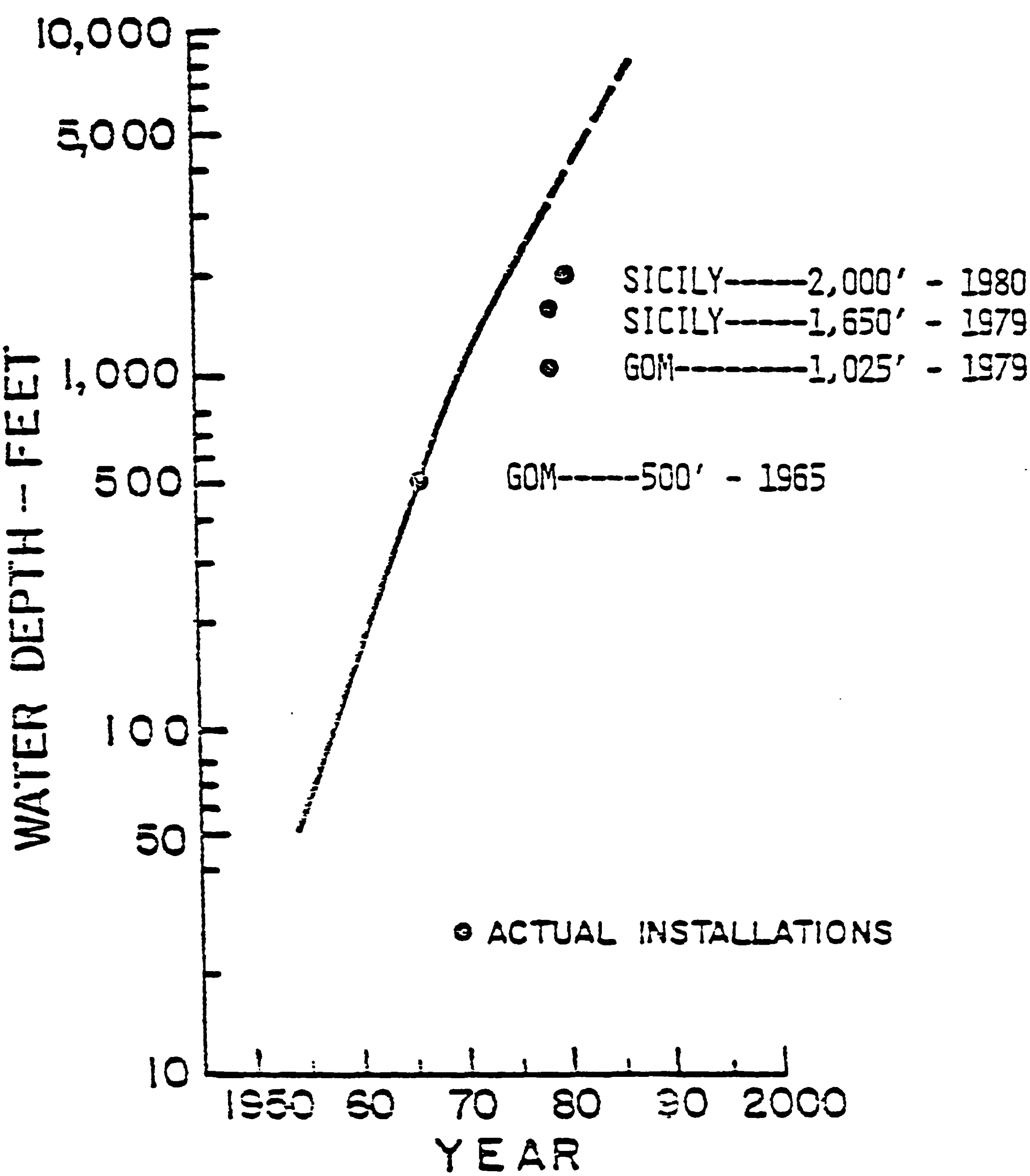



Figure 37.--Graph showing projection of pipeline-laying capability.
GOM, Gulf of Mexico.

References

Agnew, D. C., 1979, Tsunami history of San Diego, *in* Abbott, P. L., and Elliott, W. J., eds., Earthquakes and other perils, San Diego region: Geological Society of America Annual Meeting, San Diego, California, Field Trip Guidebook, p. 117-122.

American Petroleum Institute, 1970, Organization and definitions for the estimation of reserves and productive capacity of crude oil: Washington, D.C., American Petroleum Institute Technical Report 2, 44 p.

______1975, Reserves of crude oil, natural gas liquids, and natural gas in the United States and Canada and the United States productive capacity as of December 31, 1974: American Petroleum Institute, v. 29, May 1975, 254 p.

Atwater, Tanya, and Molnar, Peter, 1973, Relative motion of the Pacific and North American plates deduced from sea-floor spreading in the Atlantic, Indian, and South Pacific Oceans, *in* Kovach, R. L., and Nur, Amos, eds., Conference on Tectonic Problems of the San Andreas Fault System, Proceedings: Stanford University Publications in the Geological Sciences, v. 13, p. 136-148.

Barnes, B. B., 1970, Marine phosphorite deposit delineation technique tested on the Coronado Bank, southern California: Offshore Technology Conference, 2nd Annual Meeting, Houston, Texas, OTC Paper 1259 (preprint) 36 p.

Bea, R. G., 1977, Platform design: Oil and Gas Journal, v. 75, no. 35, p. 275.

Blake, M. C., Jr., Campbell, R. H., Dibblee, T. W., Jr., Howell, D. G., Nilsen, T. H., Normark, W. R., Vedder, J. G., and Silver, E. A., 1978, Neogene Basin formation in relation to plate-tectonic evolution of San Andreas fault system, California: American Association of Petroleum Geologists Bulletin, v. 62, p. 344-372.

Bleakley, W. B., 1980, 1980 Ushers in offshore innovations: Petroleum Engineer International, v. 52, no. 6, p. 19-24.

California Division of Oil and Gas, 1978, Public-PR 06, 63rd Annual Report of the State Oil and Gas Supervisor, p. .

Campbell, R. H., Wolf, S. C., Hunter, R. E., Wagner, H. C., Junger, Arne, and Vedder, J. G., 1975, Geologic map and sections, Santa Barbara Channel region, California: U.S. Geological Survey Open-File Map 75-123, 1 pl., scale 1:250,000.

Church, T. M., and Wolgemuth, K., 1972, Marine barite saturation: Earth and Planetary Science Letters, v. 15, no. 1, p. 35-44.

Collipp, Bruce, 1977, Mobile marine rigs to extend capabilities: Oil and Gas Journal, v. 75, no. 35, p. 206-209.

Cook, H. E., ed., 1979, Geologic studies of the Point Conception deep stratigraphic test well OCS-CAL 78-164 No. 1 Outer Continental Shelf, southern California, United States: U.S. Geological Survey Open-File Report 79-1218, 148 p.

Crawford, Diane, 1980, Converted ship to drill record depths: Offshore, v. 40, no. 6, p. 45-53.

Cronan, D. S., 1972, Regional geochemistry of ferromanganese nodules in the world ocean, *in* Horn, D. R., ed., Papers from a conference on ferromanganese deposits on the ocean floor (Arden House, Harriman, New York and Lamont-Doherty Geological Observatory, Columbia University, Palisades, New York, January 20-22, 1972): Washington, D.C., National Science Foundation, p. 19-20.

Crouch, J. K., 1980, Speculations on hydrocarbon potential of deep-water basins in outer southern California borderland (abs.): American Association of Petroleum Geologists, v. 64, no. 3, p. 440.

Dietz, R. S., Emery, K. O., and Shepard, F. P., 1942, Phosphorite deposits on the seafloor off southern California: Geological Society of America Bulletin, v. 53, p. 815-848.

Dolton, G. L., and others, 1979, Estimates of undiscovered oil and gas, Permian basin, west Texas and southeast New Mexico: U.S. Geological Survey Open-File Report 79-838, 72 p.

Emery, K. O., 1960, The sea off southern California, a modern habitat of petroleum: New York, John Wiley and Sons, Inc., 366 p.

Field, M. E., and Clarke, S. H., Jr., 1979, Small-scale slumps and slides and their significance for basin slope processes, southern California borderland, *in* Doyle, J. J., and Pilkey, O. H., eds., Geology of continental slopes: Society of Economic Paleontologists and Mineralogists Special Publication 27.

Field, M. E., and Edwards, B. D., 1980, Slopes of the southern California continental borderland: A regime of mass transport, *in* Field, M. E., Colburn, Ivan, and Bouma, A. H., eds., Quaternary depositional environment of the Pacific Coast: Society of Economic Paleontologists and Mineralogists, Pacific Section Symposium 4.

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

Gerwick, B. C., and others, 1980, Engineering for deep sea drilling for scientific purposes: Washington, D.C., National Research Council-National Academy of Sciences, Marine Board of Engineering, 98 p.

Greene, H. G., Bailey, K. A., Clarke, S. H., Jr., Ziony, J. I., and Kennedy, M. P., 1979, Implications of fault patterns of the inner California continental borderland between San Pedro and San Diego, *in* Abbott, P. L., and Elliott, W. J., eds., Earthquakes and other perils, San Diego region: Geological Society of America Annual Meeting, San Diego, California, Field Trip Guidebook, p. 21-27.

Greene, H. G., Clarke, S. H., Jr., Field, M. E., Linker, F. I., and Wagner, H. C., 1975, Preliminary report on the environmental geology of selected areas of the southern California continental borderland: U.S. Geological Survey Open-File Report 75-596, 62 p., 29 pls., 6 figs.

Greene, H. G., Wolf, S. C., and Blom, K. G., 1978, The marine geology of the eastern Santa Barbara Channel, with particular emphasis on the ground-water basins offshore from the Oxnard Plain, southern California: U.S. Geological Survey Open-File Report 78-305, 104 p., 13 pls., 11 figs.

Hammett, Dillard, 1980a, What are industry's deepwater capabilities?: Ocean Industry, v. 15, no. 11, p. 65-68.

Haner, B. E., and Gorsline, D. S., 1978, Processes and morphology of the Continental Slope between Santa Monica and Dume Canyons, southern California: Marine Geology, v. 28, p. 77-87.

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

Hawkins, J. W., Allison, E. C., and MacDougall, D., 1971, Volcanic petrology and geologic history of Northeast Bank, southern California borderland: Geological Society of America Bulletin, v. 82, no. 1, p. 219-228.

Hileman, J. A., Allen, C. R., and Nordquist, J. M., 1973, Seismicity of the southern California region 1 January 1932 to 31 December 1972: California Institute of Technology, Division of Geological and Planetary Sciences, Contribution No. 2385, 83 p.

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

Howell, D. G., McCulloch, D. S., and Vedder, J. G., 1978, General geology, petroleum appraisal, and nature of environmental hazards, eastern Pacific shelf, latitude 28$^{o}$ to 38$^{o}$ north: U.S. Geological Survey Circular 786, 29 p.

Howell, D. G., and Vedder, J. G., 1981, Structure implications of stratigraphic discontinuities across the southern California borderland, *in* Ernst, W. G., ed., the geotectonic development of California, Rubey, v. I: Englewood Cliffs, New Jersey, Prentice-Hall Inc., p. 535-558.

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

Inderbitzen, A. L., and others, 1970, The submarine phosphate deposits off southern California: Offshore Technology Conference, 2nd Annual Meeting, Houston, Texas, OTC Paper 1257, p. 287-304.

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

Junger, Arne, and Wagner, H. C., 1977, Geology of the Santa Monica and San Pedro Basins, California continental borderland: U.S. Geological Survey Miscellaneous Field Studies Map MF-820, 10-p. text, 5 sheets, scale 1:250,000.

Klemme, H. D., 1975, Giant oil fields related to their geologic setting: A possible guide to exploration: Bulletin of Canadian Petroleum Geology, v. 23, no. 1, p. 30-66.

Krause, D. C., 1965, Tectonics, bathymetry, and geomagnetism of the continental borderland west of Baja California, Mexico: Geological Society of America Bulletin, v. 76, p. 617-650.

Lamar, D. L., Merifield, P. M., and Proctor, R. J., 1973, Earthquake recurrence interval on major faults in southern California, *in* Moran, D. E., Slossohn, J. E., Stone, R. O., and Yelverton, C. A., eds., Geology, seismicity and environmental impact: Association of Engineering Geologists Special Publication, p. 265-276.

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

Legg, M. R., and Kennedy, M. P., 1979, Faulting offshore San Diego and northern Baja California, *in* Abbott, P. L., and Elliott, W. J., eds., Earthquakes and other perils, San Diego region: Geological Society of America Annual Meeting, San Diego, California, Field Trip Guidebook, p. 29-46.

Lonsdale, Peter, A deep-sea hydrothermal site on a strike-slip fault: Nature [in press].

Manheim, F. T., 1965, Manganese-iron accumulations in the shallow marine environment: University of Rhode Island, Narragansett Marine Laboratory, Occasional Publication No. 3, p. 217-276.

McCulloch, D. S., ed., 1980, A summary report of the regional geology, environmental geology, OCS resource appraisal, petroleum potential, and operational considerations in the area of proposed Lease Sale 73, offshore California: U.S. Geological Survey Open-File Report 80-2007.

McNally, Rich and Hale, Dean, 1979, Industry expanding offshore capabilities: Petroleum Engineer International Special Edition, Energy Operations and Equipment Forecast, p. 12-17.

Menard, H. W., Jr., 1955, Deformation of the northeastern Pacific basin and the west coast of North America: Geological Society of America Bulletin, v. 66, no. 9, p. 1149-1198.

Mero, J. L., 1967, Ocean mining--a potential major new industry: World Dredging Conference, 1st New York, May 6-8, 1967, Proceedings, p. 625-641.

Miller, B. M., Thomsen, H. L., Dolton, G. L., Coury, A. B., Hendricks, T. A., Lennartz, F. E., Powers, R. B., Sable, E. G., and Varnes, K. L., 1975, Geological estimates of undiscovered recoverable oil and gas resources in the United States: U.S. Geological Survey Circular 725, 78 p.

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

Nardin, T. R., Edwards, B. D., and Gorsline, D. S., 1979, Santa Cruz Basin, California: Dominance of slope processes in basin sedimentation, *in* Doyle, L. J., and Pilkey, O. H., eds., Geology of continental slopes: Society of Economic Paleontologists and Mineralogists Special Publication 27.

Pasho, D. W., 1972, Character and origin of marine phosphorites: University of Southern California, Department of Geological Sciences Report USC-GEOL 72-5, 144 p.

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

Plawman, T. L., 1978, Crustal structure of the continental borderland and adjacent portion of Baja California between latitudes 30° N and 33° N: Corvallis, Oregon, Oregon State University, unpub. M.S. thesis, 72 p.

Rawson, M. D., and Ryan, M. B., 1978, Ocean floor sediment and polymetallic nodules: Lamont-Doherty Geological Observatory Map sponsored by U.S. Department of State, Office of the Geographer, scale 1:23,230,300.

Riedel, W. R., Ladd, H. S., Tracey, J. I., Jr., and Bramlette, M. N., 1961, Preliminary drilling phase of Mohole Project II: Summary of coring operations: American Association of Petroleum Geologists Bulletin, v. 45, no. 11, p. 1793-1798.

Sellers, C. A., and Wickizer, C. L., 1977, Subsea completions - 2,: Oil and Gas Journal v. 75, no. 35, p. 270-272.

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

Sorensen, P. E., and Mead, W. J., 1969, A new economic appraisal of marine phosphorite deposits off the California coast: Transcripts of the Fifth Annual Marine Technology Conference of "The Decade Ahead 1970-1980" Miami, Florida, June 15-18, p. 491-500.

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

Talbot, W. J. Jr., and Creel, B. B., 1977, Future to see 6000-ft-deep lines: Oil and Gas Journal, v. 75, no. 35, p. 309-310.

U.S. Bureau of Mines and U.S. Geological Survey, 1976, Principles of the mineral resource classification system of the U.S. Bureau of Mines and U.S. Geological Survey: U.S. Geological Survey, Bulletin 1450-A, 5 p.

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

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

Vedder, J. G., Wagner, H. C., and Schoellhamer, J. E., 1969, Geologic framework of the Santa Barbara Channel region: U.S. Geological Survey Professional Paper 679-A, p. 1-11.

Vedder, J. G., and others, 1974, Composition and correlation of bedrock and sediment cores, R/V Sea Sounder cruise S-3-79-SC, May 1979, California Contintental Borderland, 92 p.

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

Witt, Robert R., Jr., 1980, Exploring the deeper seas: Offshore, v. 40, no. 6, p. 54-60.

Yerkes, R. F., and Lee, W. H. K., 1979a, Late Quaternary deformation in the western Transverse Ranges, California: U.S. Geological Survey Circular 799-B, p. 27-37.

Yerkes, R. F., and Lee, W. H. K., 1979b, Maps showing faults and fault activity, and epicenters, focal depths, and focal mechanisms for 1970-75 earthquakes, western Transverse Ranges, California: U.S. Geological Survey Miscellaneous Field Studies Map MF-1032, 2 sheets, scale 1:250,000.

Ziony, J. I., and others, 1974, Preliminary map showing recency of faulting in coastal southern California: U.S. Geological Survey Miscellaneous Field Studies Map MF-585, 15-p. text, 3 sheets.