UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

# INTERIM REPORT ON PETROLEUM RESOURCES POTENTIAL AND GEOLOGIC HAZARDS IN THE OUTER CONTINENTAL SHELF — OREGON AND WASHINGTON TERTIARY PROVINCE

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*With a section on*

RESOURCE APPRAISAL ESTIMATE

*By*

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UNITED STATES DEPARTMENT OF THE INTERIOR

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# INTERIM REPORT ON PETROLEUM RESOURCES POTENTIAL AND GEOLOGIC HAZARDS IN THE OUTER CONTINENTAL SHELF -- OREGON AND WASHINGTON TERTIARY PROVINCE

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## SUMMARY

The petroleum potential of the continental shelf of the Oregon and Washington Tertiary province cannot be assessed with any degree of confidence because of the paucity of offshore geophysical and geological information. The lack of substantial shows of oil or gas in the 10 wells drilled on the continental shelf from 1965 to 1967 suggests a low possibility of finding large accumulations of petroleum. However, the presence of Tertiary marine sedimentary rocks with a thickness in excess of 20,000 feet (6,000 m), occurrence of numerous untested structural and stratigraphic traps, and indications of petroleum in strata of Neogene age along coastal Washington indicate that the region has not been adequately tested by the drill.

The most critical factor controlling the accumulation of petroleum on the Oregon-Washington OCS unquestionably is the availability of reservoir rocks. Based upon onshore geologic mapping and stratigraphic studies, it is interpreted that source areas for sand existed near a former shelf edge and this sand may have been transported through channels into the deep marginal basins that existed off Coos Bay, Newport, Astoria and Grays Harbor. The most favorable prospective areas, therefore, may lie seaward of these onland source areas where upper Eocene to middle Miocene deltaic deposits accumulated near ancient shelf-edges.

Many of the large anticlinal structures drilled onland, and in several places offshore, are supported by "bald" cores of either lower and middle Eocene basalt flows and breccias, intensely deformed lower and middle Eocene sedimentary rocks, or sheared siltstone and mélange in diapiric structures. Therefore, the best target horizons for petroleum may be along the flanks of these large structures where stratigraphic traps may result from onlap of upper Eocene to middle Miocene strata onto these pre-mid-late Eocene structures. Deep erosion of structural highs on the inner OCS has truncated pre-upper Miocene strata and may have allowed any trapped oil and gas to escape from near-surface reservoirs. Also, the upper Miocene and Pliocene strata are deformed in a different style than the older rocks that unconformably underlie them. Thus in many places it is difficult to predict structural trends in the buried older rocks. The economic basement on much of the inner Washington OCS is an Oligocene and middle Miocene mélange and broken formation assemblage which onshore contains oil and gas seeps.

In most places tectonically complex siltstone and mudstone in the mélange are mature with respect to the generation of hydrocarbons. The upper Miocene and Pliocene sequence that was deposited on the mélange and broken formation contains sandstone beds that are potential reservoir rocks. However, the thickness of Pliocene sediments above the larger anticlines and diapiric structures, may not be sufficient to form suitable cap rock -- in fact, many of the diapirs penetrate the entire upper Miocene and Pliocene sequence and reach the seafloor.

Heavy minerals including gold, platinum, magnetite, chromite, and ilmenite occur on the southern part of the Oregon OCS. Because of relatively low concentrations of these minerals on the seafloor and environmental concerns attendant to offshore placer mining, they are not considered to be of economic value.

Potential geoenvironmental hazards are known to exist on the Oregon-Washington OCS, but they cannot be accurately evaluated due to the paucity of high-resolution seismic data and seafloor samples. Geologic and seismic evidence indicates that the study area has been tectonically active throughout the Tertiary and Quaternary and that this activity continues to the present. Warping and offset of the seafloor and areas of landslide are evident on the few available high-resolution seismic reflection profiles. Geologic mapping near the coast indicates that numerous faults deform or off-set Pleistocene deposits and several faults displace recent soil profiles. Although there is evidence of late(?) Pleistocene faulting and regional uplift along the Oregon coast, vertical tectonic activity is probably more intense along the Olympic coast and on the inner Washington OCS -- the rapid uplift of the Olympic Mountains since the Pliocene testifies to this activity.

No systematic program of bottom sampling and geophysical surveys have been carried out on the Oregon and Washington OCS. As a consequence, adequate data essential to making an intelligent evaluation of the resources potential and geoenvironmental hazards do not exist. Such data not only need to be acquired in advance of any resources development of the OCS, but sufficient time needs to be provided to interpret these data within the geologic framework of the entire Tertiary province of western Oregon and Washington and the adjacent continental margin.

INTRODUCTION

The purpose of this report is to provide a summary of the status of geologic knowledge and possible geologic hazards in the Oregon and Washington Tertiary Province prior to proposed leasing of tracts on the Outer Continental Shelf (OCS) for petroleum exploration.

As used in this report, the study area includes the Tertiary rocks in the coast ranges and on the continental shelf from southern Oregon (latitude 42°45'N) northward to the U.S.-Canadian border between Washington State and Vancouver Island, British Columbia (latitude 48°30'N). The Oregon-Washington OCS covers about 15,800 $mi.^2$ (41,000 $km^2$) to a water depth of 3,280 ft. (1,000 m). In this Tertiary province, the area of the seafloor above specified depth ranges is approximately as follows:

| Depth | | Area | |
|---|---|---|---|
| 0 - 650 ft. | [0 - 200 m] | 10,830 $mi.^2$ | [28,040 $km^2$] |
| 650 - 3,280 ft. | [200 - 1,000 m] | 7,050 $mi.^2$ | [18,270 $km^2$] |
| | Total | 17,880 $mi.^2$ | [46,310 $km^2$] |

The Tertiary geology of the OCS is largely extrapolated from that interpreted from U. S. Geological Survey published and unpublished geologic mapping in the bordering coast ranges and from limited geophysical data and sparse sample data offshore. Therefore, the geologic interpretations presented in this report for the OCS must be considered tentative at best.

## PHYSIOGRAPHY OF THE OCS

The continental shelf of Oregon and Washington, ranges in width from 8.8 miles (14 km) off Cape Blanco, Oregon, to 42 miles (68 km) at Heceta Bank, Oregon. The continental margin (shelf and slope) becomes progressively wider northward, ranging from 17.5 miles (28.2 km) on the southern Oregon OCS near Cape Blanco, to 90 miles (145 km) off the Hoh River of northern Washington (fig. 1). The continental slope off Oregon is steep and its base is generally straight and northward-trending. In contrast, off Washington the base of slope is irregular, trends northwest and the inclination of the slope is gentle.

An important geomorphic feature of the continental slope north of latitude 44°30' is a series of north- and northwest-trending ridges that commonly occur in water depths of more than 3,280 ft. (1,000 m). The internal structure of these ridges, as interpreted from seismic profiles, suggest that some are diapiric in origin. A broad terrace or bench 1,148-2,461 ft. (350-750 m) below sea level is an important feature off the central Oregon OCS between latitude 45°50' to 44°20'. It is generally widest where the shelf is narrowest (Byrne, 1963).

Several prominent banks occur on the Oregon OCS--the largest are Siltcoos, Heceta, Perpetua, Coquille, Nehalem and Stonewall. They are outlined by 50-60 m contours with water depths of as little as 23 ft. (7 m) on Stonewall Bank. Heceta Bank, the largest shoal, is about 25 miles (40 km) long and 6 to 8 miles (10-13 km) wide.

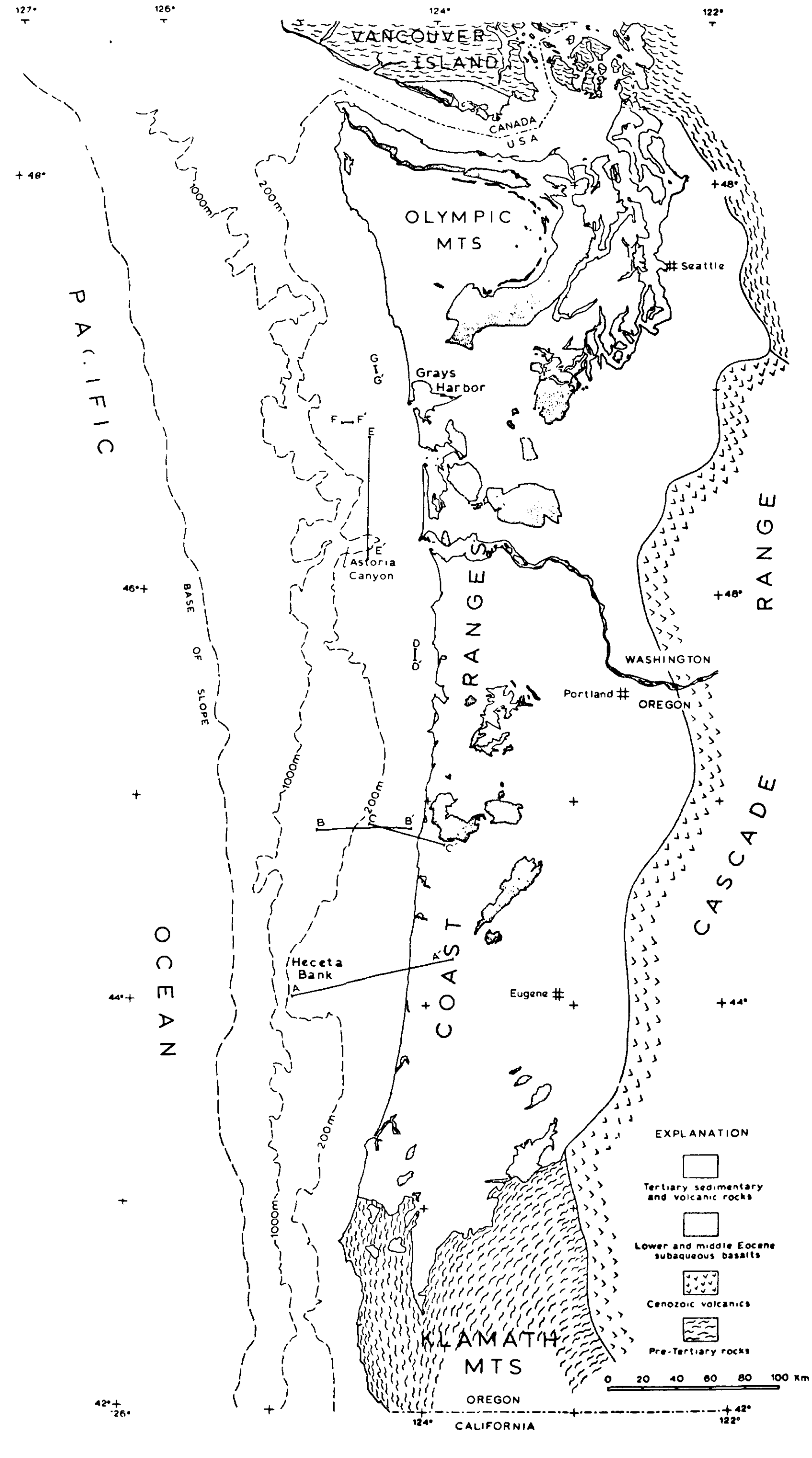



Figure 1.--Index map of the Tertiary Province of western Oregon and Washington and adjacent areas showing the names of physiographic features and the locations of cross sections and seismic profiles.

Stonewall Bank, located about 20 miles northeast of Heceta Bank, is about 14 miles (22.5 km) long and 8 miles (13 km) wide. Pliocene, and less commonly upper Miocene, sedimentary rocks crop out on these Oregon submarine banks (Kulm and Fowler, 1974) and Quaternary sediments onlap their flanks. Seismic profiles indicate that most of the banks are complex structural highs. Both Heceta and Stonewall banks were drilled for oil and gas. Submarine banks are absent on the Washington OCS, but Swiftsure Bank lies just north of the international boundary between the U.S. and Canada.

The Washington shelf is cut by several large submarine canyons, including the Willapa, Guide, Grays, Quinault, Juan de Fuca, and Nitinat canyons. Most of these canyons were cut by large rivers that dissected soft marine sediments during the late Pleistocene low stand of sea level. The only large submarine canyon on the Oregon shelf is Astoria Canyon (fig. 1), the head of which is 10 miles (16 km) west of the mouth of the Columbia River. It extends nearly 60 miles (97 km) to a depth of about 6,000 ft. (1,829 m) where it joins the Astoria fan. This fan overlaps the continental slope extending from a depth of 6,000 ft. (1,829 m) along the slope to 9,000 ft. (2,743 m) at the abyssal plain (Byrne, 1962). The largest fan adjacent to the Washington slope is Nitinat fan whose source was on the southwest side of Vancouver Island, British Columbia.

The northern part of the Washington coastal region is characterized by numerous seastacks and small islands such as Ozette and Destruction islands. Similar features also are common along the southern Oregon coast.

## REGIONAL STRATIGRAPHIC FRAMEWORK

### General Statement

The Oregon and Washington Coast Ranges, the Olympic Mountains, and the adjacent continental margin was the site of an elongate trough in which as much as 8,000 m of Tertiary sedimentary and volcanic rocks accumulated. This Tertiary trough extended from Vancouver Island approximately 640 km southward to the Klamath Mountains (Snavely and Wagner, 1963). The western boundary of the trough lies near the base of the continental slope. The eastern boundary lies near the western margin of the Cascade Range and is covered by upper Cenozoic volcanic rocks (fig. 1).

### Geologic History

In response to episodic periods of convergence or divergence between the Pacific (Farallon) and North American plates, the Tertiary sedimentary and volcanic rocks in this province record two depositional environments which shift with time, a deep marginal basin facies and a shelf facies. The deep marginal basin, floored by early Eocene oceanic crust, and associated seamounts occupied most of western Oregon and Washington and the adjacent OCS in early to middle Eocene time. A mid-upper Eocene regional unconformity separates these older rocks from an upper Eocene to Pliocene sequence that was deposited largely in a shelf environment in western Oregon and most of western Washington. Offshore, coeval strata were laid down in a deep marginal basin that extended along coastal Washington and the adjacent continental shelf and along the present Oregon continental shelf. These deep water sedimentary rocks consist predominantly of thin-bedded siltstone and sandstone with interbedded packets of turbidite sandstone. Thick clastic wedges and channels of conglomerate (olistostromes) are interbedded with these deep water deposits along the southern and northern parts of the basin where a narrow shelf separated the basin from areas of high relief on Vancouver Island and in the ancestral Klamath Mountains.

The last known period of major underthrusting took place in late middle Miocene time and is recorded as a regional unconformity in western Washington and on the continental shelves of both Oregon and Washington. In most places, the upper Miocene and Pliocene strata are only broadly folded except where pierced by siltstone diapirs.

Post middle Eocene igneous rocks are rare in the deep marginal basin. Mudflow deposits derived from ancient late Eocene volcanic centers which were located near the present coast are interbedded with deep water sediments on the Oregon continental shelf and sill and subaqueous flows of middle Miocene basalt were penetrated in test wells off the central Oregon coast. Water-laid volcanic ash derived from the Cascade Range occurs as discrete beds in upper Eocene to Pleistocene strata.

## Tertiary Sequence

### Early to mid-late Eocene

In early to mid-late Eocene time, a deep marginal basin floored by oceanic crust occupied western Oregon and Washington. A wide shelf bordered by a broad low-lying floodplain marked the basin on the east and a narrow shelf with adjacent highlands probably existed along the southern and northern parts of the basin.

The oldest rocks exposed in western Oregon and Washington are pillow lavas and breccias with interbedded marine siltstone and basaltic sandstone of early and middle Eocene age that now form the rugged upland areas in the Coast Ranges and the westward facing horeshoe-shaped rim that flanks the Olympic Mountains (fig. 1). This volcanic sequence can broadly be divided into two genetic types, an older unit which is interpreted as oceanic ridge basalts and a younger unit that represents seamounts and oceanic islands. Thin beds of deep water pelagic limestone and limy siltstone occur interbedded with the older oceanic tholeiite on the Olympic Peninsula, whereas the younger sequence intertongues complexly with shallow water basaltic sandstone and siltstone.

These lower and middle Eocene basalts (fig. 2) are referred to the Crescent Formation (Arnold, 1906) in Washington, to the Siletz River Volcanics (Snavely and Baldwin, 1948; Snavely and others, 1968) in northern and central Oregon, and to

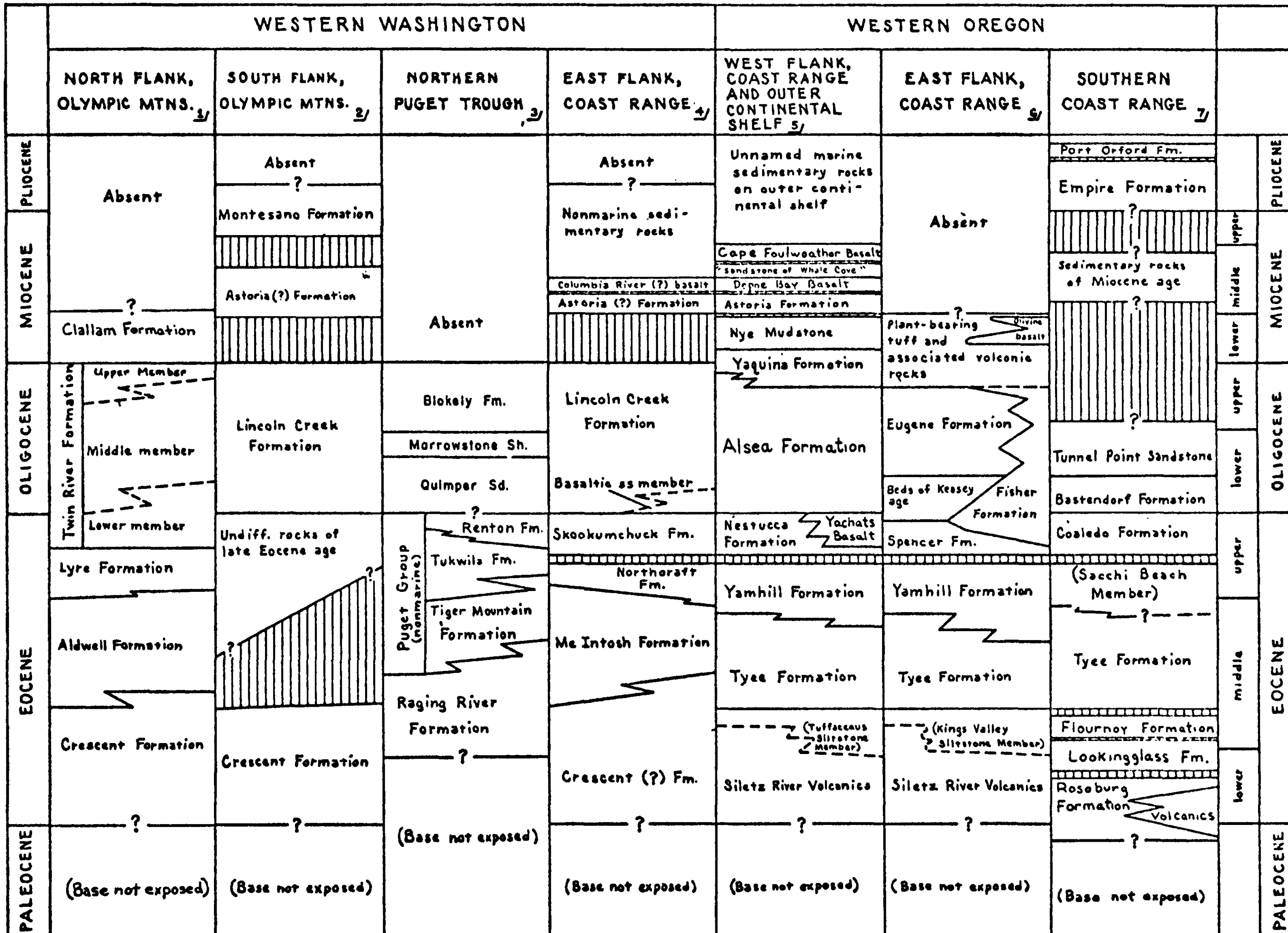



Fig. 2.—Correlation chart of principal Tertiary formations of western Oregon and Washington. Data adapted from (1) Brown and others (1960); Brown and Gower (1958); Gower (1960); (2) Rau (1967); (3) Weaver (1937); (4) Vine (1962); (5) Snavely and others (1958); (6) Snavely and others (1976a, b, c); (7) Vokes and others (1954); (8) Baldwin (1964a and 1974).

the Roseburg Formation (Baldwin, 1974) in southern Oregon. Coeval basalt flows and associated sills in the southernmost part of Vancouver Island are named the Metchosin Volcanics (Clapp, 1912).

During early Tertiary time, streams transported large quantities of arkosic material to broad, low-lying flood plains that bordered the northeastern and southern parts of the geo-syncline. In Washington, coal bearing continental beds--represented by the Puget Group (Wolfe and others, 1961), Chuckanut Formation (McLellan, 1927, and Swauk Formation (Russell, 1900) formed in lowland areas. A well east of Tacoma penetrated 12,000 ft. (3,660 m) of continental beds of the Puget Group without reaching the base of the sequence. Some of this coarse clastic material was transported along channels into the deeper parts of the basin and formed submarine fans and turbidites. In places, arkosic sandstone derived from the bordering continental land mass is interbedded with pillow lavas and breccia erupted from oceanic islands. In southern Oregon, early Tertiary deposits are represented by marine siltstone and basaltic sandstone of the Umpqua Formation (Diller, 1898) and Roseburg Formation (Baldwin, 1974).

In late middle Eocene time, downwarping of the trough was intensified, and concomitant uplift occurred in the area of the present Klamath Mountains on the south and in the Vancouver Island area on the north. Material was eroded rapidly from the bordering highlands south of the basin and was transported to the marine environment. In the southern part of the basin, periodic slumping of submarine fans produced turbidity flows that carried debris from the Klamaths northward along the axis of the trough for more than 240 km. In the Oregon Coast Range, preexisting volcanic highs were buried and as much as 10,000 ft. (3,008 m) of rhythmically bedded strata of the Tyee Formation (Snavely and others, 1964) accumulated.

In the northern part of the basin along the north flank of the Olympic Mountains, thin and graded beds of lithic sandstone and siltstone derived from Vancouver Island were deposited in a deep marginal basin that flanked the southwestern margin of Vancouver Island. The fine-grained clastic sediments are represented by the Aldwell (Brown and others, 1960) and McIntosh Formations (Snavely and others, 1951).

Late Eocene to middle Miocene

Regional uplift occurred throughout the basin in mid-late Eocene time in response to renewed plate convergence. The locus of underthrusting probably lay along the central part of the present continental shelf. This orogenic event was followed by regional uplift which segmented and shoaled the deep marginal basin to produce a number of shallow shelf basins. The late Eocene strandline generally paralleled the present foothills of the Cascade Range, southernmost Vancouver Island, and the northern part of the Klamath Mountains.

Essentially continuous sedimentation occurred in the outlying shelf basins as well as in deep marginal basins that lay to the west on the present OCS from late Eocene to late middle Miocene time. This sedimentary sequence consists of thin-bedded to massive tuffaceous siltstone with interbedded arkosic sandstone of a nearshore channel and deltaic facies that were deposited on the shelf, whereas a predominantly siltstone sequence with interbedded turbidite sands was deposited in the deep marginal basins. Near the western margin of the shelf, submarine and subaerial flows of basalt are interbedded with upper Eocene and middle Miocene strata, whereas along the eastern part, andesitic and dacitic breccias and volcaniclastic rocks are complexly intercalated throughout the mid-Tertiary marine strata. Gabbro and diabase stocks and sills of early late Eocene age, nepheline syenite and camptonite sills and small stocks of early(?) Oligocene age, ferrogabbro and diorite sills of late Oligocene age, and dikes and sills of basalt of middle Miocene age intrude the middle Eocene to middle Miocene marine sequence.

Late Miocene and Pliocene

A major period of underthrusting occurred in late middle Miocene time and is recorded as a regional unconformity in the coast ranges and on the continental shelf. The youngest volcanic rocks associated with the marine Tertiary sequence are basalt flows (with K/A age of about 10 m.y.) that occur near the base of this unconformity in the Grays Harbor basin of southwestern Washington (Snavely and others, 1973). Regional uplift in response to this tectonic event, particularly in the Olympic Peninsula, formed highland areas that were rapidly eroded and supplied large amounts of coarse clastic detritus to shelf basins (as the Grays Harbor Basin) and to elongate basins on the present continental shelf. More than 2,500 m of upper Miocene and Pliocene sediments were deposited in these basins on the OCS.

Braislin and others (1971) report that in the Heceta-Stonewall Bank area (off the central Oregon coast) exploratory wells and ocean floor mapping have established a composite thickness of more than 3,400 ft. (1,070 m) of tuffaceous sandy siltstone of late Miocene (Mohnian and Delmontian) age. Bottom sampling and marine seismic mapping also revealed more than 5,000 ft. (1,520 m) of Pliocene rocks in the major synclines in the area (figs. 3, 4). These rocks are a monotonous sequence of massive, foraminifer-rich, olive-gray siltstone and claystone. Biostratigraphically, the sequence is similar to that found in the Ventura and Los Angeles basins of southern California; all four microfaunal stages of the West Coast Pliocene are present in the Oregon section (Braislin and others, 1971).

Because of the thick Holocene and Pleistocene overburden and availability of subsurface data in only three exploratory wells,

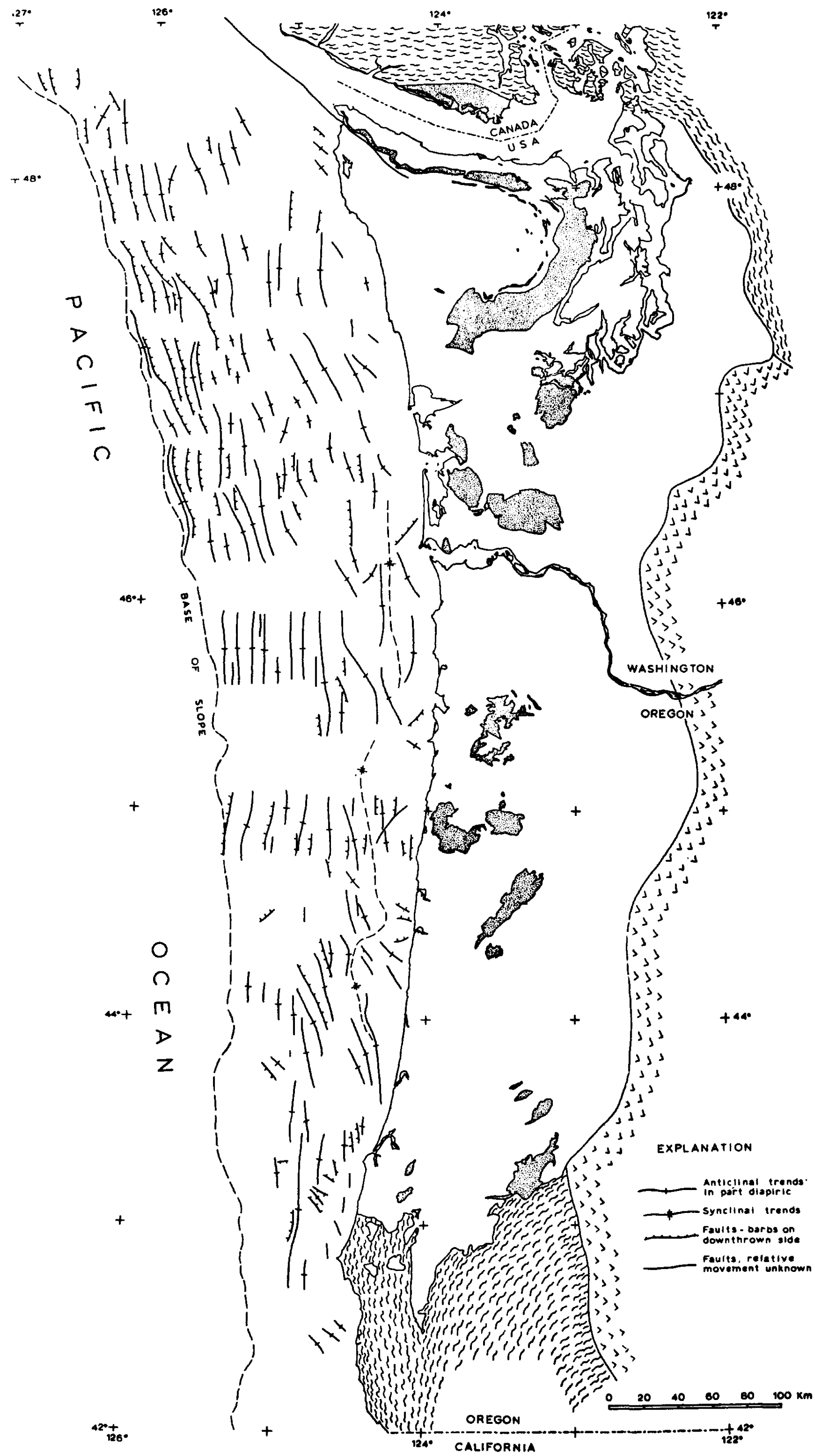



Figure 3.--Generalized structural map showing selected anticlinal trends and faults on the continental margin of Oregon and Washington. See page 21 for sources of data.

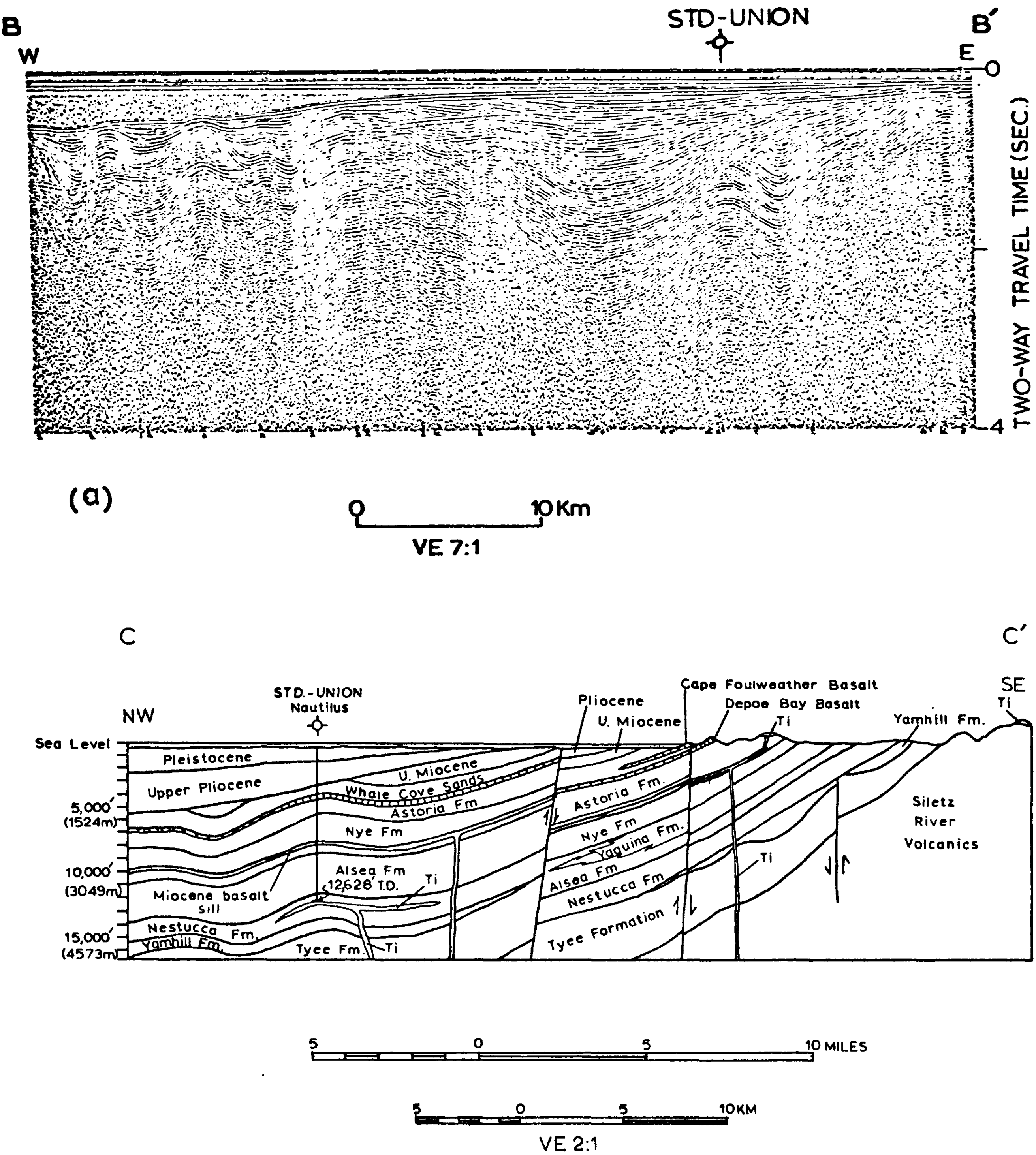



Fig. 4-Seismic reflection profile and geologic cross section on the continental shelf of Oregon near latitude 44°45' N.; (a) unannotated 160 kj seismic profile along line B-B' on figure 1 and (b) cross section C-C' from the Oregon Coast Range onto the shelf, modified after Braislin and others (1971). Note that both the profile and the cross section are through the Standard-Union, Nautilus test well.

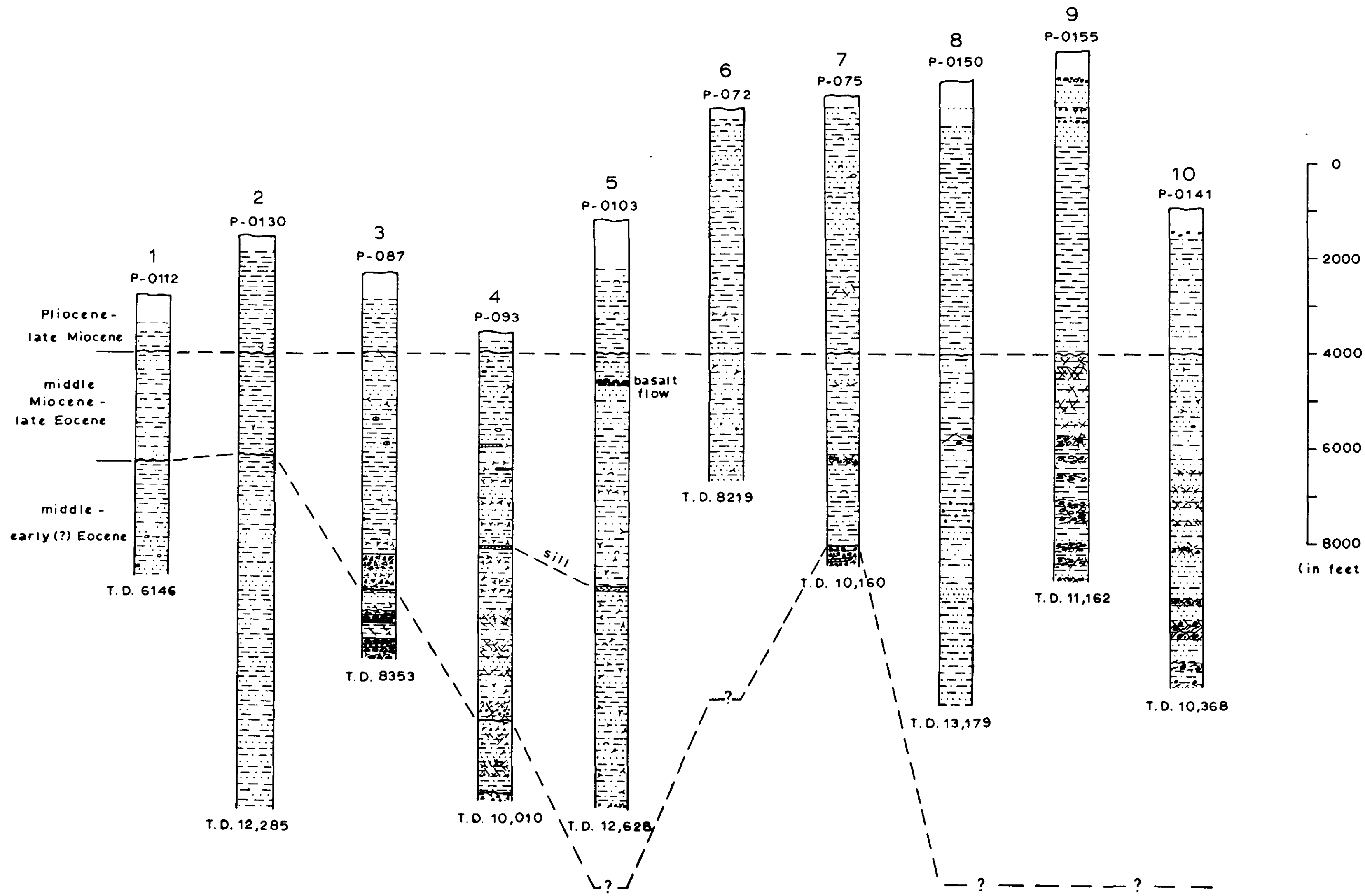



Figure 5.--Generalized stratigraphy and tentative correlations between test wells on the Oregon-Washington OCS.

little is known about the nature and distribution of the upper Tertiary sediments on the outer continental shelf off Washington. However, seismic reflection records and data from these wells (fig. 5) indicate that more than 3,000 m of upper Miocene and Pliocene sediments may be present on the Washington OCS. Biostratigraphically, these sediments are similar to the Quinault Formation (Rau, 1970) that crops out along the central Washington coast. The Cygnet test well drilled by Shell Canada just north of the outer continental shelf of Washington bottomed at 8,070 feet in siltstone of middle(?) Miocene age (Shouldice, 1971).

Pleistocene and Holocene

Sand and silt with interbedded gravel of Pleistocene and Holocene age veneer the Tertiary rocks throughout most of the Oregon and Washington OCS. In the axial parts of an elongate and sinuous syncline on the inner shelf, as off Oregon (fig. 3), these deposits have a maximum thickness of more than 500 m. Seismic profiles record several unconformities in the Pleistocene-Holocene sequence (fig. 6) testifying to continued tectonic activity in the area.

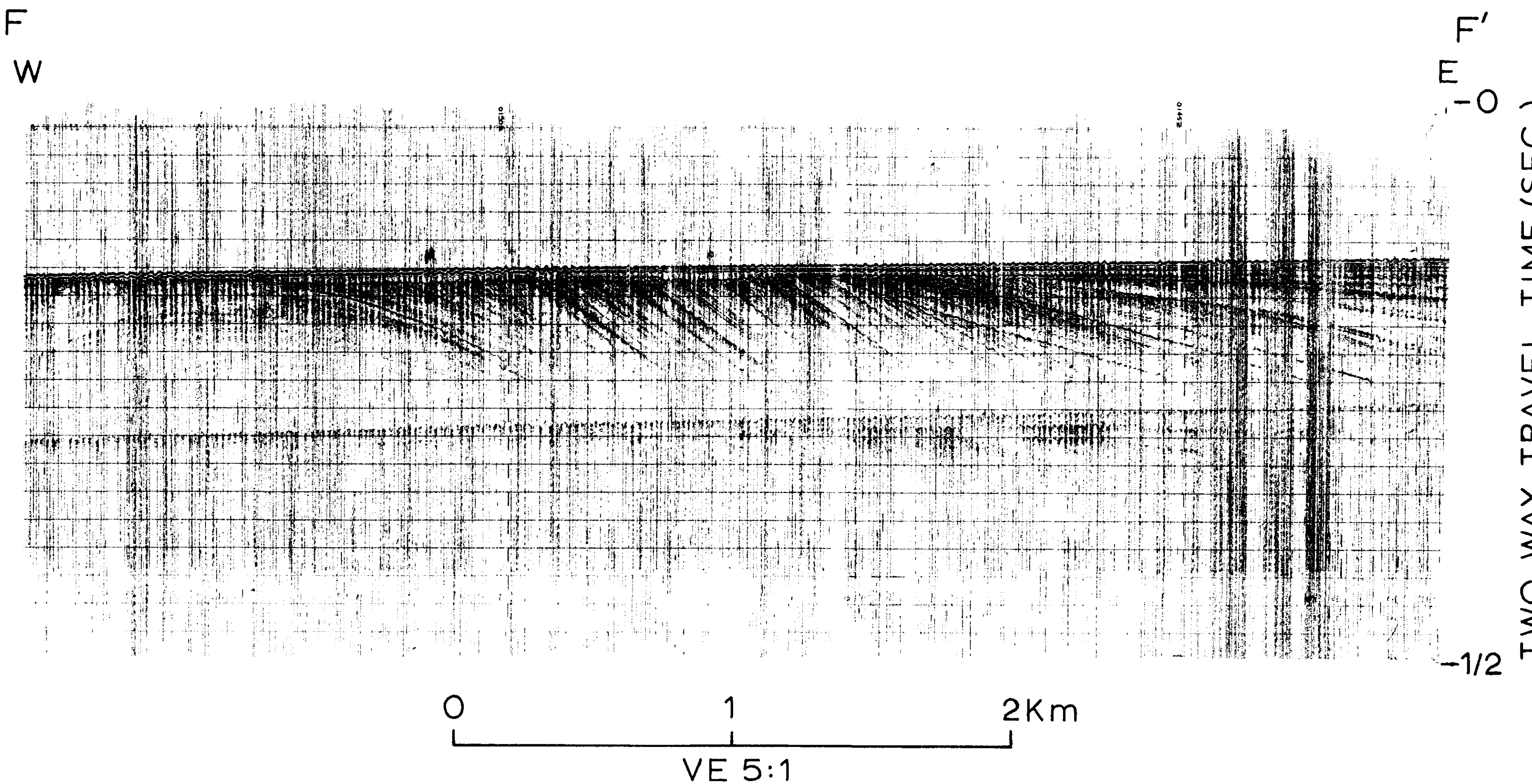



Figure 6.--High-resolution seismic profile F-F' showing unconformities in Pleistocene and Holocene strata on the west flank of a broad anticline on the Washington shelf. See figure 1 for location of profile.

## STRUCTURE

Two major orogenic events, one in mid-late Eocene and the other in late middle Miocene time, resulted in deformation of the Tertiary rocks in western Oregon and Washington and on the OCS. Pre-upper Eocene strata are more complexly folded and faulted than are the post upper Eocene rocks which have been involved in but one major period of tectonism. Fold patterns in the lower and middle Eocene rocks trend predominantly northeastward in the southern part of the Oregon Coast Range, northward in the central part, and northwesterly in the Washington Coast Range. These trends may roughly parallel the former margins of the oceanic plate that underthrusted the North American plate in early Eocene time. In places, major faults paralleled the axis of the folds, as in southwestern Washington, however, in the central Oregon coast range, northwest-trending faults offset the northeast trending folds (Snavely and others, 1976a,b,c). Folds in the lower Tertiary sequence are commonly of short wave length and their trends are usually divergent from trends of folds in the upper Tertiary strata.

Folds and faults in the Olympic Peninsula roughly parallel the west facing horseshoe-shaped outcrop of the lower to middle Eocene Crescent basalt (fig. 3). The tectonic style here is one of imbricate thrust faults with eastward dips. Tear faults, such as the Calawah Fault (Gower, 1960), along the northwestern part of the Olympic Peninsula, appear to form the northern boundary of a small plate that underthrust the continent near the present coast in late middle Miocene time.

The structural style of the middle Eocene to middle Miocene strata of the Olympic Peninsula is highly complex. A broad zone of mélange and broken formation that probably defines a locus of understrusting occurs along the western part of the peninsula (Rau, 1975; Snavely and Pearl, 1975). Here, upper Eocene to middle Miocene strata form infolded blocks several miles in length that are "floating" in mélange. Landward-dipping thrust faults often cut the strata which are commonly tightly folded and locally overturned.

Upper Miocene and Pliocene strata are broadly folded in many places on the Oregon and Washington OCS (fig. 3)[1/]. They are also intruded by shale diapirs which produce antiformal dips in the young strata (fig. 7). On the outer part of the continental shelf, fold axes trend roughly parallel to the base of the slope (Silver, 1972) (fig. 3). On the inner shelf, trends of the folds in upper Miocene and Pliocene strata appear to more closely parallel those in the older Tertiary rocks.

The late middle Miocene orogenic episode was followed by differential uplift and faulting in the Olympic Mountains and in the coast ranges of Oregon and Washington. This uplift has continued to the present. This regional uplift probably results from isostatic adjustment of less dense sedimentary rocks that

[1/] Generalized structure of OCS based upon seismic data collected by Oregon State University and University of Washington under contract to U.S. Geological Survey, Scripps Institute of Oceanography, and by the U.S. Geological Survey.

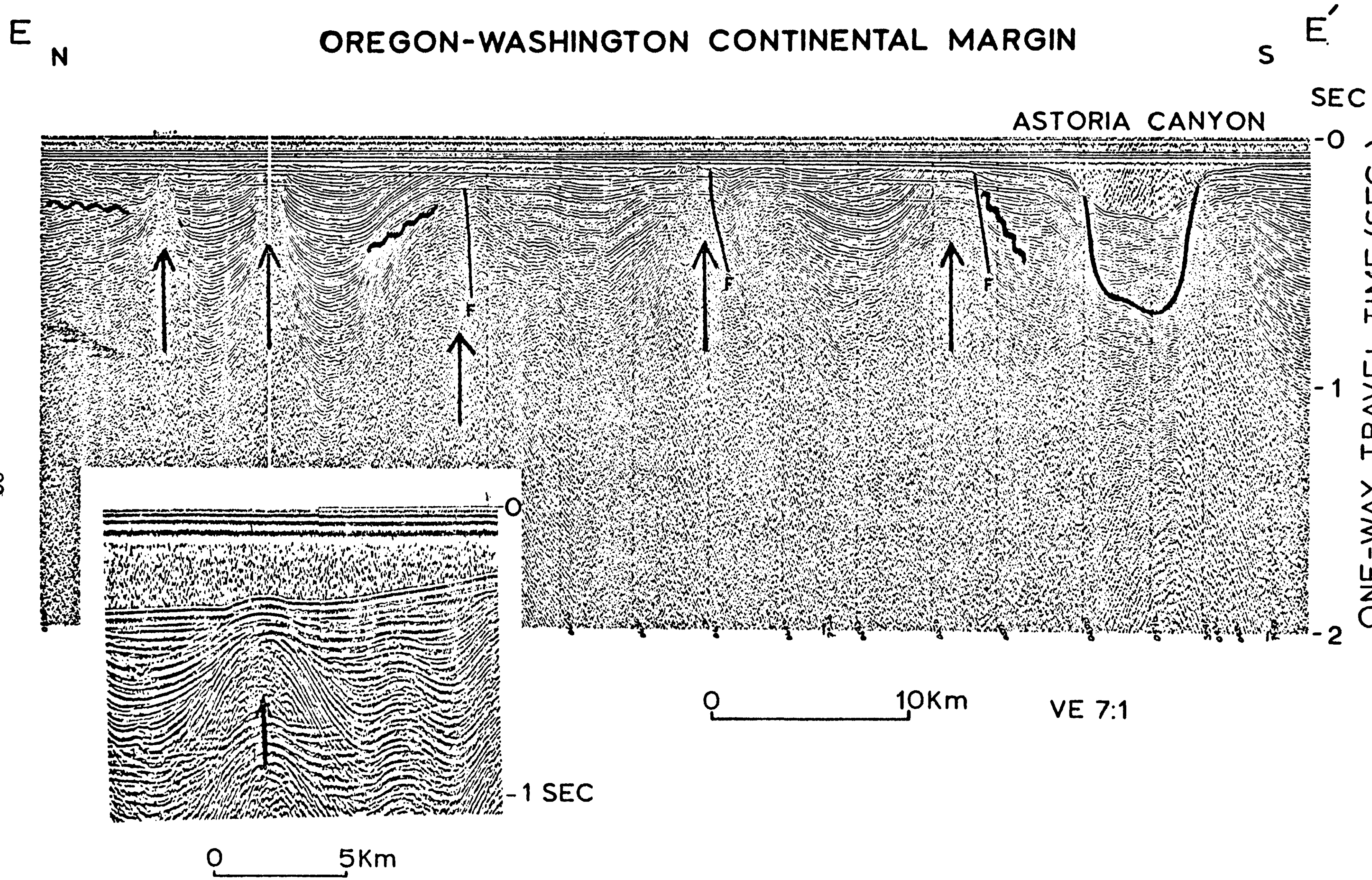



Figure 7.--Siltstone diapirs on the inner shelf off southern Washington. Note growth faults (F) and local unconformities on flanks of diapirs. Insert shows warping of seafloor above diapir. See figure 1 for location of seismic profile.

were thrusted beneath older and denser Tertiary rocks.

In late Miocene to Pliocene time, the continental shelf was probably under extension. Middle Miocene and older strata were folded, uplifted, and then truncated to produce the late Miocene unconformity (fig. 4). Later they were downwarped (or faulted) and overlapped by late Miocene and Pliocene sediments. Elongate, generally north-trending, basins on the OCS formed during this period of east-west extension and were rapidly filled by sediment derived from the uplifted Olympic Mountains and the Oregon-Washington coast ranges. Uplift was greatest in the Olympic Mountains because a larger volume of early Cenozoic sedimentary rocks (formerly in basins off western Vancouver Island) were underthrusted in this area.

Continuing active deformation in the Quaternary is indicated by several uplifted marine terrace deposits along coastal Oregon and southwestern Washington; the highest may be as much as 100 m above sea level. Downwarp of inner shelf basins is indicated by several unconformities in Pleistocene deposits (fig. 6) and by faults that offset the youngest sediment on the seafloor (fig. 8). On land, faults have been mapped that offset Holocene soil zones. Others have deformed upper Pleistocene glacial drift in the northwestern part of the Olympic Peninsula (Snavely and MacLeod, 1974).

Byrne and others (1966) and Kulm and Fowler (1971) report uplifted abyssal sediments on the outer continental shelf and

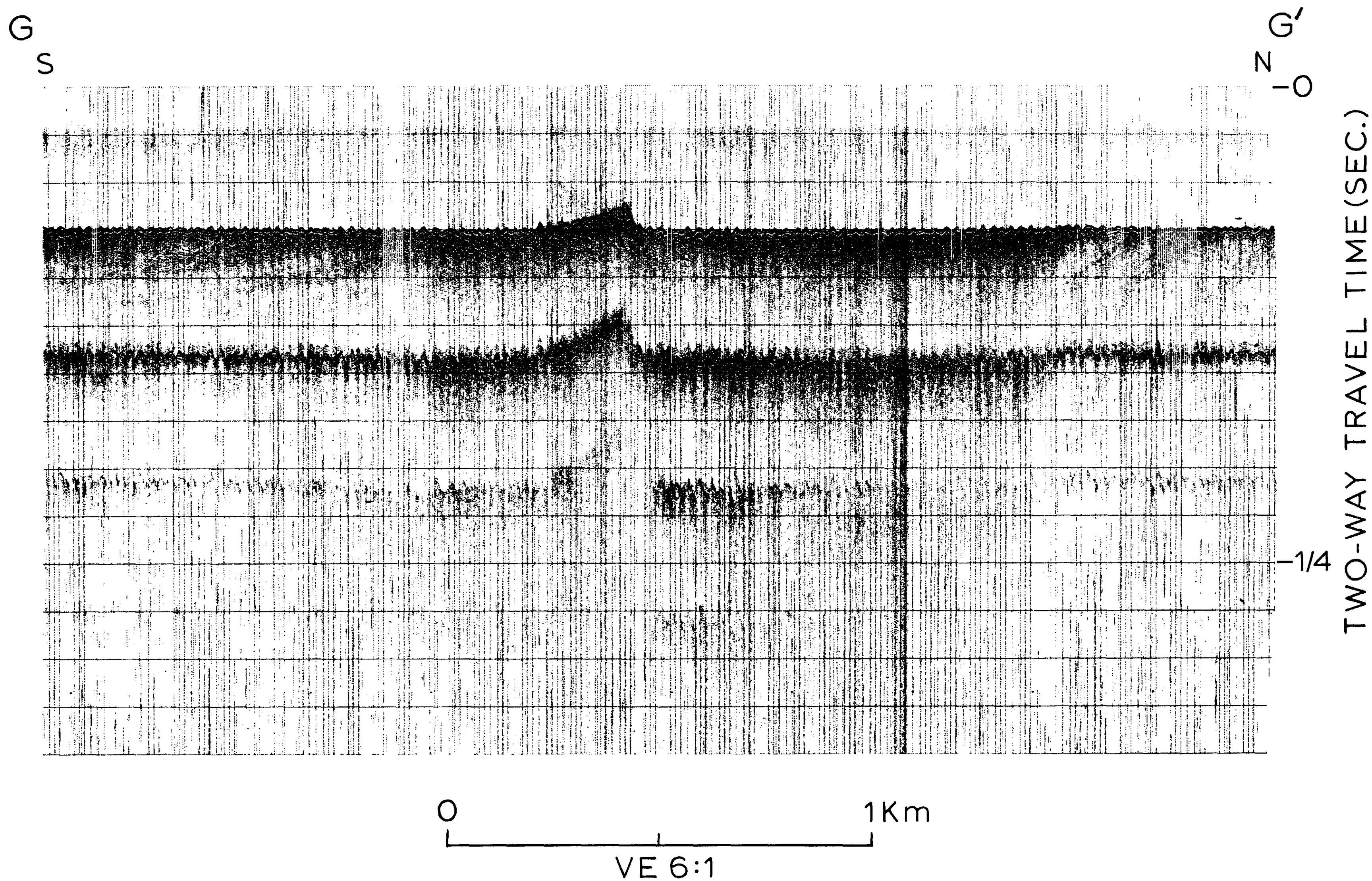



Figure 8.--High-resolution seismic profile G-G' showing fault on inner Washington shelf that offset the seafloor sediments about 7 m. See figure 1 for location of profile.

slope; they estimate maximum uplift of about 1,000 m during the late Pliocene and Pleistocene.

On the continental shelf off Oregon, late Eocene and younger strata onlap older structural highs, for instance at Heceta Bank strata of late Eocene or early Oligocene age onlap a high of lower Eocene sandstone (fig. 9). The unconformity at the base of the late Miocene is also evident on many of the profiles on the OCS as these younger strata rest unconformably on folded rock as young as middle Miocene (see fig. 4).

Igneous activity in western Oregon and Washington also was in response to tectonic activity. Upper Eocene basalt was extruded from a number of local centers near the present coastline and were probably generated from magma that rose to the surface along a north-trending deep fault zone (Snavely and MacLeod, 1974). Middle Miocene basaltic volcanic rocks and associated dikes and sills also were derived from the mantle and intruded into and extruded from a north-trending extensional zone (Snavely and others, 1973); numerous north-trending faults have been mapped along coastal central Oregon (Snavely and others, 1976a, b, c) and are evident in seismic records on the inner shelf. These faults offset all except the youngest seafloor strata of probable Holocene age.

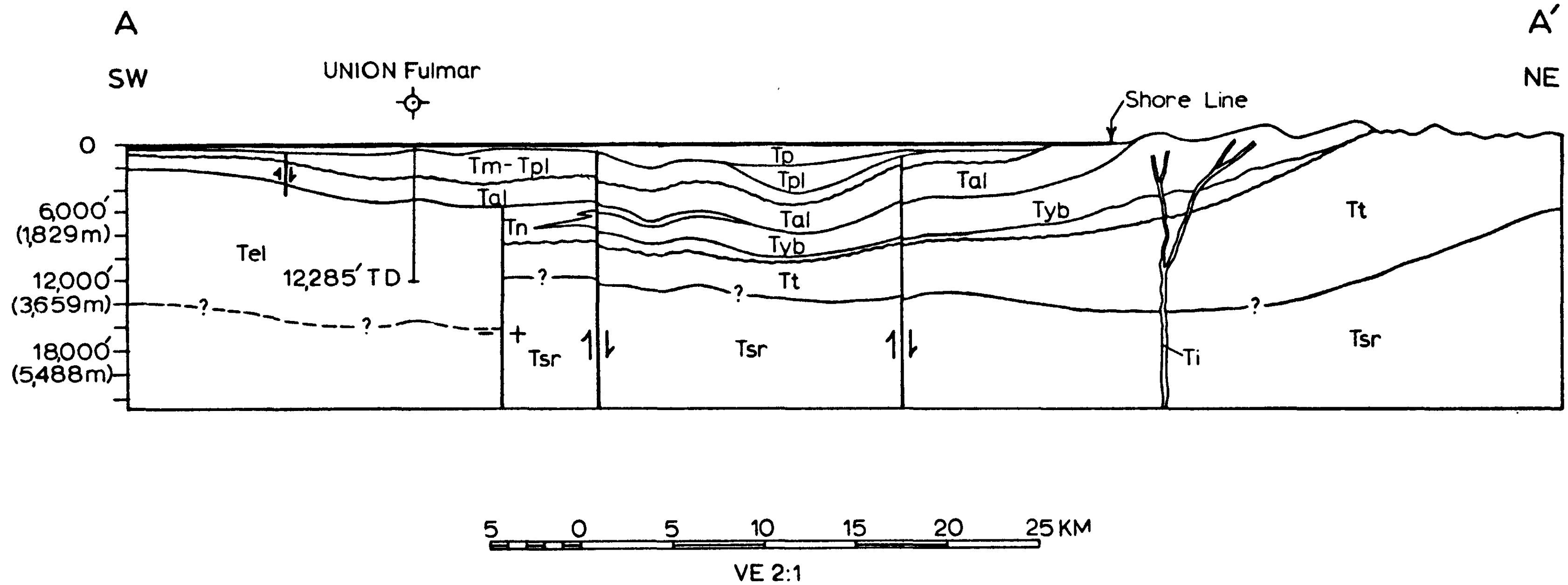



Figure 9.--Cross section A-A′ from central Oregon Coast Range to the continental shelf near latitude 44°15'N. See figure 1 for location of section. Modified from Braislin and others (1971). Symbols used in cross section are as follows: Tsr, Siletz River Volcanics (lower and middle Eocene); Tt, Tyee Formation (middle Eocene); Tn, Nestucca Formation (upper Eocene); Tyb, Yachats Basalt (upper Eocene); Tal, Alsea Formation (Oligocene); Tel, early Eocene; Tm-Tpl, late Miocene and Pliocene; Tp, Pleistocene.

## HISTORY OF PETROLEUM EXPLORATION

Interest in oil and gas in the Pacific Northwest began before the turn of the century (Livingston, 1958).[1/] Oil seeps were first reported in Washington about 1881 along the sea cliffs on the west side of the Olympic Peninsula. In the same general area, early investigators also reported natural gas seeps associated with mud cones and mounds.

The first known test for oil in western Washington was drilled between 1900 and 1902 near Stanwood Station or Machias(?) in Snohomish County. In Oregon the initial test for oil was drilled about 1902 near the town of Newberg, Yamhill County (Stewart and Newton, 1965). Since that time, approximately 380 wells for oil and gas have been drilled in Washington, and approximately 185 exploratory holes have been drilled in Oregon.

Many of the first wells drilled in western Washington were in the vicinity of seeps or in areas where gas shows were found in water wells. Although commercially significant quantities of oil and gas have not been produced in either state, shows of hydrocarbons have been documented in many exploratory wells drilled in Washington. In Oregon, however, confirmed reports of petroleum are few.

1/ This section on exploration history is largely taken from Braislin, Hastings and Snavely (1971) but has been updated based on more recent data.

Over the years, exploratory activity in the Pacific Northwest has been somewhat cyclic. The early 1930's was a particularly active period, and most wells were drilled by independents and small operators. Relatively few wells drilled during the period were based on sound geologic considerations. After World War II, major oil companies became more aggressive in the area, and modern geophysical methods were used for the first time. After these more intensive geophysical and geological studies, several drilling programs were initiated. One of the most promising of these programs was by Union Oil Company of California in the Ocean City area, Grays Harbor County, Washington. There, excellent shows of gas and high-gravity oil were found in Oligocene and Miocene strata, but commercial production could not be established because of the low permeability of the reservoir rocks.

In 1957, Sunshine Mining Co. drilled the Medina No. 1 in the Ocean City area to a total depth of 4,140 ft (1,262 m). A series of production tests in the interval 3,952-3,958 ft (1,204-1,206 m) resulted in a maximum indicated flow rate of 175 bbl/day of 38.9° gravity paraffin-base oil. Rapid drops in pressure characterized these tests, and although more than 12,000 bbl of oil were produced, the well was plugged and abandoned in August 1962.

Near Coos Bay, Oregon, many attempts have been made to establish dry gas production from extensive coal-bearing sandstone beds of late Eocene age. In the Willamette Valley, oil and gas shows were reported from several wells drilled between 1940 and 1965, but commercially significant quantities of petroleum were not found.

Beginning in 1960, exploratory interest shifted from the Coast Ranges to the outer continental shelf (OCS) off Oregon and Washington. Geophysical surveys established numerous depositional centers on the shelf; several contain estimated thicknesses of more than 25,000 ft. (7,620 m) of Tertiary sedimentary rocks. A westerly decrease in the amount of interbedded volcanic rocks in the sedimentary sequence and the thicker upper Tertiary section offshore also stimulated interest in the OCS acreage.

Between 1960 and 1964, several groups of companies engaged in exploratory operations of the continental shelf between Cape Blanco and the Strait of Juan de Fuca. In October 1964, the federal government offered a total of 1,090,000 acres for oil and gas leasing in 10 separate areas on the shelf. More than $35.6 million in bonus money was received from this sale, of which $27.8 million was for acreage on the Oregon shelf.

As of December 1, 1969, 10 exploratory wells had been drilled on federal OCS leases off Oregon and Washington (see Table 1) and three shallow holes on state tideland leases off Washington. However, no commercial oil was indicated as a result of this exploratory activity. Federal offshore lands which had not been quit-claimed expired on December 1, 1969.

During the period from January 1970 through December 1975 (since the publication of Braislin, Hastings, and Snavely, 1971), oil and gas exploration activity in western Oregon and Washington has included the drilling of 35 commercially unsuccessful test wells. Washington has shown the most activity with the drilling

Table 1.--Significant data on exploratory test wells drilled on the Oregon-Washington OCS.

| Number on figure 11 | Company and Name of Well | Year | Location | | Total Depth ft. | Tertiary Rocks Penetrated | Remarks |
|---|---|---|---|---|---|---|---|
| | | | Latitude | Longitude | | | |
| 1 | Pan America Well No. 1,P-0112 | 1967 | 43° 14.8' | 124° 35.6' | 6,146 | Pliocene to early(?) Eocene | Bottomed in cemented sand-stone |
| 2 | Union-Fulmar P-0130 | 1966 | 44° 3.6' | 124° 38.8' | 12,221 | Pliocene to early Eocene | Bottomed in cemented sand-stone |
| 3 | Shell Oil Well 1 ET-2 ET P-087 | 1965 | 44° 13.3' | 124° 28.2' | 8,353 | Mio-Pliocene to early(?) Eocene | Bottomed in basalt |
| 4 | Union Oil-Grebe P-093 | 1966 | 44° 29.8' | 124° 24.9" | 10,010 | Mio-Pliocene to middle(?) Eocene | |
| 5 | Standard Oil - Nautilus #1,P-0103 | 1965 | 44° 51.5' | 124° 16.7' | 12,628 | Mio-Pliocene to late(?) Eocene | Hole bottomed in volcanic rocks |
| 6 | Shell Oil P-072 1 ET | 1965-1966 | 46° 2.8' | 124° 29.9' | 8,219 | Pliocene - (?) | -- |
| 7 | Shell Oil P-075 1 ET | 1966 | 46° 9.1' | 124° 24.5' | 10,160 | Pliocene(?) to middle Eocene(?) | Bottomed in basalt |
| 8 | Shell Oil and Pan Amer. P-0150 | 1966 | 46° 43.5' | 124° 21.3' | 13,179 | Pliocene - lower Miocene(?) | Drilled on dia-piric structure |
| 9 | Shell Oil 1ET P-0155 | 1967 | 46° 51.2' | 124° 24.5' | 11,162 | Pliocene(?) - Miocene(?) | Drilled on dia-piric structure |
| 10 | Pan American P-141 | 1967 | 47° 39.7' | 124° 47.5' | 10,368 | Pliocene - Miocene(?) | |

of 29 wells ranging from 680 ft. (207 m) to 9675 ft. (2950 m) in depth. Twenty of these wells are located in the Grays Harbor area and most were drilled to test the post-Oligocene sequence. Shows of gas were reported in several of these wells. In 1970, Shell Oil Company drilled 14 of these wells north of Grays Harbor which range from 1,344 ft. (410 m) to 4,600 ft. (1,402 m) in depth. During 1974 and 1975, El Paso Products Company drilled 4 wells just east of Grays Harbor. In 1975, they drilled a well in Jefferson Co. which tested gas at a subcommercial rate. The Puget Sound area has been the other major focus for exploration activity in Washington. In 1972, Mobil Oil Corp., Union Oil Co., and Standard Oil Co. of California drilled 4 unsuccessful wells north and west of Seattle; these wells ranged from 4,019 ft. (1,225 m) to 9,475 ft. (2,900 m) in depth. Another area of exploration activity was near Forks where during 1973, Eastern Petroleum Co. drilled 2 unsuccessful wells which reached total depths of 1,680 ft. (512 m) and 3,095 ft. (943 m).

Western Oregon had only limited oil and gas exploration activity with 6 wells drilled from 1970 to 1975. During 1975, Reichhold Energy Corp. drilled 4 unsuccessful wells in the Willamette Valley near Portland. NNG #1, with a TD of 7,300 ft. (2,226 m), had minor shows of gas at shallow depth between 1,000 ft. (305 m) and 1,500 ft. (457 m). During the same year, Reichhold Energy Corp. also drilled an unsuccessful well south of Tillamook with a TD of 5,557 ft. (1,694 m).

## PETROLEUM POTENTIAL

### General Considerations

The accumulation of commercial quantities of oil and gas requires a combination of: (1) suitable source rocks which have been subjected to temperatures sufficiently high to generate petroleum; (2) strata with permeability and porosity adequate to permit migration of petroleum toward potential traps or reservoirs; and (3) presence of traps where the petroleum can accumulate in pools and be preserved against loss and destruction. The lack of anyone of these essential elements precludes commercial deposits of petroleum.

### Reservoir Rocks

The Oregon and Washington OCS is deficient in one of these elements, the availability of sandstones that are suitable reservoirs for oil and gas. Most of the strata encountered in test wells on the OCS are fine-grained silty sandstone and siltstone; coarser clastic debris probably constitutes less than 20 percent of the pre-Pliocene strata. The sandstone units present in the OCS are probably turbidite sands with relative low permeability and porosity (Table 2) because clay minerals and calcareous cement often fill the pores between grains. In areas where the sandstone units have been highly deformed tectonically, zeolite minerals and in places silica cement the sandstones and greatly reduce their porosity and thus reservoir potential.

| Age | | Shelf Facies | | Deep Marginal Basin | |
|---|---|---|---|---|---|
| | | Porosity[1] | Permeability[2] | Porosity | Permeability |
| Miocene | | 22.1* | 21.4 | 14.4 | .05 |
| | | 29.2* | 1682.0 | 10.2 | .16 |
| | | 26.6* | 31.2 | 18.2 | 234.0 |
| | | 22.0* | 20.1 | | |
| | | 25.6* | 29.2 | | |
| | | 20.4* | 3.0 | | |
| Oligocene | | 20.7 | 34.9 | 24.6 | 675.0[3] |
| | | 23.4 | 15.6 | 20.2 | 7.5[3] |
| | | 25.3 | 319 | 20.7 | 2.0[3] |
| | | 24.5 | 18.6 | 14.7 | .13 |
| | | 27.1 | 69.7 | 24.3 | 14.0 |
| | | | | 18.2 | 17 [3] |
| Eocene | Upper | 35.2* | 3306.0 | 8.5 | 1.1 |
| | | 19.4* | .05 | 9.4 | 0.7 |
| | | 13.3* | 8.5 | 7.4 | 0.3 |
| | | 29.3* | 558.0 | 9.7 | 1.4 |
| | | 33.1* | 530.0 | 8.7 | 0.9 |
| | | 21.1* | 1.8 | 6.6 | 2.3 |
| | | 20.7* | 3.4 | 9.2 | 0.4 |
| | | 21.5* | 82.1 | 5.1 | 0.2 |
| | | 27.9* | 478.0 | 16.9 | 14 |
| | | 30.5* | 1992.0 | | |
| | Middle | | | 15.1 | 0.30 |
| | | | | 19.4 | 47.0 |
| | | | | 16.6 | 1.8 |
| | | | | 9.3 | 4.1 |
| | | | | 4.8 | 0.2 |
| | | | | 16.1 | 3.3 |
| | | | | 18.5 | 3.3 |
| | | | | 16.4 | 2.5 |
| | | | | 20.9 | 4.4 |
| | | | | 10.4 | 0.4 |

* Drill hole cores
- remainder, surface samples.

1. Effective porosity in percent.
2. Permeability in millidarcys
3. Turbidite sandstones in northwesternmost part, Olympic Peninsula.

Table 2.--Porosity and permeability for selected Tertiary sandstones--western Oregon and Washington.

The nearshore coarser clastic Tertiary shelf deposits do not extend for any great distance beyond former strandlines. However, some coarse clastic debris was transported into the deep marginal basins by density currents, mass flowage, or by the slumping of delta-fronts and the redistribution of sand by turbidity currents into deep parts of the basin.

Despite the fact that many turbidite sands contain a high clay content (up to 20%), which reduces effective porosity and permeability, some turbidite sands appear to have been "cleaned-up" as they were transported into the basins. Measurements on four samples of Oligocene turbidite sandstone from the northwestern part of the Olympic Peninsula for instance, indicates they are potential reservoir rocks (see Table 2, footnote 3). Table 2 also lists porosities and permeabilities for selected Tertiary sandstones that crop out in western Oregon and Washington and which were deposited in either a shelf or deep marginal basin environment. It is readily evident from the data in Table 2 that sandstone deposited in a shelf environment forms a potentially better reservoir rock than sandstone deposited in a deep marginal basin environment.

In order to define offshore areas that have the greatest potential for sand development, one must consider the depositional history of the bordering land mass to delineate areas such as ancient deltas, delta-front fans, or fan channels where coarse-grained clastic debris was available for transportation beyond the shelf edge into the deeper water environment. In figure 10 four areas are outlined in coastal Oregon and Washington where surface mapping and stratigraphic studies indicate that environments of deposition were such that sand could be transported across the shelf into deeper offshore basins. These areas include the upper Eocene deltaic deposits at Coos Bay, upper Oligocene deltaic deposits at Newport, middle Miocene deltaic deposits in the Seaside area, and probable Pliocene deltaic deposits along the southwest side of the Olympic Peninsula.

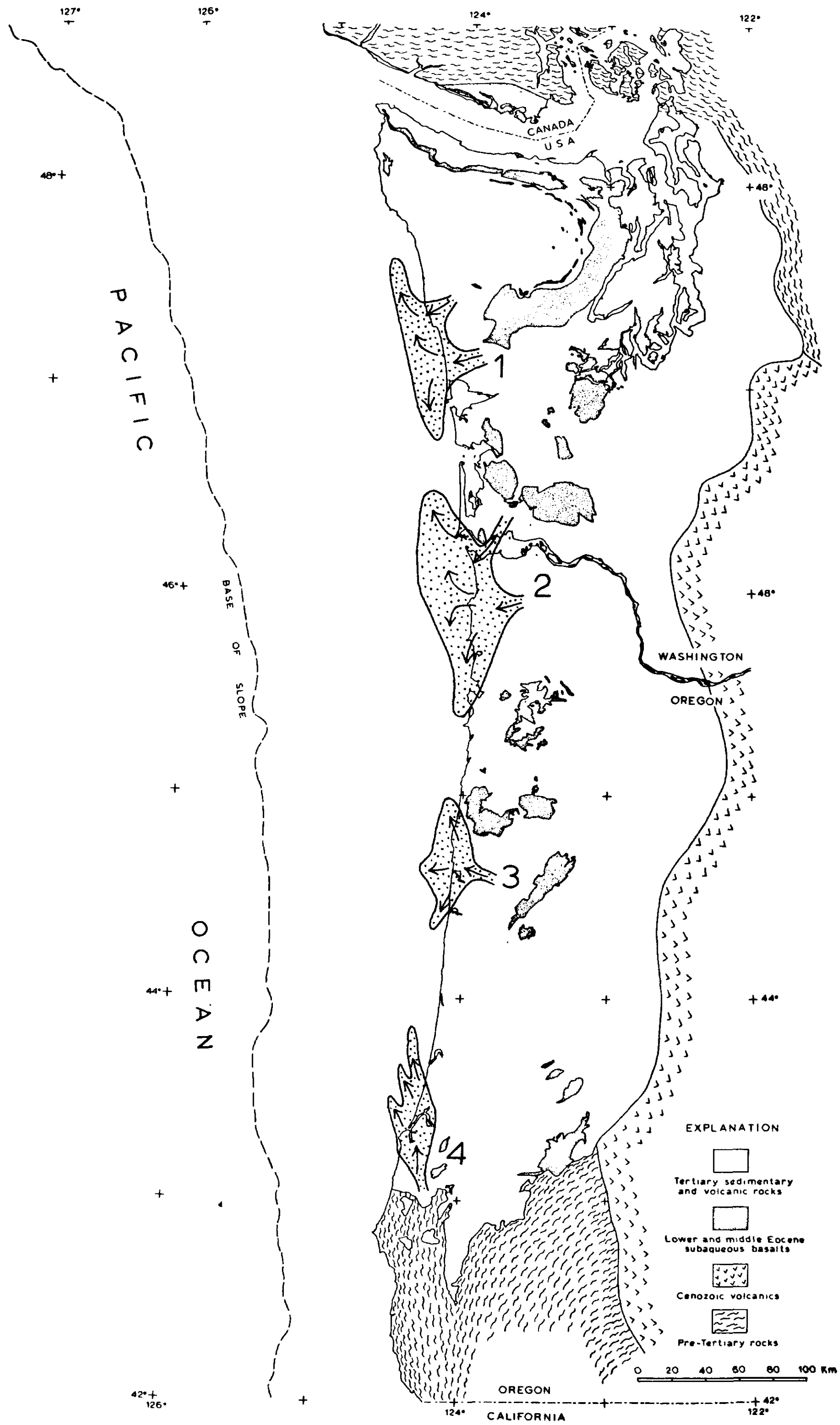



Figure 10. --Map showing locations of Tertiary deltas, delta-front fans, or fan channels that may have been the source for coarse-grained clastic detritus to deeper offshore basins. Age of these potential source areas are: (1) Pliocene, (2) middle Miocene, (3) late Oligocene, and (4) late Eocene.

## Source Beds

Thick sequences of organic-rich siltstone and mudstone that range in age from middle Eocene to Pliocene are present in the Tertiary of western Oregon and Washington and the adjacent OCS (fig. 5). Predominantly fine-grained clastic units include the Yamhill, McIntosh, and Aldwell Formations of middle or late Eocene age, the Alsea, Nestucca and Twin River Formations of Eocene and Oligocene age, and the Nye Mudstone of early Miocene age and the Quinault Formation of Pliocene age. Although some of these siltstone units (e.g. Nye Mudstone) give off a petroliferous odor when freshly broken, hydrocarbon analysis indicates that they are immature with respect to the temperature history required for hydrocarbon generation and many have marginal-to-adequate organic richness for petroleum source beds. Table 3 lists 27 hydrocarbon analyses and their interpretation by George Claypool, U. S. Geological Survey, Denver, Colorado.

The fine-grained clastic rocks that are mature and have the highest oil content are chiefly from the tectonically complex mélange and broken formation assemblage along the west coast of the Olympic Peninsula. These mudstones have been subjected to underthrusting and the resulting greater depth of burial or frictional heat produced temperatures high enough to make the petroliferous "smell muds" and small gas seeps that are common along the west coast. The 12,000 barrels of oil produced from the Medina No. 1 in the Ocean City area probably were generated from lower to middle Miocene mélange that underlies this part of the Washington coast.

Table 3.--Hydrocarbon analyses of selected fine-grained clastic rocks from middle Eocene to middle Miocene deep marginal basins, western Washington and Oregon. Samples collected by Parke D. Snavely, Jr. Analysis and interpretation by George Claypool.

| Location | | | | Pyrolysis yield $10^6$ i.u./mg | | (-43) | Pyrolytic oil yield | | Oil content | Estimated 1/ | Oil content | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Sec | Tnap | Rng | State | 0-360° | Total | T max yield | gal/ton | wt. % | ppm | $C_{org}$ (%) | $C_{org}$ | Source rock evaluation |
| 9 | 11S | 11W | Ore. | .004 | .865 | 447 | 1.1 | 0.43 | 20 | 0.98 | 0.2 | Immature; inadequate organic richness |
| 8 | " | " | " | .008 | .753 | 451 | 1.0 | 0.37 | 40 | 1.46 | 0.27 | Immature; very good |
| 14 | 32N | 13W | Wash. | .0093 | .239 | 463 | 0.30 | 0.12 | 46 | (0.87) | 0.53 | |
| 15 | " | " | " | .0046 | .470 | 471 | 0.36 | 0.14 | 22 | (1.13) | 0.19 | |
| 22 | " | " | " | .008 | .217 | 475 | 0.28 | 0.11 | 40 | (0.84) | 0.47 | Immature; adequate organic richness for petroleum source potential if buried deeper |
| 22 | " | " | " | .0067 | .283 | 460 | 0.36 | 0.14 | 33 | (0.92) | 0.36 | |
| 22 | " | " | " | .007 | .215 | 460 | 0.27 | 0.11 | 35 | (0.84) | 0.42 | |
| 28 | " | " | " | .0163 | .296 | 469 | 0.38 | 0.15 | 80 | 1.02 | 0.78 | |
| 28 | " | " | " | .0113 | .295 | 478 | 0.38 | 0.15 | 56 | 0.87 | 0.64 | |
| 28 | " | " | " | .0016 | .103 | 475 | 0.13 | 0.05 | 8 | (0.71) | 0.11 | Immature, low to inadequate organic richness very low oil content/ $C_{org}$ ratios probably non-source |
| 32 | " | " | " | .0019 | .186 | 476 | 0.23 | 0.09 | 10 | (0.81) | 0.12 | |
| 32 | " | " | " | .0011 | .0845 | 475 | 0.10 | 0.04 | 5 | (0.71) | 0.07 | |
| 5 | " | " | " | .0008 | .0435 | 475 | 0.05 | 0.02 | 5 | 0.68 | 0.07 | |
| 5 | 31N | " | " | .0007 | .0955 | 477 | 0.12 | 0.05 | 5 | (0.70) | 0.07 | |
| 5 | " | " | " | .0171 | .1062 | 499 | 0.13 | 0.05 | 85 | (0.72) | 1.18 | Mature, hydrocarbon-generating sediments, low or inadequate organic richness |
| 36 | 31N | 15W | " | .0134 | .127 | 500 | 0.16 | 0.06 | 67 | (0.74) | 0.91 | |
| 10 | 30N | " | " | .007 | .0397 | 475 | 0.05 | 0.02 | 35 | (0.64) | 0.55 | Immature; inadequate source potential |
| 2 | " | " | " | .019 | .309 | 489 | 0.39 | 0.15 | 95 | (0.95) | 1.00 | Mature, hydrocarbon-generating rock, adequate to good organic richness |
| 15 | 32N | 14W | " | .0031 | .0984 | 475 | 0.12 | 0.05 | 15 | (0.71) | 0.21 | Immature, low-to-inadequate organic richness |
| " | " | " | " | .033 | .210 | 462 | 0.26 | 0.10 | 83 | (0.83) | 1.0 | Mature; inadequate organic richness |
| " | " | " | " | .0103 | .217 | 475 | 0.27 | 0.11 | 50 | (0.84) | 0.60 | Immature; low organic richness |
| 16 | " | " | " | .0013 | .0294 | 475 | 0.03 | 0.015 | | 0.52 | 0.13 | Immature; inadequate |
| 9 | " | 13W | " | .014 | .329 | 471 | 0.42 | 0.16 | 71 | (0.97) | 0.73 | Immature; adequate-to-good organic richness |
| 12 | 33N | 15W | " | .0013 | .108 | 462 | 0.13 | 0.05 | 6 | (0.72) | 0.08 | Immature; inadequate |
| 15 | 29N | 15W | " | .053 | 1.370 | 495 | 1.8 | 0.68 | 260 | 2.10 | 1.2 | Mature; very good organic richness |
| 16 | " | " | " | .025 | .359 | 481 | 0.46 | 0.18 | 126 | 1.16 | 1.1 | Mature; adequate-to-good organic richness |
| 27 | " | " | " | .007 | .110 | 484 | 0.10 | 0.04 | 28 | 0.64 | 0.44 | Mature; low-to-inadequate organic richness |

1/ Bracketed values are estimated by pyrolysis response of organic carbon, other values were measured.

Only one gas seep has been recognized in the deep marginal basin sedimentary sequence. This seep is along the Pysht River in section 27, T.13N., R.12W., an area underlain by near vertical dipping sandstone and siltstone beds of the lower member of the Twin River Formation of late Eocene age. An analysis of this gas by A. J. Miller, Mobil Oil Company, is shown in Table 4.

Table 4.--Molecular Composition of the Hydrocarbons in the Pysht River Seep; analyst, A. J. Miller.

| | |
|---|---|
| Methane | 94.33% (Mole percent) |
| Ethane | 3.50 |
| Propane | 1.54 |
| Butanes | 0.43 |
| Pentanes | 0.135 |
| Total $C_6$'s | 0.054 |
| Total $C_7$'s | 0.009 |

## Traps

Many structural and stratigraphic type traps are present on the Oregon and Washington OCS (fig. 3). The 10 deep test wells drilled on the OCS in the mid and late 1960's (Table 1) were located on known or inferred anticlinal highs. These wells, and many of those drilled on anticlinal highs onshore, were unsuccessful apparently because many of these structures were either complex at depth or the cores were formed of older lower Eocene sandstone or basalt that is intensely deformed and has low porosity and permeability. Other wells drilled on anticlinal highs, such as the Grebe and Nautilus wells, chiefly penetrated a fine-grained clastic sequence with few sands. Several test wells drilled on diapiric structures on the Washington OCS encountered sheared siltstone or mélange that forms the cores of these diapirs (fig. 7). One observation that can be made in hindsight is that most of the exploration test wells drilled in the study area were too high on structure and more rewarding plays probably are on the flanks of these older structural highs. The unconformity at the base of upper Eocene provides stratigraphic onlap of the upper Eocene - middle Miocene sequence on the "bald" high of older Eocene sedimentary and volcanic rocks. The flanks of diapiric structures, both domes and elongated diapiric ridges, on the Washington OCS probably are more fruitful targets than the axial parts of the structures drilled in the late 60's. Reservoir sand development associated with diapirs, however, is probably restricted to strata of Pliocene age, which provides little opportunity for development of cap rock to preserve against loss and destruction of petroleum that may have migrated to these structures.

Along the eastern margins of the Newport and probably Astoria basins, north-trending normal faults intersect the up-dip sequence of upper Oligocene and middle Miocene strata that probably contain potential reservoir rocks. Here, combinations of stratigraphic fault traps may exist.

## RELATIVE PETROLEUM POTENTIAL BY AREA

Based upon the seaward extrapolation of the onland geologic framework, the relative abundance of anticlinal and stratigraphic traps, and the inferred offshore distribution of coarse-grained clastic sediments that may form suitable reservoir rocks; there are several areas in the Oregon-Washington OCS that appear to have greater petroleum potential than the remainder. This evaluation must be considered tentative and undoubtedly will be revised when more and better offshore geophysical and geologic data are obtained. Table 5 presents a qualitative ranking of these areas on a scale of 1 to 5 which reflects our best judgment as to their petroleum potential. The location of these basins are shown on figure 11.

The highest ranked area, the Astoria Basin, contains several large anticlinal structures and a thick sequence of Tertiary rocks which includes potential source beds. Of particular importance, however, is that it may contain suitable reservoir sands derived from middle Miocene delta-front fans and fan-channels which were located near the former shelf-edge and west of the mouth of an ancestral Columbia River (Alan Niem, written communication, 1976).

The east flank of the Newport Basin is ranked second because a broad late Oligocene delta existed along the east margin of this basin and parts of these coarse-grained clastics may have found their way into the deeper parts of the basin along channels or by mass wasting.

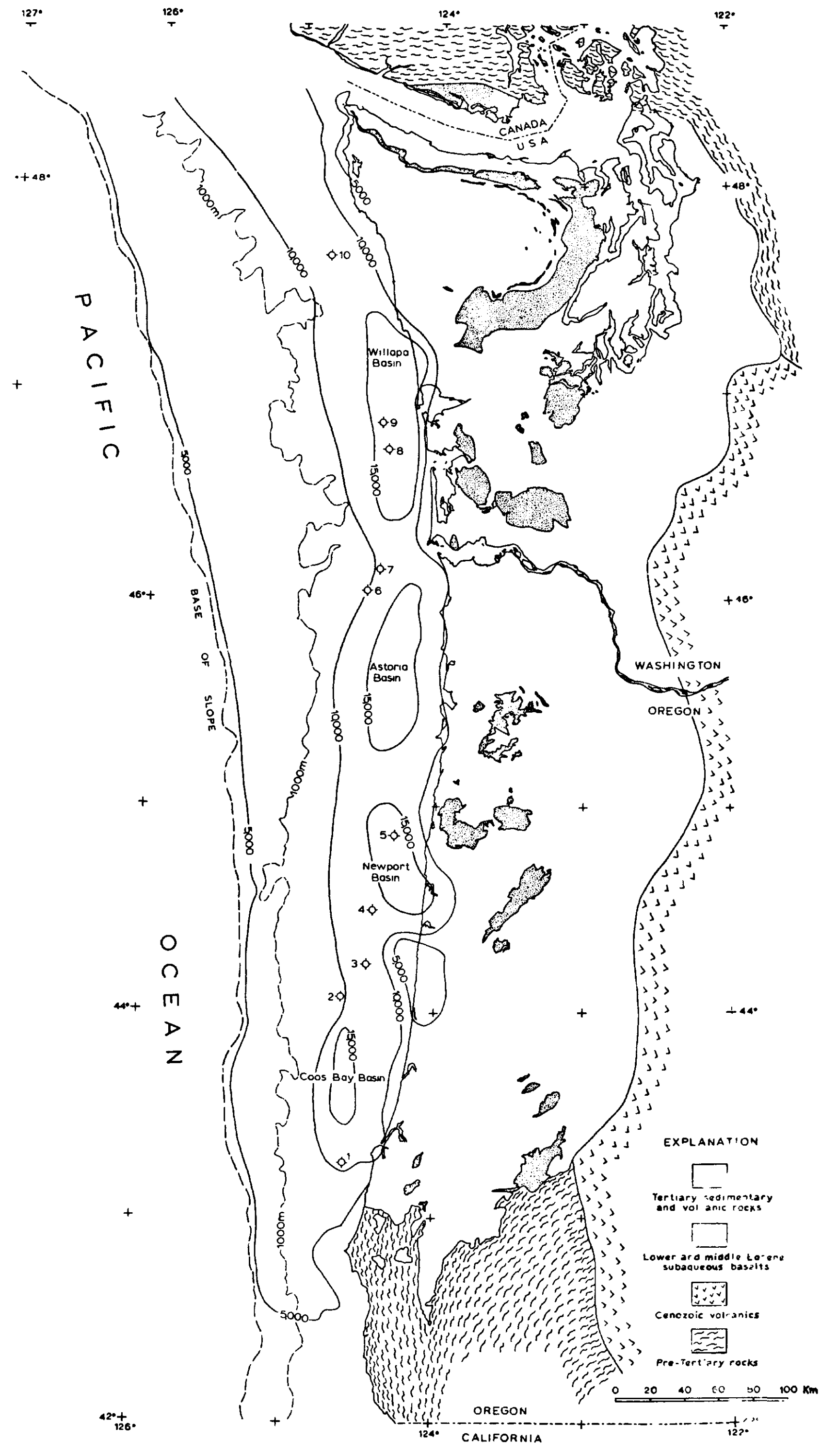



Figure 11.--Isopach map of net objective section and location of major basins basins on the Oregon-Washington OCS. Contours are in 5,000 ft. intervals. See Table 1 for names of test wells 1-10 plotted on the continental shelf.

Table 5.--Tentative rating of Tertiary basins of the Oregon-Washington OCS according to inferred petroleum potential (1 highest, 5 lowest). Locations of basins shown in Figure 10.

1. Astoria Basin - eastern margin
2. Newport Basin - eastern margin
3. Coos Bay Basin - eastern margin
4. Astoria Basin - western margin
4. Coos Bay Basin - western margin
5. Willapa Basin diapirs
5. Newport Basin - western margin

Although large anticlinal structures may be lacking in this area, a combination of stratigraphic and fault traps probably exist along the eastern margin of the basin where reservoir sands of late Oligocene and perhaps middle Miocene age are likely present.

The third ranked area is the eastern margin of the Coos Bay Basin where a thick Tertiary sequence may contain potential reservoir sands derived from delta-fronts of late Eocene and middle Miocene age. Although only few seismic records are available along the eastern margin of the basin, there appear to be two large north-trending anticlinal structures on the inner shelf and numerous small anticlines are present in the deeper part of the basin.

Ranked fourth are the western margins of both the Astoria and Coos Bay basins which probably are bounded by broad north-trending highs of lower to middle Eocene basalt and lower to middle Eocene indurated sandstone respectively. The exploration targets in these areas would be stratigraphic traps formed by the onlap of a late Eocene to middle Miocene sequence (above the mid-late Eocene regional unconformity) onto these older highs. One unfavorable aspect to these exploration target areas may be the lack of suitable reservoir sands in the late Eocene to middle Miocene sequence.

In the lowest ranked areas, the Willapa Basin diapirs and the west margin of the Newport Basin, where the middle Miocene and older sedimentary rocks consist chiefly of fine-grained clastic rocks and suitable reservoir rocks may be lacking. The cores and "basement" rocks of the diapirs consist of sheared siltstone and perhaps mélange. The folded upper Miocene and Pliocene strata on the flanks of the diapiric structures offer the best exploration targets, particularly those diapiric uplifts that do not breach the upper Miocene and Pliocene sequence. The west margin of the Newport Basin has been partly tested on Stonewall Bank where test well P-093 (fig. 5) encountered a sequence of chiefly fine-grained sedimentary rocks. The east flank of the Stonewall Bank anticlinorium may contain greater sand development in the Eocene to middle Miocene section than the axial part of the structure that was drilled. Also stratigraphic traps may exist along the east flank where upper Miocene to Pliocene strata onlap older rocks.


(PAGE 47 FOLLOWS)

## RESOURCE APPRAISAL ESTIMATE

by Edward W. Scott

An appraisal was made of the potential oil and gas resources of offshore Oregon and Washington in 1975 by the Resource Appraisal Group, Branch of Oil and Gas Resources, U.S. Geological Survey, and it was incorporated into Geological Survey Circular 725, Geological Estimates of Undiscovered Recoverable Oil and Gas Resources in the United States, 1975. The estimates that were derived for all of the offshore provinces were limited to the areas of less than 656 feet (200 m) water depth.

Subsequent to the published report, estimates have been made by the Resource Appraisal Group for the offshore area of Oregon-Washington between water depths of 656-8,200 feet (200-2,500 m). This work has not been published.

The resource estimates of the two projects have been aggregated by Monte Carlo simulation techniques and the following figures are the estimates for the amounts of undiscovered recoverable oil and gas that may be present in offshore Oregon-Washington between water depths of 0 to 2,500 meters:

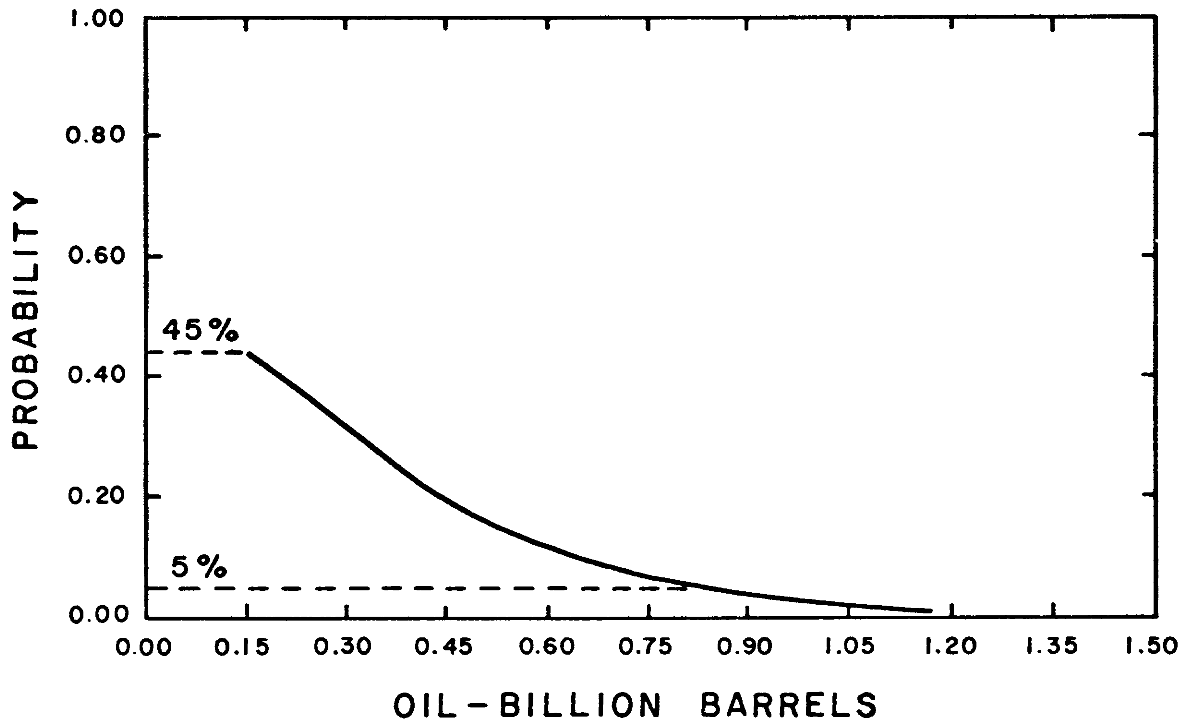
| | 95% Probability | 5% Probability | Statistical Mean |
|---|---|---|---|
| OIL-billions of barrels | 0 1/ | 0.66 | 0.24 |
| GAS-trillions of cubic feet | 0 1/ | 2.25 | 0.60 |

1/ The possibility exists that there is no commercial oil or gas in this frontier province and consequently, a marginal probability is assigned. It is assumed that there is a 55% probability that there is no commercial accumulation in the province.

There are two qualifications for use of these estimates with reference to the proposed sale area: (1) the sale area is limited to a water depth of 1,000 meters; and (2) both State and Federal acreages are included in the estimate. With reference to some allocation of the total amount of estimated resources to the more restricted area of less than 1,000 meters, this latter portion covers about 70% of the total area assessed. However, an allocation based upon percent of area is not justified. The basic definition of the estimate is undiscovered recoverable and it was stipulated that this meant recovery under conditions of present economy and technology. Under these conditions, most, if not all, of the estimated oil and gas would be allocated to the restricted part of the offshore province.

The State-Federal boundary was not taken into account in the geological estimation and no separate allocations have been made for the two areas. It is noted however that about 94% of the area between water depths of 0-1,000 meters is Federal acreage. For water depths less than 200 meters, Federal acreage covers about 91% of the area.

The log normal probability curves are shown on figure 12 and indicates the estimates of undiscovered recoverable oil and gas resources of the Oregon-Washington offshore. The chart shows a 45 percent probability of 0.15 billion barrels of oil and 0.300 trillion cubic feet of gas. This is related to the 55 percent probability of no commercial deposits. The 5 percent probability is indicated by a dashed line and other probability estimates can be read directly from the curves.



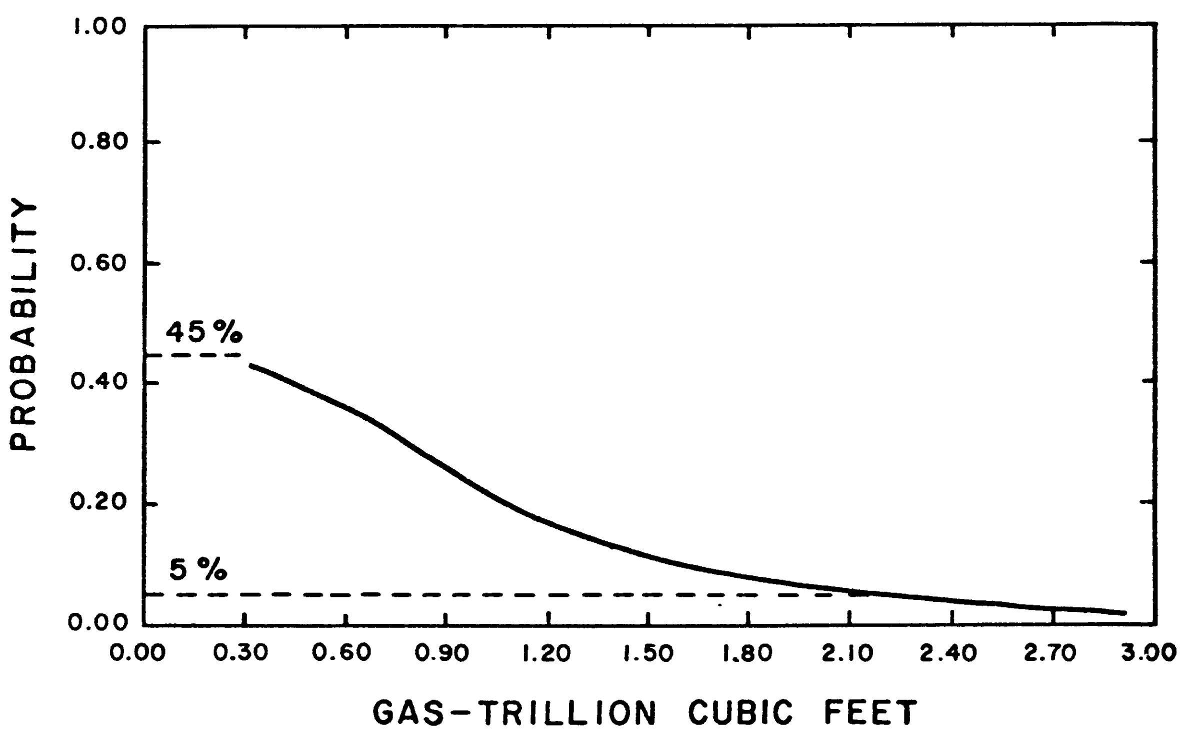




Figure 12.--Log normal probability curves that indicate the estimate of undiscovered recoverable oil and gas resources of the Oregon-Washington OCS.

# OTHER MINERAL RESOURCES

## Heavy Minerals

Local concentrations of heavy minerals, (namely gold, platinum, ilmenite, chromite, and magnetite) occur in beach deposits and on the continental shelf of Oregon (Clifton, 1968; Kulm and others, 1968). A small amount of placer gold has been mined in places along the western Olympic coast, but the deposits are thin and restricted to the high energy beach zone (Weissenborn and Snavely, 1968).

The most significant deposits of heavy minerals are on the continental shelf off southern Oregon as the source rocks for these minerals are the pre-Tertiary igneous and metamorphic rocks of the Klamath Mountains. Most larger and richer concentrations, with few exceptions, are found 2 to 13 km seaward of the present-day river mouths (e.g. Rogue and Sixes Rivers) in water as deep as 90 m (Kulm and others, 1968; Libbey, 1976).

As the highest concentrations of heavy minerals are associated with a coastal zone that has a high recreational use, it is questionable if they can be exploited because of the constraints dictated by their environmental setting.

## GEOLOGIC HAZARDS

### General Statement

High-resolution seismic reflection data and seafloor samples are sparse (or lacking) in most areas on the Oregon-Washington OCS. Therefore, it is not possible to make an intelligent assessment of potential geo-environmental hazards of the region. Based upon the intense tectonic activity recorded in the Upper Cenozoic and Quaternary rocks, and the earthquake history of the region (Table 6), tectonism appears to continue undiminished to the present.

### Faulting and Warping

Numerous faults have been mapped in the coastal zone that offset upper Pleistocene deposits and in several places, as along the Olympic coast, faults offset recent soil zones up to 2 m. A high-resolution profile off Grays Harbor shows the seafloor sediments offset approximately 7 m by a "trap-door"-type fault (fig. 8). Off Depoe Bay, Oregon, a north-trending zone of normal faults offset all but the most recent seafloor sediments (fig. 9). Although most of the recently recorded major earthquakes are concentrated in the Puget Sound area, there are historical accounts of apparent large earthquakes along the Washington coast. For example, a major earthquake which Indians reported in 1914, threw the large rivers along the west side of the Olympic Mountains out of their banks. Based upon past experience, major earthquakes can be expected in the future on the continental shelf. Therefore, ground shaking, fault displacements, tectonic warping, and earthquake generated landslides all pose potential hazards to installations on the OCS.

Table 6.--Earthquakes in and near the Tertiary Province of Oregon and Washington and the adjacent continental margin, 1963 through 1975

[Includes earthquakes whose epicenters lie between 42° and 48.5° North latitude and between 122° and 127° West longitude]

| Date | | | Latitude | Longitude | Depth | Magnitude |
|---|---|---|---|---|---|---|
| Day | Month | Year | (Degrees N) | (Degrees W) | (Kilometers) | |
| 07 | 03 | 63 | 44.90 | 123.50 | 33 | 4.60 |
| 02 | 07 | 63 | 42.90 | 126.20 | 33 | 4.10 |
| 04 | 07 | 63 | 43.70 | 126.40 | 33 | 4.40 |
| 22 | 08 | 63 | 42.00 | 126.40 | | 5.60 |
| 16 | 09 | 63 | 43.20 | 126.80 | 33 | 4.70 |
| 22 | 09 | 63 | 42.00 | 126.50 | 33 | 4.30 |
| 18 | 12 | 63 | 43.70 | 126.90 | 33 | 4.20 |
| 27 | 12 | 63 | 45.70 | 123.40 | 33 | 4.50 |
| 01 | 01 | 64 | 43.70 | 126.30 | 33 | 3.70 |
| 26 | 01 | 64 | 46.01 | 122.40 | 33 | |
| 28 | 01 | 64 | 43.30 | 125.90 | 17 | 4.50 |
| 12 | 02 | 64 | 43.30 | 126.00 | 33 | 4.10 |
| 14 | 02 | 64 | 43.60 | 126.00 | 33 | 4.50 |
| 31 | 03 | 64 | 43.60 | 126.60 | 33 | 4.50 |
| 23 | 04 | 64 | 43.30 | 126.50 | 33 | 4.30 |
| 08 | 05 | 64 | 43.40 | 126.60 | 33 | 4.30 |
| 04 | 07 | 64 | 43.60 | 126.70 | 33 | 4.70 |
| 13 | 07 | 64 | 42.50 | 126.70 | 33 | 5.60 |
| 21 | 07 | 64 | 42.20 | 125.50 | 33 | |
| 27 | 07 | 64 | 42.40 | 125.30 | 33 | 4.50 |
| 30 | 07 | 64 | 47.70 | 122.10 | 33 | |
| 06 | 08 | 64 | 43.40 | 126.70 | 33 | 5.30 |
| 13 | 08 | 64 | 42.00 | 126.10 | | 4.90 |
| 13 | 08 | 64 | 42.30 | 125.50 | 33 | 4.90 |
| 01 | 10 | 64 | 43.50 | 126.90 | 33 | 6.00 |
| 01 | 10 | 64 | 45.70 | 122.80 | 33 | 5.30 |
| 07 | 10 | 64 | 43.50 | 126.00 | 23 | 4.50 |
| 15 | 10 | 64 | 47.70 | 122.10 | 33 | 4.10 |
| 06 | 11 | 64 | 43.50 | 126.60 | 33 | 4.60 |
| 10 | 03 | 65 | 43.40 | 125.40 | 33 | 4.00 |
| 26 | 03 | 65 | 43.20 | 126.20 | 33 | 5.00 |
| 27 | 03 | 65 | 43.80 | 126.90 | 33 | 3.90 |
| 27 | 03 | 65 | 43.50 | 125.90 | 33 | 3.80 |
| 29 | 04 | 65 | 47.40 | 122.40 | 57 | 6.50 |
| 30 | 04 | 65 | 43.60 | 127.00 | 33 | 4.60 |
| 17 | 06 | 65 | 43.20 | 126.00 | 33 | 4.60 |
| 20 | 06 | 65 | 43.10 | 126.00 | 33 | 4.60 |
| 20 | 06 | 65 | 42.90 | 126.10 | 33 | 5.60 |
| 20 | 06 | 65 | 43.20 | 126.10 | 33 | 4.20 |
| 24 | 06 | 65 | 43.60 | 126.90 | 33 | 4.10 |

Table 6.--(continued)

| Date | | | Latitude | Longitude | Depth | Magnitude |
|---|---|---|---|---|---|---|
| Day | Month | Year | (Degrees) | (Degrees W) | (Kilometers) | |
| 25 | 07 | 65 | 42.10 | 126.00 | 33 | 4.60 |
| 31 | 08 | 65 | 43.30 | 126.00 | 33 | 4.20 |
| 04 | 09 | 65 | 42.10 | 125.40 | 33 | 4.10 |
| 14 | 10 | 65 | 43.40 | 126.30 | 34 | 4.20 |
| 23 | 10 | 65 | 47.50 | 122.40 | 23 | 4.80 |
| 24 | 11 | 65 | 43.40 | 125.50 | 32 | 3.90 |
| 09 | 03 | 66 | 43.40 | 126.00 | 11 | 4.30 |
| 11 | 06 | 66 | 47.83 | 122.55 | 33 | |
| 12 | 07 | 66 | 42.10 | 125.00 | 33 | 4.00 |
| 30 | 07 | 66 | 47.20 | 122.00 | 16 | 3.40 |
| 17 | 08 | 66 | 48.00 | 123.60 | 33 | 3.50 |
| 20 | 11 | 66 | 42.20 | 125.80 | 33 | 4.50 |
| 30 | 12 | 66 | 42.50 | 124.80 | 33 | 4.30 |
| 03 | 01 | 67 | 45.59 | 126.02 | 33 | 4.40 |
| 18 | 01 | 67 | 47.30 | 122.57 | 22 | 3.60 |
| 03 | 02 | 67 | 43.27 | 126.08 | 33 | 4.10 |
| 07 | 03 | 67 | 47.84 | 122.65 | 35 | 4.20 |
| 16 | 04 | 67 | 43.42 | 126.41 | 33 | 4.20 |
| 16 | 04 | 67 | 43.36 | 126.57 | 33 | 4.30 |
| 18 | 05 | 67 | 43.62 | 126.32 | 33 | 4.00 |
| 22 | 05 | 67 | 43.63 | 126.84 | 12 | 4.40 |
| 25 | 05 | 67 | 48.15 | 122.80 | 33 | 4.30 |
| 13 | 08 | 67 | 43.50 | 126.90 | 33 | 5.00 |
| 07 | 10 | 67 | 43.40 | 126.90 | 33 | 4.40 |
| 25 | 10 | 67 | 43.40 | 126.70 | 33 | 4.40 |
| 13 | 11 | 67 | 43.40 | 126.80 | 33 | 4.20 |
| 13 | 12 | 67 | 43.20 | 125.90 | 33 | 4.30 |
| 18 | 12 | 67 | 42.60 | 126.00 | 33 | 4.40 |
| 19 | 01 | 68 | 43.40 | 126.60 | 33 | 4.60 |
| 27 | 01 | 68 | 45.70 | 122.80 | 37 | |
| 30 | 01 | 68 | 43.50 | 126.50 | 22 | 4.10 |
| 13 | 03 | 68 | 43.50 | 126.50 | 33 | 4.00 |
| 21 | 03 | 68 | 42.30 | 126.20 | 33 | 4.60 |
| 08 | 05 | 68 | 43.89 | 127.00 | 33 | 4.30 |
| 09 | 05 | 68 | 43.44 | 126.97 | 33 | 5.20 |
| 19 | 06 | 68 | 47.20 | 122.50 | | |
| 26 | 06 | 68 | 42.20 | 125.93 | 33 | 4.10 |
| 12 | 08 | 68 | 43.52 | 126.37 | 06 | 4.20 |
| 06 | 09 | 68 | 48.02 | 122.70 | 38 | 3.90 |
| 06 | 09 | 68 | 47.80 | 122.80 | | |
| 15 | 09 | 68 | 43.96 | 125.28 | 33 | 3.90 |
| 25 | 09 | 68 | 47.80 | 122.70 | | |
| 19 | 10 | 68 | 42.17 | 125.82 | 33 | 4.30 |

Table 6.--(continued)

| Day | Month | Year | Latitude (Degrees N) | Longitude (Degrees W) | Depth (Kilometers) | Magnitude |
|---|---|---|---|---|---|---|
| 30 | 11 | 68 | 46.50 | 122.40 | 13 | 4.30 |
| 15 | 12 | 68 | 45.81 | 127.01 | 33 | 4.30 |
| 18 | 12 | 68 | 45.77 | 127.05 | 33 | 4.60 |
| 21 | 12 | 68 | 43.08 | 126.19 | 33 | 4.60 |
| 23 | 12 | 68 | 43.30 | 125.97 | 33 | 4.40 |
| 25 | 12 | 68 | 43.50 | 126.74 | 33 | 3.90 |
| 06 | 02 | 69 | 43.45 | 126.03 | 33 | 4.30 |
| 07 | 07 | 69 | 43.77 | 126.66 | 33 | 4.20 |
| 13 | 08 | 69 | 48.50 | 122.50 | | |
| 13 | 08 | 69 | 48.48 | 126.47 | 33 | 4.60 |
| 19 | 08 | 69 | 48.50 | 122.50 | | |
| 01 | 10 | 69 | 48.50 | 126.48 | 23 | 4.70 |
| 28 | 11 | 69 | 47.40 | 122.70 | | |
| 31 | 01 | 70 | 42.24 | 126.47 | 33 | 4.50 |
| 10 | 02 | 70 | 47.70 | 122.30 | 33 | |
| 22 | 02 | 70 | 43.49 | 126.82 | 33 | 4.50 |
| 14 | 05 | 70 | 42.52 | 126.39 | 33 | 4.70 |
| 14 | 05 | 70 | 42.43 | 126.58 | 33 | 4.10 |
| 28 | 05 | 70 | 48.45 | 126.66 | 03 | 4.90 |
| 11 | 09 | 70 | 42.18 | 126.60 | 33 | 4.60 |
| 10 | 24 | 70 | 47.30 | 122.40 | 25 | |
| 12 | 12 | 70 | 43.47 | 127.03 | 33 | 4.60 |
| 14 | 01 | 71 | 47.34 | 123.43 | 40 | |
| 25 | 02 | 71 | 43.22 | 126.61 | 33 | 5.00 |
| 17 | 05 | 71 | 42.53 | 126.36 | 33 | 4.90 |
| 20 | 05 | 71 | 42.19 | 126.89 | 33 | 4.70 |
| 20 | 05 | 71 | 42.31 | 126.34 | 33 | 5.00 |
| 28 | 12 | 71 | 47.57 | 122.24 | 30 | 4.00 |
| 23 | 01 | 72 | 43.53 | 127.04 | 33 | 4.80 |
| 23 | 03 | 72 | 42.69 | 126.24 | 33 | 4.90 |
| 24 | 03 | 72 | 42.69 | 126.27 | 33 | 4.80 |
| 08 | 04 | 72 | 42.65 | 126.32 | 11 | 5.60 |
| 09 | 04 | 72 | 42.70 | 126.27 | 33 | 4.70 |
| 25 | 05 | 72 | 45.49 | 122.43 | 10 | |
| 25 | 06 | 72 | 47.99 | 122.13 | 30 | |
| 25 | 05 | 73 | 43.34 | 126.77 | 33 | 4.20 |
| 06 | 06 | 73 | 43.42 | 126.11 | 33 | 4.50 |
| 16 | 06 | 73 | 44.98 | 125.77 | 33 | 5.60 |
| 18 | 06 | 73 | 43.48 | 126.60 | 33 | 4.80 |
| 20 | 08 | 73 | 43.55 | 126.47 | 33 | |
| 22 | 11 | 73 | 43.47 | 126.79 | 17 | 4.50 |
| 05 | 01 | 74 | 42.30 | 126.61 | 33 | 4.00 |
| 05 | 01 | 74 | 42.32 | 126.86 | 33 | 4.30 |

Table 6.--(continued)

| Date Day | Month | Year | Latitude (Degrees N) | Longitude (Degrees W) | Depth (Kilometers) | Magnitude |
|---|---|---|---|---|---|---|
| 05 | 01 | 74 | 42.55 | 126.45 | 33 | 4.00 |
| 05 | 01 | 74 | 42.63 | 126.42 | 33 | 4.60 |
| 05 | 01 | 74 | 42.47 | 126.60 | 33 | 4.90 |
| 05 | 01 | 74 | 42.37 | 126.60 | 33 | 4.20 |
| 05 | 01 | 74 | 42.58 | 126.33 | 33 | 4.30 |
| 05 | 01 | 74 | 42.52 | 126.60 | 33 | 4.40 |
| 05 | 01 | 74 | 42.58 | 126.58 | 22 | 5.00 |
| 04 | 03 | 74 | 43.54 | 126.89 | 33 | 5.00 |
| 23 | 03 | 74 | 42.68 | 126.09 | 33 | 4.50 |
| 28 | 03 | 74 | 42.60 | 126.39 | 33 | 4.60 |
| 29 | 04 | 74 | 43.38 | 126.67 | 33 | 4.50 |
| 16 | 05 | 74 | 48.14 | 122.92 | 54 | 3.80 |
| 08 | 06 | 74 | 42.78 | 126.15 | 33 | 4.10 |
| 29 | 07 | 74 | 45.90 | 122.60 | | |
| 15 | 08 | 74 | 47.30 | 122.40 | | |
| 18 | 10 | 74 | 43.48 | 126.39 | 33 | 4.00 |
| 19 | 10 | 74 | 43.29 | 126.49 | 33 | 4.50 |
| 21 | 10 | 74 | 43.60 | 126.61 | 33 | 4.30 |
| 17 | 11 | 74 | 43.50 | 127.04 | 12 | 5.10 |
| 01 | 12 | 74 | 47.60 | 122.31 | 13 | |
| 15 | 12 | 74 | 42.52 | 126.58 | 33 | 4.20 |
| 15 | 12 | 74 | 48.50 | 122.08 | 01 | |
| 15 | 12 | 74 | 48.50 | 122.10 | | |
| 17 | 02 | 75 | 43.56 | 126.88 | 33 | 4.60 |
| 01 | 03 | 75 | 43.32 | 126.22 | 33 | 4.40 |
| 16 | 04 | 75 | 47.57 | 122.90 | 47 | |
| 23 | 04 | 75 | 47.08 | 122.65 | 46 | 4.00 |
| 14 | 07 | 75 | 47.32 | 122.41 | 07 | |
| 17 | 07 | 75 | 43.80 | 126.77 | 33 | 3.9 |
| 24 | 07 | 75 | 43.20 | 126.21 | 33 | 4.9 |
| 24 | 07 | 75 | 47.32 | 122.41 | 06 | |
| 25 | 07 | 75 | 43.61 | 127.02 | 33 | 4.5 |
| 29 | 07 | 75 | 43.69 | 126.10 | 33 | 5.2 |
| 06 | 08 | 75 | 43.09 | 126.19 | 33 | 4.9 |
| 25 | 09 | 75 | 43.40 | 126.87 | 33 | 4.2 |
| 22 | 11 | 75 | 43.42 | 126.75 | 33 | 4.3 |

Source of data:

U.S. National Oceanic and Atmospheric Administration, Earthquake data file, 1841-1975, National Geophysical and Solar-Terrestrial Data Center.

One potential non-seismic geologic hazard is warping of the seafloor above diapiric intrusions. Some 50 to 100 diapirs probably exist on the Washington OCS and on the outer continental shelf of Oregon. These siltstone piercement structures in many places warp, and less commonly, offset seafloor sediments (fig. 7). Also, the siltstone in these diapirs is probably over-pressured and gas pockets at shallow depths may be encountered during exploration drilling. Gas seeps are found along the flanks of several diapirs along coastal Washington and one just north of Taholah has produced a mud mound. Possible areas of unstable, poorly consolidated deposits may exist on offshore diapirs which could be a threat to structures sited on them.

## Ground Failure

Water-saturated or highly sheared Tertiary sedimentary rocks (mélange) and semiconsolidated Quaternary deposits which border much of the Oregon and Washington coasts are subject to ground failures. These rocks and deposits are highly susceptible to loss of bearing strength and slope failure either under the influence of gravity or ground shaking during earthquakes. The few high-resolution profiles available on the OCS indicate that areas of moderate and relatively steep slopes contain numerous slump features. These are most prevalent in areas of thick sediment accumulation on steep slopes such as the continental shelf-slope break throughout the study area and on the flanks of several submarine canyons that incise into the shelf, such as the Juan de Fuca, Astoria, Quinault, Willapa, and the Eel River canyons. Submarine landslides occur in several areas. For example a profile off Tillamook Bay (fig. 13), shows a submarine landslide area about 2.8 km long and 100 m thick that disrupts Holocene(?) sediments and that contains several strong reflectors. These reflectors, which on high-resolution records are continuous for more than 30 km, may be interbeds of volcanic ash that provide planes of weakness, thus facilitating landsliding. Volcanic ash from Mount Mazama has been cored on the Oregon shelf (Nelson, 1976) and ash from an unidentified volcanic source in the Cascade Range occurs on Heceta Bank. A significant part of the great volumes of ash erupted from the Cascades of Oregon and Washington throughout the late Tertiary and Quaternary found its way into the marine environment via rivers and by direct ash falls. The ash which devitrifies readily in a marine environment undoubtedly has an important effect in reducing the bearing strength of the sediments on the OCS.

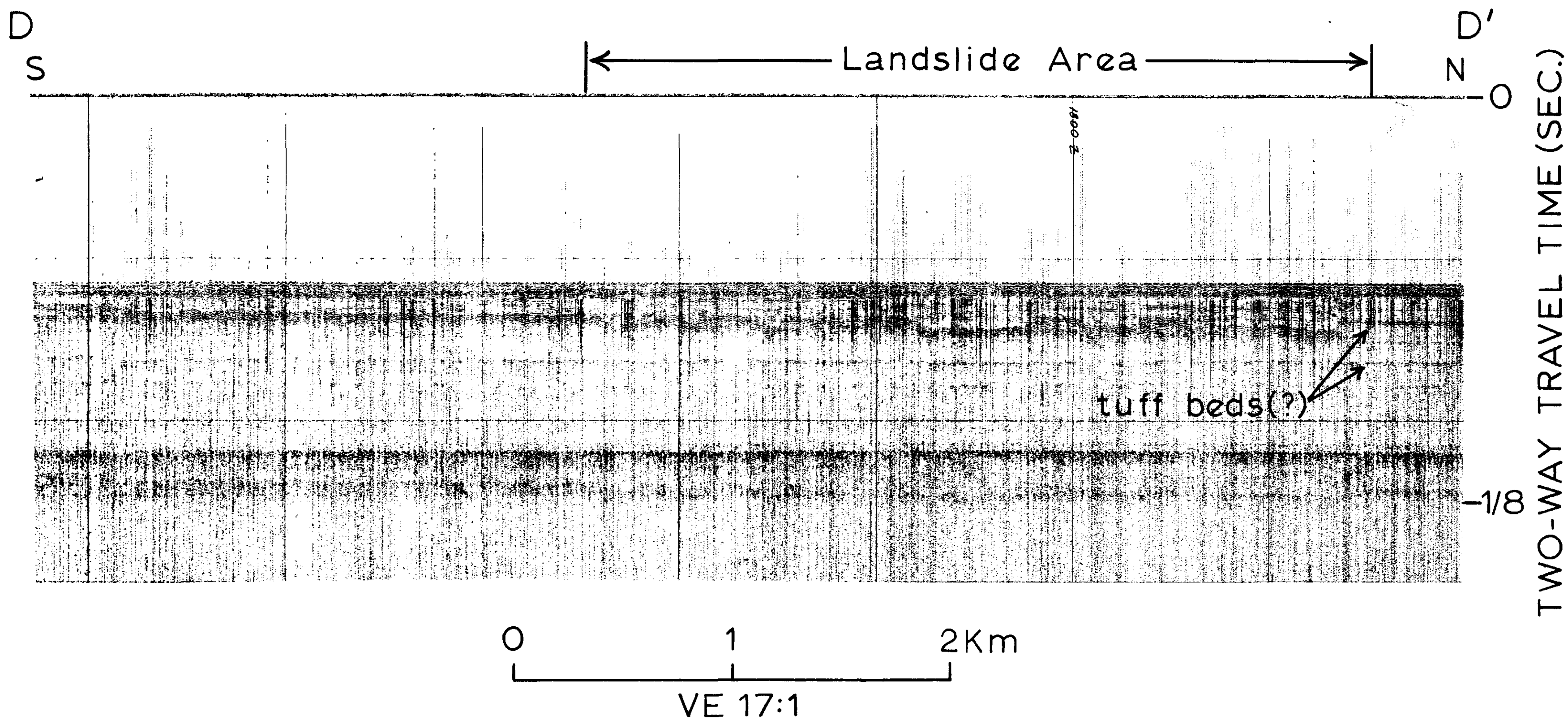



Figure 13.--High-resolution seismic profile D-D' on inner Oregon shelf near latitude 45°45'N showing landslide in Holocene(?) sediments. Strong continuous reflectors may be ash beds. See figure 1 for location of profile.

## Tsunamis

Faults with apparent large vertical tectonic displacements are present on the OCS of the study area (fig. 3) and may be capable of generating seismic seawaves. Tsunamis, however, have not been reported following earthquakes whose epicenters lie on the OCS of Oregon and Washington. A tsunami wave generated by the March 1964 Gulf of Alaska earthquake struck Beverly Beach 6 miles north of Newport, Oregon, and claimed the lives of two campers sleeping on the beach. A total of 15 deaths and major damage occurred in British Columbia, Oregon, and California.

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