STATE OF WASHINGTON
DEPARTMENT OF NATURAL RESOURCES
BRIAN J. BOYLE, Commissioner of Public Lands
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DIVISION OF GEOLOGY AND EARTH RESOURCES
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PRELIMINARY GEOLOGIC FRAMEWORK STUDIES SHOWING BATHYMETRY, LOCATIONS OF GEOPHYSICAL TRACKLINES AND EXPLORATORY WELLS, SEA FLOOR GEOLOGY AND DEEPER GEOLOGIC STRUCTURES, MAGNETIC CONTOURS, AND INFERRED THICKNESS OF TERTIARY ROCKS ON THE CONTINENTAL SHELF AND UPPER CONTINENTAL SLOPE OFF SOUTHWESTERN WASHINGTON BETWEEN LATITUDES 46°N. and 48°30'N. AND FROM THE WASHINGTON COAST TO 125°20'W.

by

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and
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for

Washington State Offshore Geologic Framework Studies

between 46°N. and 48°30'N.

Prepared under Cooperative Agreement No. 14-12-0001-30115

between U.S. Minerals Management Service and

The University of Texas at Austin,
Bureau of Economic Geology

Washington Department of Natural Resources
Division of Geology and Earth Resources
Olympia, WA 98504

Open-File Report 86-1

February 1986

February, 1986

Final report submitted to the Minerals Management Service through the Washington State Department of Natural Resources, Division of Geology and Earth Resources

under

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for

Project titled: Geologic Framework of Offshore Washington

Report Titled

Geologic framework of the Continental Shelf off western Washington--a preliminary geologic study showing bathymetry, locations of geophysical tracklines and exploratory wells, sea floor geology and deeper geologic structures, magnetic contours, and inferred thickness of Tertiary rocks between latitudes 46°N. and the Strait of Juan de Fuca and from the Washington coast to 125°20'W.

INTRODUCTION

1. Objectives of Project

A. To compile existing published and unpublished geologic and geophysical data of the U.S. Geological Survey, as well as a major part of studies published by other workers, on the Continental Shelf of Washington between latitudes 46°N. and 47°30'N.

B. To prepare a map of said area at a scale of 1:250,000 showing the major faults and folds (including diapirs) on the Washington Continental Shelf based upon geologic interpretations of single and multichannel seismic-reflection profiles.

C. To prepare a map of said area at a scale of 1:250,000 showing the inferred thickness of Tertiary rocks based upon seismic, gravity, and magnetic data, as well as subsurface information from oil company deep exploratory wells drilled on the continental shelf and onland near the coast.

D. To compile, at a scale of 1:250,000, a map showing all aeromagnetic data acquired by the U.S. Geological Survey.

E. To prepare a bathymetric base map for use in plotting the above geologic and geophysical data onto scale-stable base material and provide such a base map to the Washington Department of Natural Resources, Division of Geology and Earth Resources.

2. Accomplishments

All above objectives have been completed; however, because of the proposed extension of the study area northward to the Canadian border, and because the purpose of this report is to provide in map form the geologic hazards and other knowledge in the study area, a more comprehensive text and listing of reference materials will be delayed until completion of the northern extension of the area.

A. Preliminary bathymetric map. The preliminary bathymetric map (plate 1) was compiled from bathymetric contours developed by the National Ocean Service (1968, 1983), by Venkatarathnam and McManus (1973) and by Gerin (1977). North of 48°00' latitude, the sea floor contours were taken from charts of the Canadian Hydrographic Service (1976, 1979). Accuracy of bathymetric contouring on the map was checked against an unpublished offshore stream-channel map prepared from data obtained during the GLORIA survey of the area in 1984 and kindly supplied by Monty A. Hampton of the U.S. Geological Survey (personal communication, 1985). The contour interval is 20 m on the Continental Shelf but changes to 200 and 400 m on the Continental Slope. Plate 1 was particularly helpful in analyzing the distribution of geologic hazards such as slumps and landslides observed on the seismic reflection profiles. A new compilation of all sea floor topographic data is currently underway by NOAA

but has not yet been completed into useful form.

B. Trackline map. Approximately 5,000 km of seismic reflection profiles, shown on plates 2 and 3, were used in this study. Of these, more than 4,500 km produced single-channel profiles and 1,100 km produced multichannel profiles. Single-channel profiles were obtained using the University of Washington Research Vessel Thomas G. Thompson in 1966 and 1967 by Grim and Bennett (1969), Oregon State University Research Vessel Cayuse in 1969, and the Thomas G. Thompson in 1970 by Silver (1972). Additional single-channel profiles were taken aboard the U.S. Geological Survey Research Vessel Samuel P. Lee in 1976, 1977, and 1980 by Snavely in conjunction with multichannel profiles along most of the lines. Reconnaissance, v-shaped, tracklines are laid out to provide the greatest areal coverage in the shortest amount of shiptime and the 1967 single-channel profiles and 1976-1980 multichannel profiles were run under those restrictions. Such coverage makes correlation of acoustic units from line to line very tenuous. The mainly east-west profiles of Silver's 1970 7-tow cruise were very helpful in bridging the gaps in the other surveys.

Also shown on the trackline map are the positions of six offshore exploratory test wells. The lithologic faunal and sonic data from these wells (Snavely and others, 1977) were used to extrapolate "ground truth" into locally distinct acoustic units observed on the seismic reflection profiles where they crossed over or near the exploratory wells. Without the well data the actual seismic stratigraphy generated from the seismic reflection profiles would have been essentially nameless because the several periods of tectonic activity, clearly revealed by unconformities on the profiles, could not be correlated with those seen in poor exposures onshore. Needless to say, we are extremely grateful to members of the oil industry who made offshore stratigraphic data available.

C. Sea floor geologic map. The sea floor geologic map (plate 4) depicts in graphic form the geology that one would encounter if the seawater cover were removed. Because of the wide spacing of multichannel seismic reflection data in many parts of the area, the 7-tow seismic data of Silver were used in conjuction with stratigraphic knowledge gained from onshore geologic mapping in an adjacent onshore area (Wagner, 1967a, b; Rau, 1970, 1973, 1975, 1979) in order to make judgmental correlations of offshore units. However, many rock outcrops may have been omitted and contacts between stratigraphic units in places may be off by as much as several kilometers because of the variable line spacing. Furthermore, preliminary bathymetry was used to its maximum extent in depicting landslide direction and continuity. The user should keep these qualifying statements in mind when utilizing the map.

In the preparation of this map, the senior author made geologic interpretations of all seismic-reflection profiles onto mylar

overlays. These overlays were then reduced to the same horizontal scale in order to make more accurately the correlations of structures from trackline to trackline. Also, intersections of all profiles were determined and plotted, and water depths and acoustic-stratigraphic data at crossings were compared. Navigation problems, made obvious by differences in depth to sea floor and noncorrespondence of geology, were discovered and corrected prior to correlation of acoustic-stratigraphic units. The acoustic-stratigraphic units on the profiles were determined through use of sonic-log data from the exploratory wells. The well data (Snavely and others, 1977, p. 17) were then changed from a foot-depth mode to a time-depth mode, and fossil-dated stratigraphic units in the wells (W. W. Rau, written communications, 1973-1982) were correlated with acoustically characteristic units on the seismic-reflection profiles.

Determination of whether Quaternary sediments overlie Tertiary sediments at the sea floor is unclear on many profiles due to the masking effect of a thick (20-60 m) bubble pulse, particularly on the 3- to -4 second single-channel and the 6- to 7-second multichannnel records. The presence of this bubble pulse precluded accurate differentiation of the Holocene and Pleistocene acoustic equivalents on many profiles. The position of the contact between these two units is questionable in many places, and since additional data from high-resolution seismic profiles is sparse and generally poor it was not very helpful in refining this contact. However, sea floor sediment maps by Moore and Lukin (1979) were helpful in places by showing the positions of gravel deposits that are assumed to be Pleistocene in age. On some profiles, steeply dipping Tertiary strata could be seen projecting to the sea floor; on others, bubble-pulse masking was complete. On many profiles, basins between outer ridges and in downslope valleys of the Continental Slope were filled with flat-lying sediments during Quaternary time as noted by Barnard (1978). Many Pleistocene gravel deposits and channel fillings form flat-topped highs in the area of the Juan de Fuca Canyon. In a few places Holocene landslides have exposed Pleistocene sediments.

The rocks encountered during oil company exploration drilling range in age from middle Eocene to Holocene and indicate that the unbroken sedimentary sequence is nearly 3,000 meters thick locally. These strata, which are described briefly in Snavely and Wagner (1982, p. 6), have been subjected to two major periods of convergence between the Pacific (Juan de Fuca) and North American plates creating a highly faulted and folded terrain. Each period of convergence developed a thick zone of melange and broken formation which has a generally non-stratified acoustic signal made up of a series of small hyperbolic curves. In many places this melange has been remobilized and been injected into and through the overlying stratigraphic sequence as diapirs. Snavely and others (1977, p. 22) show an excellent example of diapirs on a seismic reflection profile, and piercement structures along the Washington coastline are

well described by Rau and Grocock (1974). Their description of the lithologic character of these onshore structures agrees well with the acoustic characters observed in the seismic reflection profiles. Eleven structures with these characteristics have sea floor outcrops as shown on plate 4; two others lie beneath the sea floor under Quaternary and upper Tertiary deposits. These units, as described onshore, consist of phacoidally shaped mobilized blocks of massive siltstone, sandstone, and volcanic rocks in a matrix of clay- to silt-size particles.

A brief appraisal of the map shows that many of the faults, although active during Miocene and even Pliocene time, were inactive during the Quaternary. However, many faults appear to reach near or to the sea floor in very young rocks, and some offset the sea floor. These latter faults may have had accompanying earthquakes that triggered much of the landsliding and slumping on the upper part of the Continental Slope and possibly on the Continental Shelf. The three faults off the mouth of the Columbia River, which are shown with question marks, are boundaries between different basement rocks to the west and east, as shown by bottom-hole data from offshore wells 5 (melange) and 6 (Crescent(?) basalt) of Snavely and Wells (1984, plate 1 and table 2, p. 7).

Many folds, both anticlines and synclines, are noted on the seismic reflection profiles. In many places, folds in the Miocene rocks (symbolized dotted lines on plate 4) were folded and then subjected to erosion which truncated the crestal parts of the anticlines. These truncated surfaces were then covered by horizontally or near-horizontally deposited sediments which were themselves subjected to stresses which folded them. In many places, and at various time intervals, the younger sediments, too, were subjected to erosion as shown clearly on the seismic reflection profiles.

D. Preliminary magnetic map. The magnetic map (plate 5) was developed from several sources. Four aeromagnetic maps of western Washington were contracted for by the U.S. Geological Survey (U.S. Geological Survey, 1980a, 1980b, 1980c, 1984). However, these maps did not overlap and an unmapped area was present between two of them offshore. Magnetic data, taken during the 7-tow cruise of 1970, were kindly made available to us by Eli Silver (personal communication, 1983). By contouring that information, we were able to develop a magnetic map that filled the gap between the USGS data (plate 5). The western edge of the magnetic map lies between high magnetic anomalies 4 and 5 as shown on NOS magnetic map 12042-12M (NOS, 1974b). The magnetic highs off Cape Flattery and near the Columbia River are underlain by volcanic rocks of the Crescent Formation.

E. Preliminary sediment thickness maps. The preliminary isopach map of post middle Miocene sedimentary rocks offshore from western Washington (plate 6) was constructed from acoustic-stratigraphic data obtained from the interpretation of USGS

multichannel seismic reflection profiles taken during cruises by Snavely in 1976, 1977, and 1980, and from the single-channel 1970 7-tow survey by Silver (1972), and the 1967 T. G. Thompson survey by Bennett and others (1967). These interpretations were tied to faunal and stratigaphic data from offshore exploratory test wells drilled in 1966-67 by the Union Oil Co., the Shell Oil Co., and the Pan American Petroleum Corp., by magnetic data prepared for this report, and by gravity data (at scale 1:1,000,000) published by the National Ocean Survey (NOS, 1974a). Age correlation data for onshore wells (Rau and McFarland, 1982) and offshore wells (W. W. Rau, personal communications, 1973-1982) were used liberally.

Construction of this map involved initial interpretation of seismic reflection profiles that traversed across or very near test well sites, extrapolation of these data laterally, plotting points showing thickness above the late Miocene unconformity at .25-second intervals, contouring these points, and then generalizing these contours into 500-meter isopachs using velocities obtained in the exploratory wells. The isopachous lines represent only approximate thicknesses due to the paucity of well data and the wide and diverse distribution of multichannel trackline coverage available in the study area (plate 2). An inferred total thickness of sedimentary rocks above the oceanic crust can be obtained by adding 6 to 14 km of upper Oligocene to upper middle Miocene sheared siltstone and melange to thicknesses on plate 6. The addition would be in an eastward direction from the west edge of plate 6, as suggested by models of Silver (1972, p. 247) and McClain (1981, p. 69, 79).

REFERENCES CITED

Barnard, W. D., 1978, The Washington Continental Slope--Quaternary tectonics and sedimentation: Marine Geology, v. 27, p. 79-114.

Bennett, L. C., Jr., Henry, M., and Lewis, L., 1969, Preliminary report of R/V Thomas G. Thompson Cruise 13, Washington Continental Shelf Survey of 17 March to 25 March, 1967: University of Washington Department of Ocenanography Report M69-31, 17 p.

Canadian Hydrographic Service, 1976, Natural Resources Map--Bathymetry: Canada Department of the Environment, Hydrographic Service Map 15783-A, scale 1:250,000.

_____, 1976, Natural Resources Map--Magnetic Anomaly Map 15783-E: Canada Department of the Environment, Ottawa, scale 1:250,000.

_____, 1979, Natural Resources Map--Bathymetry: Canada Department of the Environment, Hydrographic Service Map 15785-A, scale 1:250,000.

Gerin, M. B., 1977, Bathymetric map of Pacific Coast--Vancouver Island [British Columbia, Canada] to Tillamook Bay [Oregon]: U.S. Geological Survey Open-File Report 77-115, 6 sheets, scale 1,500,000.

Grim, M. S., and Bennett, L. C., Jr., 1969, Shallow seismic profiling of the Continental Shelf off Grays Harbor, Washington: University of Washington, Department of Oceanography Special Report No. 41, p. 72-92.

McClain, K. J., 1981, A geophysical study of accretionary processes on the Washington continental margin: University of Washington Ph.D. dissertation, 141 p.

Moore, G. W., and Lukin, M. D., 1979, Offshore sand and gravel resources of the Pacific northwest: Oregon Geology, v. 41, no. 9, p. 143-151.

National Ocean Service, 1968, Bathymetric Map of the Continental Shelf and Slope off Washington [from 46°00'N to 48°00'N Latitude and 123°50'W Longitude]: National Oceanic and Atmospheric Administration, manuscript map NOS-1309-12, scale 1:250,000.

_____, 1983a, Pre-review, Pre-revrbor, Washington: University of Washington, Department of Oceanography Special Report No. 41, p. 72-92.

McClain, K. J., 1981, A geophysical study of accretionary processes on the Washington continental margin: University of Washington Ph.D. dissertation, 141 p.

Moore, G. W., and Lukin, M. D., 1979, Offshore sand and gravel resources of the Pacific northwest: Oregon Geology, v. 41, no. 9, p. 143-151.

National Ocean Service, 1968, Bathymetric Map of the Continental Shelf and Slope off Washington [from 46°00'N to 48°00'N Latitude and 123°50'W Longitude]: National Oceanic and Atmospheric Administration, manuscript map NOS-1309-12, scale 1:250,000.

_____, 1983a, Pre-review, Pre-revision, copy of the Cape Disappointment Bathymetric Map, Washington [46°N to 47°N and 124°W to 126°W]: National Ocean Service Preliminary Map NL10-4, scale 1:250,000.

_____, 1983b, Pre-review, Pre-revision, copy of the Copalis Beach bathymetric Map, Washington [47°N to 48°N and 124°W to 126°W]: National Ocean Service Preliminary Map NL10-1, scale 1:250,000.

Rau, W. W., 1970, Foraminifera, stratigraphy, and paleontology of the Quinault Formation, Point Grenville-Raft River Coastal Area, Washington: Washington Division of Mines and Geology Bulletin 62, 40 p.

_____, 1973, Geology of the Washington coast between Point Grenville and the Hoh River: Washington Division of Geology and Earth Resources Bulletin 66, p. 1-58.

_____, 1975, Geological map of the Destruction Island and Taholah quadrangles, Washington: Washington Division of Geology and Earth Resources Geologic Map GM-13, scale 1:62,500.

_____, 1979, Geologic map in the vicinity of the lower Bogachiel and Hoh River Valleys, and the Washington Coast: Washington Division of Geology and Earth Resources Geology Map GM-24.

_____, and Grocock, G. W., 1974, Piercement structure outcrops along the Washington Coast: Washington Division of Geology and Earth Resources, Information Circular No. 51, 7 p.

_____, and McFarland, C. R., 1982, Coastal wells of Washington: Washington Division of Geology and Earth Resources Report of Investigations No. 26, 4 sheets.

Silver, E. A., 1972, Pleistocene tectonic accretion of the Continental Slope off Washington: Marine Geology, v. 13, p. 239-249.

Snavely, P. D., Jr., Pearl, J. E., and Lander, D. L., 1977, Interim report on petroleum resources potential and geologic hazards in the outer Continental Shelf--Oregon and Washington Tertiary province, with a section on Resource appraisal estimate, by E. W. Scott: U.S. Geological Survey Open-File Report 77-282, 64 p.

_____, and Wagner, H. C., 1982, Geologic cross section across the continental margin of southwestern Washington: U.S. Geological Survey Open-File Report 82-459, 10 p.

_____, and Wells, R. E., 1984, Tertiary volcanic and intrusive rocks on the Oregon and Washington Continental Shelf: U.S. Geological Survey Open-File Report 84-282, 17 p., 3 plates.

U.S. Geological Survey, 1980a, Aeromagnetic map of the central Grays Harbor County area, Washington: U.S. Geological Survey Open-File Report 80-948, 1 sheet, scale 1:125,000.

_____, 1980b, Aeromagnetic map of offshore northwest Washington: U.S. Geological Survey Open-File Report 80-976, scale 1:125,000.

_____, 1980c, Aeromagnetic map of the north-central Washington Coast: U.S. Geological Survey Open-File Report 80-977, 1 sheet, scale 1:125,000.

_____, 1984, Aeromagnetic map of southwest Washington and northwest Oregon: U.S. Geological Survey Open-File Report 84-205, 1 sheet, scale 1:250,000.

U.S. National Ocean Survey, 1974a, NOS Seamap Series--Gravity Map: Map NOS 12042-12G, 1 sheet, scale 1:1,000,000.

_____, 1974b, NOS Seamap Series--Magnetic Map: Map NOS 12042-12M, 1 sheet, scale 1:1,000,000.

Venkatarathnam, K., and McManus, D. A., 1973, Origin and distribution of sand and gravels on the northern Continental Shelf off Washington: Journal of Sedimentary Petrology, v. 43, no. 3, p. 799-811.

Wagner, H. C., 1967a, Preliminary geologic map of the Raymond Quadrangle, Washington: U.S. Geological Survey Open-File Report, map scale 1:62,500.

_____, 1967b, Preliminary geologic map of the South Bend Quadrangle, Washington: U.S. Geological Survey Open-File Report, map scale 1:62,500.

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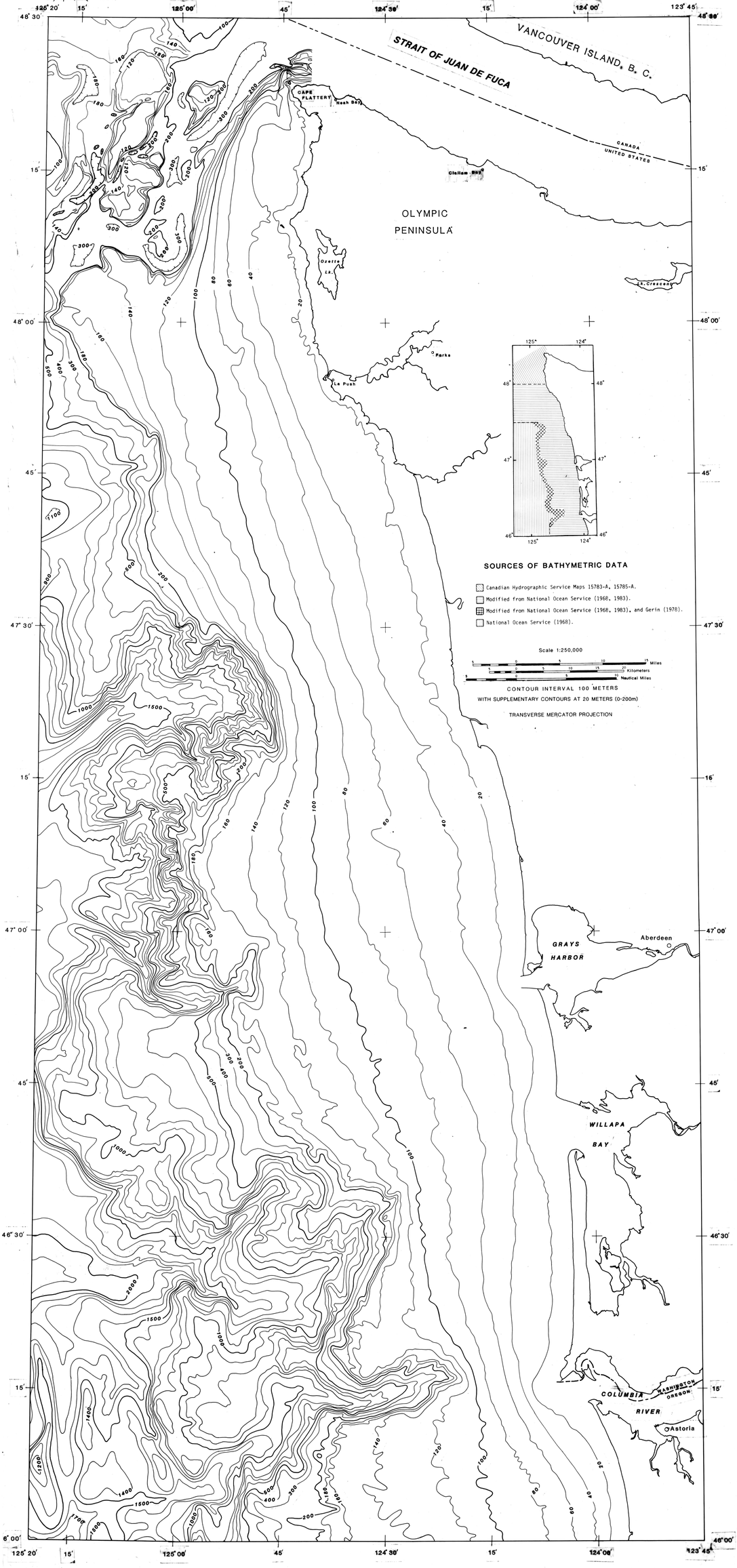

PLATE 1. PRELIMINARY BATHYMETRIC MAP OF THE CONTINENTAL SHELF AND UPPER CONTINENTAL SLOPE OFF WESTERN WASHINGTON

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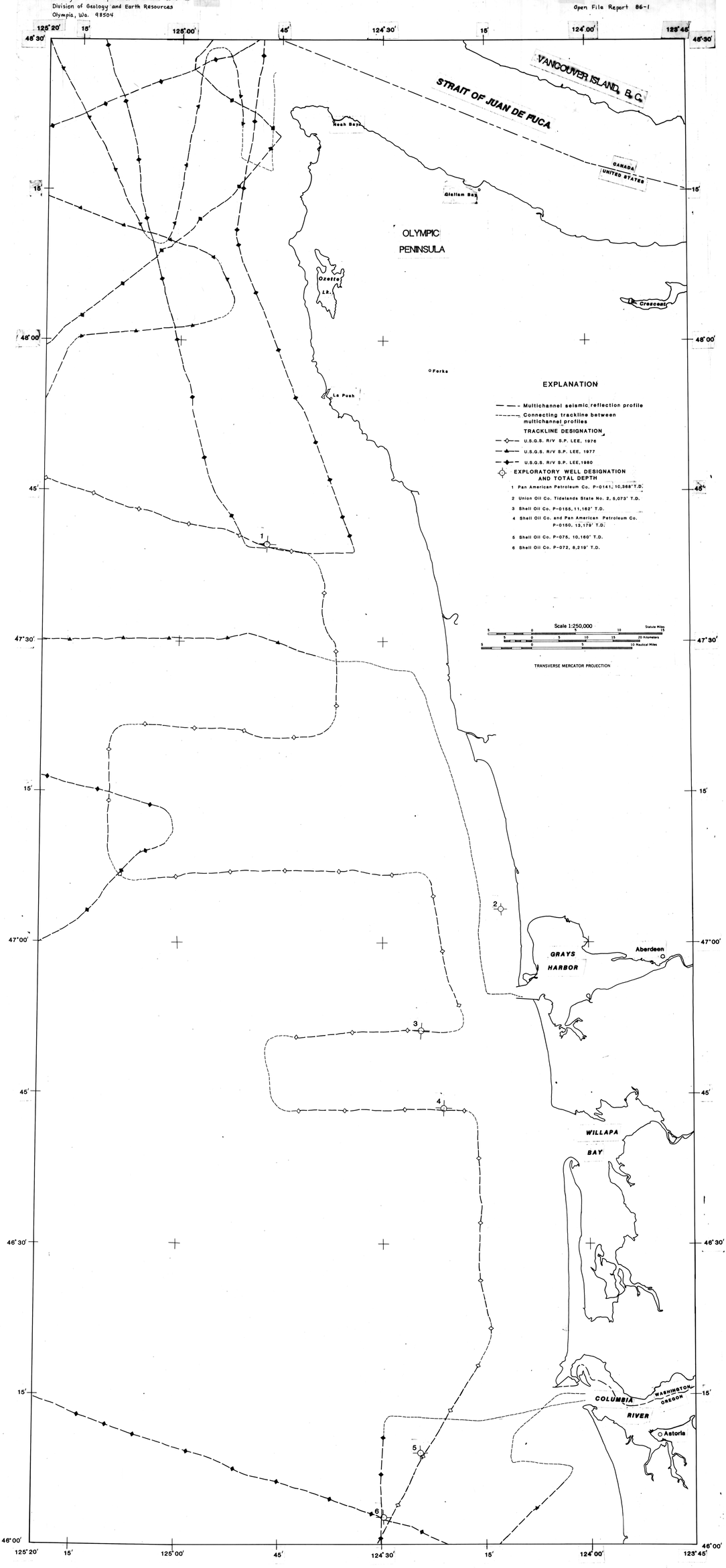

PLATE 2. MAP SHOWING LOCATIONS OF MULTICHANNEL TRACK LINES AND EXPLORATORY TEST WELLS ON THE CONTINENTAL SHELF AND UPPER CONTINENTAL SLOPE OFF WESTERN WASHINGTON

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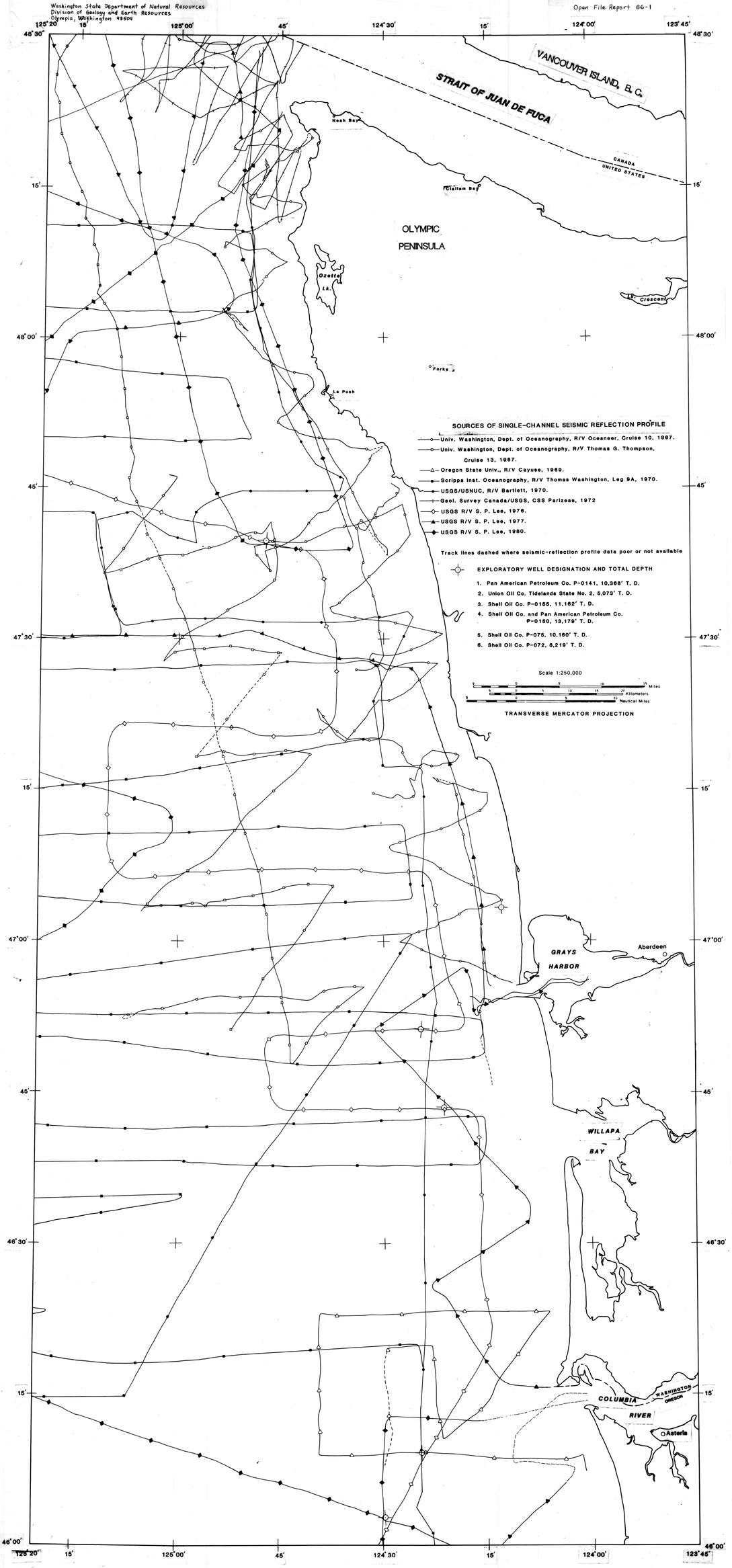

PLATE 3. MAP SHOWING LOCATIONS OF SINGLE-CHANNEL TRACK LINES AND EXPLORATORY TEST WELLS ON THE CONTINENTAL SHELF AND UPPER CONTINENTAL SLOPE OFF WESTERN WASHINGTON

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Plate 3

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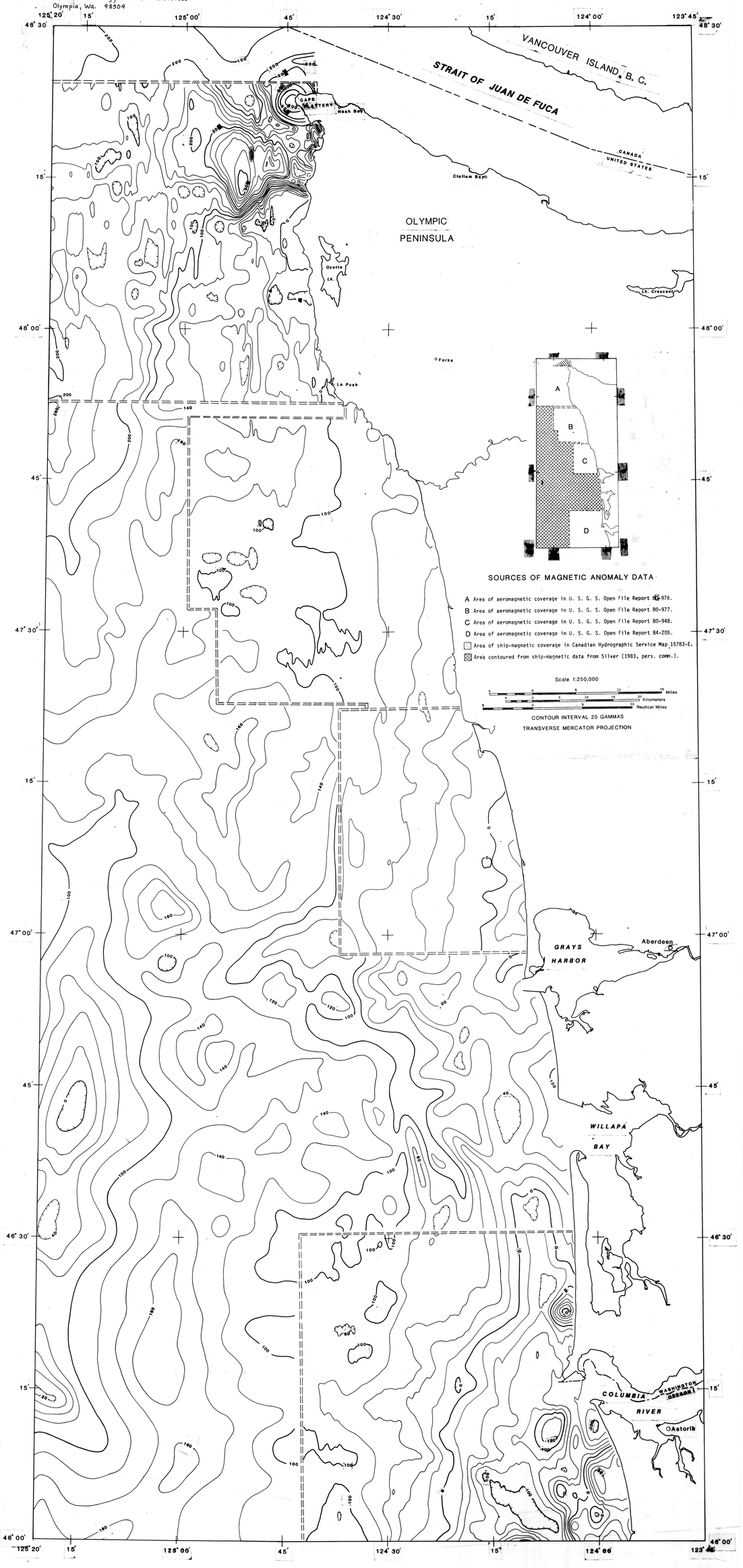

PLATE 4. PRELIMINARY MAGNETIC MAP OF THE CONTINENTAL SHELF AND UPPER CONTINENTAL SLOPE OFF WESTERN WASHINGTON

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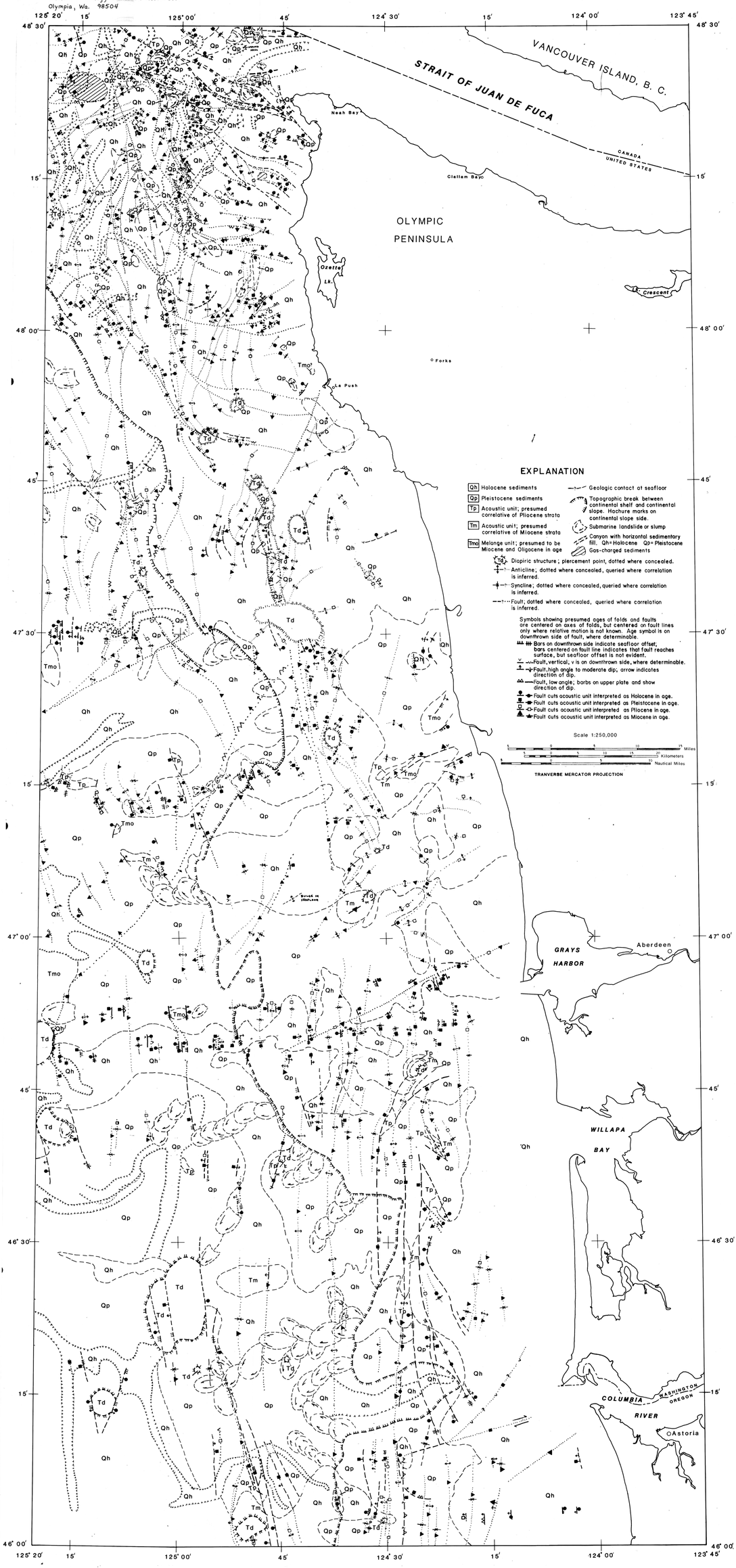

PLATE 5. PRELIMINARY MAP OF THE SEAFLOOR GEOLOGY AND DEEPER STRUCTURES OF THE CONTINENTAL SHELF AND UPPER CONTINENTAL SLOPE OFF WASHINGTON

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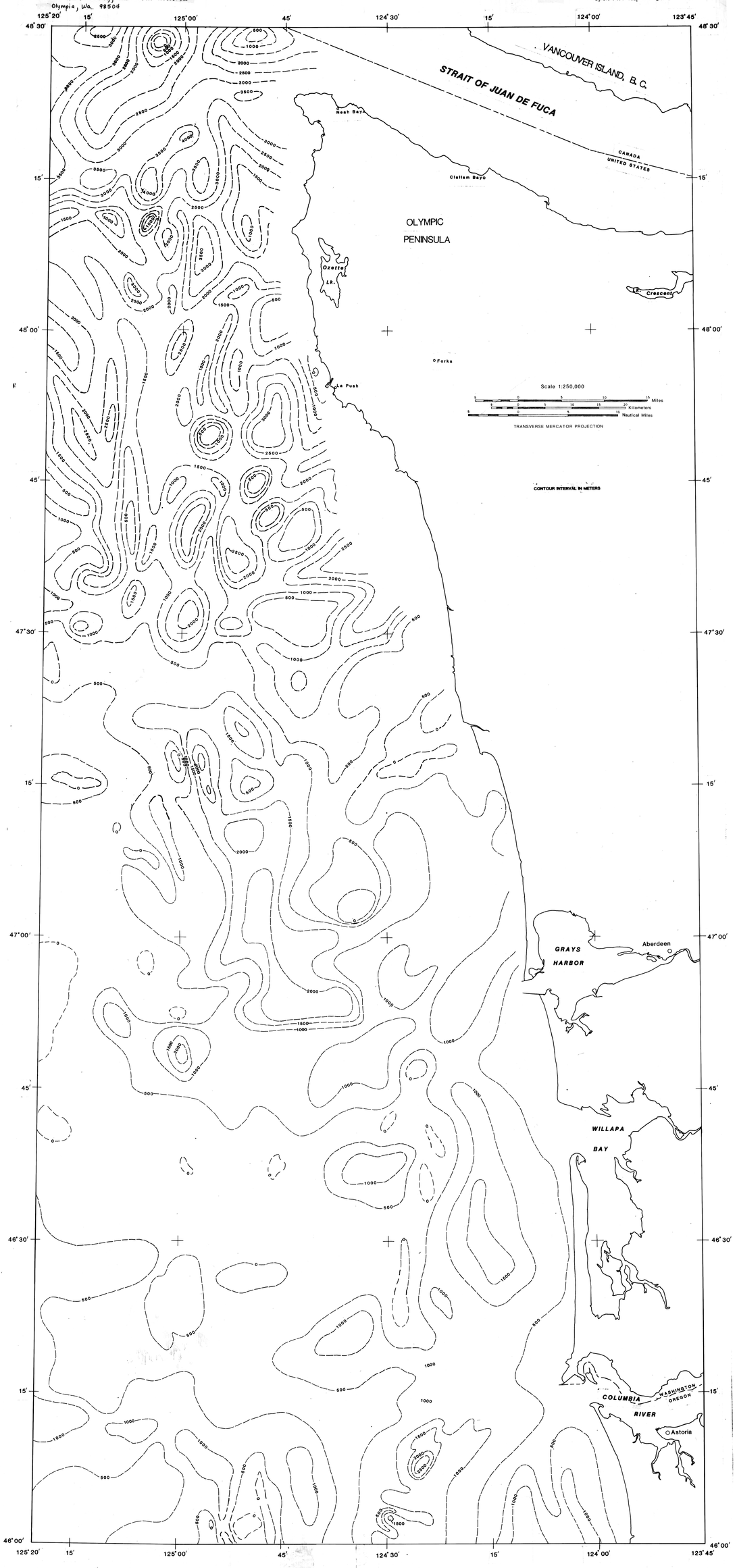

PLATE 6. GENERALIZED ISOPACH MAP SHOWING INFERRED THICKNESS OF POST MIDDLE MIOCENE ROCKS OF THE CONTINENTAL SHELF AND UPPER CONTINENTAL SLOPE OFF WASHINGTON

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