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OFFSHORE GEOLOGY OF THE STRAIT OF JUAN DE FUCA, STATE OF WASHINGTON AND BRITISH COLUMBIA, CANADA

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for

GEOLOGIC FRAMEWORK WITHIN THE STRAIT OF JUAN DE FUCA

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INTRODUCTION

1. Objectives of Project

A. To compile existing published and unpublished geologic and geophysical data of the U.S. Geological Survey and those collected jointly by the U.S. Geological Survey and the Geological Survey of Canada, as well as a major part of studies published by other workers within the Strait of Juan de Fuca from the Pacific Ocean to Puget Sound.

B. To prepare a map of said area at a scale of 1:250,000 showing the sea floor geology based upon geologic interpretations of single- and multi-channel seismic-reflection profiles and plotted on a bathymetric base map of the Canadian Hydrographic Service.

C. To prepare a map of said area at a scale of 1:250,000 showing major faults and folds in pre-Quaternary strata and plotted on a bathymetric base map of the Canadian Hydrographic Service.

D. To prepare a map of said area at a scale of 1:250,000 showing the inferred thickness of Quaternary and Tertiary rocks based upon seismic, gravity and magnetic data, as well as subsurface information from several deep exploratory wells drilled adjacent to the study area.

E. To include Canadian Hydrographic Service published magnetic and gravity maps at a scale of 1:250,000 made primarily from data acquired on the joint U.S. Geological Survey-Geological Survey of Canada research cruise of the CSS PARIZEAU, but containing data from other sources as well.

F. To update (1975-1986) bibliographic data pertinent to the Strait of Juan de Fuca geologic setting.

2. Description of Maps

PLATE 1. The materials for the bathymetric map were furnished gratis by the Resources Department, Canadian Hydrographic Service, on scale stable mylar at a scale of 1:250,000. We appreciate very much this contribution to our study as it has furnished us with a screened base for all other maps. Also shown on Plate 1 are the locations of exploratory wells drilled in the Strait of Juan de Fuca area. Data available to us concerning these wells are given in Table 1.

Table 1. Onshore exploratory wells drilled in the Strait of Juan de Fuca area[1/].

Map No.	Well Name	Total Depth	Year Drilled	Remarks
1	Russell Cobb, Merrill Ring No. 1	8,519′	1960	Bottomed in upper Twin River Fm.
2	Texaco Inc., R. D. Merrill No. 1	8,462′	1966	Bottomed in upper Twin Twin River Fm. Numerous gas shows.
3[2/]	Twin River State #1	6,570′	1986	Bottomed in lower conglomerate of Twin River Fm. or conglomerate high in the Lyre Fm. Several gas shows below 6,000′; best show near contact between Twin River and Lyre Fm.
4	Port Angeles O&G Co., Inc. Sutter No. 1	6,218′	1961	Dry hole.
5	Port Angeles O&G Co., Inc. W. L. Dilling No. 1	3,009′	1961	Dry hole.
6	Standard Oil Co. of Calif. Dungeness Spit No. 1	5,105′	1965	Dry hole.
7	Dalton-Pettet No. 2	3,490′	1950(?)	Bottom of Pleistocene about 2,900′. Poor oil shows.
8	Dalton-Pettet No. 1	3,619′	1948	Bottom of glacial drift at 1,892′. Bottomed in Twin River Fm. One slight oil show. Dry hole.
9	Dungeness O&G Co., Taylor No. 2 (Dan Dalton)	2,740′	1951	Oil shows reported at 1,140 and 2,210 ft. Dry hole.
10	Standard Oil Co. of Calif. Dungeness Unit No. 1-54	7,493′	1956	Pleistocene glacial deposits to 2,105; Twin River Fm. 3,280-6,328; Crescent Volcanics 6,363 to T.D.
11	City of Oak Harbor No. I-1	700′	1928	Gas reported at 468′. Dry hole.

12 3/	No name given; location given only as being southwest of Sooke and between Muir and Kirby Creeks (p. 129).	1,600'+	Bottomed in conglomerate above Metchosin Volcanics.

1/ All data except those in footnotes 2 and 3 are from McFarland, C. R., 1981, Oil and Gas Exploration in Washington 1900-1981: Washington Division of Earth Resources Information Circular 67R, 119 p.

2/ See Northwest Oil Report, 1986, Important Developments: Northwest Oil Report, v. 28, no. 7, no. 15, no. 17, and no. 18.

3/ Clark, B. L. and Arnold, R., 1923, Fauna of the Sooke Formation, Vancouver Island: University of California Publications in Geological Science, v. 14, p. 123-234.

Plate 1 also shows the positions of earthquake epicenters in the offshore Strait of Juan de Fuca area. The locations were taken from many sources and some duplication no doubt has occurred. However, the locations of most earthquake epicenters are on most maps in nearly the same position and can certainly be considered as reliable events. For example, the epicenter concentration in Admiralty Inlet is notable because a fault with seafloor offset and trending southeast into the inlet was mapped by Wagner and Wiley (1983); it linked to a fault trending northwest into the inlet that was mapped by Gower (1980). Fault evidence in both cases shows a Holocene age, and earthquake activity along such a fault would be expected. Another fault with associated earthquake activity is the one that trends nearly eastward from south of Victoria to north of Smith Island and goes onshore at Whidbey Island. It was called the northern Whidbey Island fault by Gower (1980) and was pictured by Wagner and Wiley (1983, p. 263).

PLATE 2. The basic seismic reflection profile data shown in Plate 2 were collected between 1966 and 1980. Joint cooperative cruises of the U.S. Geological Survey and the U.S. Naval Undersea Center using the NUC Research Vessel (R/V) BARTLETT were carried on in the Strait of Juan de Fuca in 1966 and 1970. The University of Washington mounted cruises in the Strait of Juan de Fuca in 1966 (R/V OCEANEER cruise 2), in 1967 (R/V THOMAS G. THOMPSON cruises 13, 21 and 24), in 1968 (R/V RANOS BELLE), in 1969 (R/V ONAR), and in 1970 (R/V HOH). Of these University of Washington cruises, only the records of the OCEANEER 2, T. THOMPSON 13 and 24, and RANOS BELLE were available to us. In 1972 the U.S. Geological Survey and the Geological Survey of Canada conducted a joint geophysical survey of the Strait of Juan de Fuca aboard the Canadian Survey ship (CSS) PARIZEAU. The U.S. Geological Survey conducted cruises in 1976 and 1980 aboard their R/V DON J. MILLER and in 1976, 1977 and 1980 aboard their R/V S. P. LEE. These USGS data, the BARTLETT data, and the available University of Washington data were all used in this study. They amounted to more than 2,500 km of trackline. Several seismic systems were run contemporaneously on the cruises of the PARIZEAU and LEE (1/4-sec. sweep, 1/2-sec. sweep, 1-sec. sweep, 2-sec. sweep, and 4-sec. sweep single-channel, and 5- to 7-sec. sweep multichannel). Thus, well over 7,000 km of seismic-reflection profiles were interpreted in developing information shown in Plates 3, 4, and 5 of this study. On the single-channel tracklines, the symbols are shown at one-hour intervals. On the multichannel tracklines the symbols are placed at 100 shot-point intervals.

PLATE 3. All profiles available for this study were used in one way or another in the preparation of Plate 3. In order to deterime the synchroneity of the data seen in the seismic reflection profiles and the sediments or rock outcrops on the seafloor, certain rules of thumb had to be established. The multichannel records when tied into two cross sections published by Snavely and Tabor (1983, p. 22) and Snavely and others (1986), revealed that in none of the single-channel profiles could one detect the late Miocene unconformity, and only on the R/V BARTLETT and CSS PARIZEAU could the top of the Pliocene strata be recognized and then only in local areas where the unit rose above the first seafloor multiple. All the seismic reflectors seen in the shallow-penetration, high-resolution records were of Quaternary age.

Therefore, the major effort in developing the geologic framework and hazards shown on Plate 3, was to determine which faults and folds were major and what was the age of the unit that cropped out at the seafloor. In water shallower than 100 m, the high resolution profiles of the research vessels PARIZEAU, MILLER, and LEE were generally excellent. On a few days, however, rough sea conditions reduced their signal clarity and other records were used to bridge the gaps. Also, the CSS PARIZEAU lines were almost all run in a northerly or southerly direction providing few cross-tie lines. The R/V BARTLETT, R/V OCEANEER and R/V T. Thompson lines were very helpful in those areas and in the deeper water areas. Data on bottom samples were obtained mainly from the National Ocean Survey charts 18441, 18464, 18465, and 18467. Nevertheless, because of gaps in these data and/or conficting information, it was impossible not to over extend the Holocene or Pleistocene sediment limits; in several places the decision where to draw the contact became arbitrary. In places the seafloor bathymetry was used as a means of projecting Holocene sediment to the most likely termination. Therefore, the data shown on the map should be used with caution in any but very general ways.

In order to make Plate 3 as useful as possible, an attempt was made to categorize the seismic data in terms of geologic stratigraphy. Seacliff traverses were made and much Quaternary literature absorbed in order to develop a knowledge of the characteristics of glacial types and features. An attempt was then made to translate this knowledge into seismic reflection features observed on the records. We believe that it is possible to differentiate certain acoustic characteristics appropriate to glacial drift deposits, kame deposits, bank-top deposits, overbank and deltaic deposits, drumlins, etc. (see Wagner and Wiley, 1983, p. 218-227). These we mapped separately whenever possible. The positions of characteristic features were annotated on mylar overlays made for each record and were plotted along each trackline on the map. In many cases the same feature was seen on adjacent lines and map correlation was possible. In this manner, glacial stratigraphic units were developed and mapped over broad areas.

Care was also taken to determine the nature and age of faulting. Offset of the seafloor by faulting was obvious on many high-resolution seismic profiles (Wagner and Wiley, 1983, p. 241-243) and the down direction was noted and plotted. One fault that could be followed a large distance in the western part of the Strait projected eastward into a known onshore fault of large displacement and was cut off westward by the Leech River fault. Many faults, however, were located on only one or two lines and not found beyond. We suspect that much faulting was missed because of poor data and that these

short faults are possibly due to small stresses within the Quaternary sediments as isostatic adjustment took place between times of maximum ice buildup and crustal downwarping and upward rebound after the ice melted. Other faults may be due merely to ice shove.

Faults and folds mapped onshore were projected offshore, but only where their continuity with offshore faults or folds could be substantiated adequately were they shown on the map.

Channel-fill deposits (Wagner and Wiley, 1983, p. 231-234) were in many places a problem as they did not project from one seismic profile to another. The tenuous paths of known onshore channels was used as a criterion in connecting some channel-fill deposits with others not on a direct projection. A few words of caution at this point are believed to be necessary. Since we have no paleontological control, channel-fill deposits in which the sediments (seismic reflectors) are essentially horizontal, and whose uppermost part is a projection of the present seafloor, are arbitrarily shown as of Holocene age. Similar channels overlain by presumed Holocene sediments may be of Pleistocene age, but are not differentiated as such on this map.

The Holocene landslides shown on the map are from areas on profiles that show very irregular downslope topography, commonly show a basal glide plane, have a breakaway scarp at the upper end and bulge upward at the toe (see Wagner and Wiley, 1983, p. 244-251). The map shapes of landslides have been determined by their occurrence on adjacent seismic profiles or by their topographic configuration, or both.

Contact lines that terminate Holocene sediments are based upon the pinching out at the seafloor of reflectors that generally follow the seafloor contour on the seismic profiles. Beyond the pinchout, other reflectors classed as Pleistocene are either steeply dipping and truncated at the seafloor or have the appearance of a series of small hyperbolic curves. If they pass into an area of no coherent structure, they could be Pleistocene gravel deposits or be areas of gas-charged sediments as described by Schubel (1974).

Admittedly, in compiling Plate 3, some judgements were subjective, but we believe that in general the geology depicted on the plate represents a fairly good rendition of the sediments and structures that would be encountered if the sea were to be withdrawn from the area and leave the seafloor bare of its water cover.

PLATE 4. Geophysical cruise data for plate 4 were provided in part by single channel 4-second seismic reflection profiles taken in 1970 by the R/V BARTLETT, by single channel 2- to 4-second prfiles taken in 1972 by the CSS PARIZEAU, by single channel 2- to 4-second profiles taken in 1976, 1977, and 1980 by the USGS R/V S.P. LEE, but mainly by the multichannel data obtained in the 1976 and 1980 cruises of the USGS R/V S. P. LEE. Due to the generally thick unconsolidated and semi-consolidated Quaternary sediments that blanket the seafloor in the Strait of Juan de Fuca area, the seafloor multiple produced a broad multiple and all data below that multiple were completely wiped out. Also, and particularly in the seismic-reflection profiles of the CSS PARIZEAU, an unusually broad seafloor signal was formed and it, in conjunction with its first multiple, eliminated practically all except about

0.3 second of data. Only the multichannel profiles of the 1976 and 1980 cruises of the USGS R/V S.P. LEE were able to produce data beneath the seafloor multiple. These multichannel data were of inestimable value in this area in determining the seismic reflection characteristics of the unconformity at or near the top of Miocene strata and the acoustic characteristics of strata and rocks above and below the unconformity. This particular unconformity was very evident on some lines but not as obvious on others. In our study, each crossing of any two lines was checked both as to seafloor depth and depth below the seafloor to the top of the Miocene unconformity. After all crossings had been checked and pertinent data points marked, the top of the seismic reflection correlated with the late Miocene unconformity was traced as far as possible laterally on each profile. Faults with large displacement were troublesome due to a change in seismic character across the fault on several lines. When such a change occurred, other reflectors or series of reflectors were used to correlate across the fault.

After all points on the reflector correlated with the late Miocene unconformity had been recorded on the track chart at 0.25-second intervals, the data were contoured on a mylar overlay. Minor offsets on faults were generalized out, velocities were assigned to the units above the top of the late Miocene unconformity and a generalized thickness map of sediments between the unconformity and the seafloor was drawn. This map is shown as Plate 4. Only three faults were considered of sufficient magnitude to show offset on the map and these offsets are shown at the unconformity only where the fault is an underthrust, where it dips measurably, and where downdip overlap occurs. The amount of dip on major faults appears to change laterally, possibly reflecting variation in direction of structural pressure. This lateral change is shown by the major northwest trending fault in the Strait of Juan de Fuca where the late Miocene unconformity is displaced to the north above the words "Olympic Peninsula". The fault has a nearly straight-line surface trace on Plate 3, but becomes broadly sigmoidal at depth as shown on Plate 4. Several minor faults were noted to be nearly vertical at the surface but to become listric at depth.

Because the only firm data for contouring the late Miocene unconformity was provided by the multichannel records, the contouring was not extended into the eastern part of the area.

PLATE 5. In the development of Plate 5, we have contoured only the total sediment thickness above economic basement. All available aids were used in this contouring, but since no real data were available east of the multichannel record coverage, the mapping was stopped there. The well data from three exploratory wells drilled along the south shore of the strait west of Port Angeles provided estimates to the basaltic basement rocks of middle Eocene age, and on Vancouver Island one well was drilled that reportedly reached conglomerate at the top of the Metchosin basalt in a graben area southwest of Sooke between Muir and Kirby Creeks (Clark and Arnold, 1923, p. 129; MacLeod and others, 1977, p. 234). Also cross sections by Snavely and Tabor (1983, p. 22) and Snavely and others, (1986) provided estimates to basaltic basement which were used.

A geologic model for eastern Vancouver Island and the Strait of Juan de Fuca (Clowes and others, in press) provides a thickness figure to underplated middle Eocene basalt between Victoria and Port Angeles. The S. P. LEE

multichannel records do not show the typical acoustic signature of this basalt at the model depth and, therefore, it was considered unwise to project our data beyond the multichannel coverage, particularly since our multichannel seismic profiles a few km to the west of their model suggest that the structure within the strait is much more complex. The underplated area Clowes and others (in press) postulate may, indeed, be there but may be underlain by a melange of Oligocene and early Miocene age. This underplated melange unit, if present, is not included in the figures used in contouring the total thickness of sediment above economic basement.

Data for the 1,000 and 2,000 m thickness contours southeast of Sooke were given by MacLeod and others (1977, p. 234). They credit A. K. Cooper as calculating a sediment thickness, based upon magnetic gradients, of "less than 1,000 m near the shore to more than 2,000 m near the center of the strait."

Because of the great sediment thicknesses contoured, faulting was considered inconsequential and all faults were generalized out in Plate 5.

PLATE 6. The magnetic contours shown on this plate were furnished to us on scale stable mylar at 1:250,000 scale and at no cost by the Canadian Hydrographic Service of the Department of the Environment. The contours were used to estimate fault trends and, within limits, the positions and depths of magnetically strong igneous rocks.

PLATE 7. As with the magnetic contour map, the gravity contours on this map were furnished to us on scale stable mylar at 1:250,000 scale and at no cost by the Canadian Hydrographic Service of the Department of the Environment. These gravity contours aided in the interpretation of trends of faults and locations of igneous rocks at depth.

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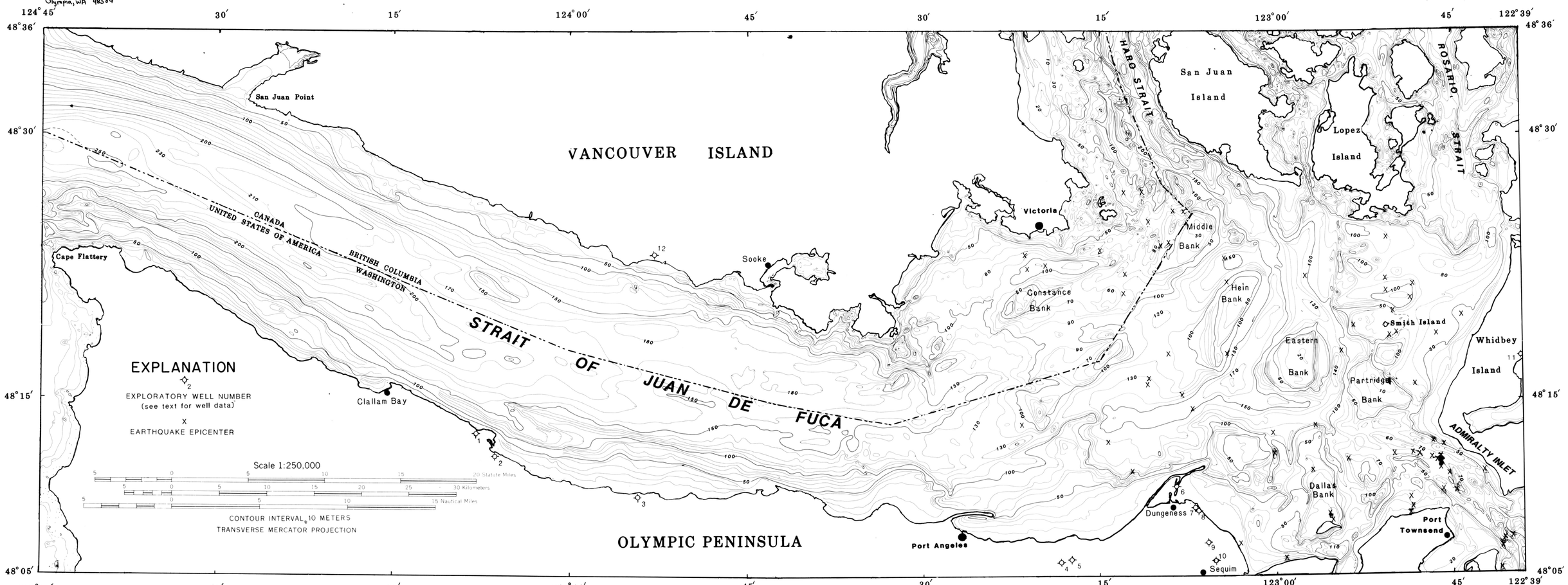

PLATE 1. MAP SHOWING BATHYMETRIC FEATURES IN THE STRAIT OF JUAN DE FUCA AREA, WASHINGTON, U.S.A. AND BRITISH COLUMBIA, CANADA.

Bathymetric contours from Canadian Hydrographic Service Map 15783-A.

Prepared under Cooperative Agreement No. 14-12-0001-30296
between U.S. Minerals Management Service and American Association of State Geologists

by
Holly C. Wagner
U.S. Geological Survey

February 1987

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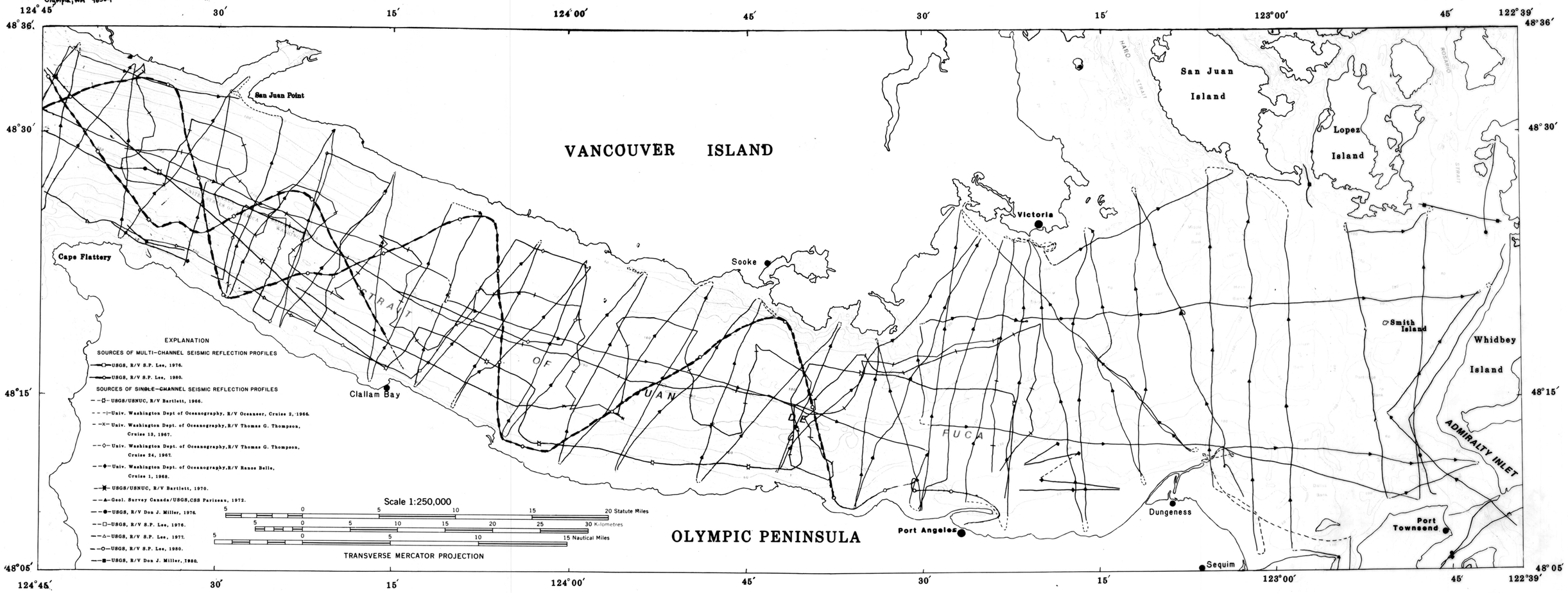

PLATE 2. MAP SHOWING SEISMIC REFLECTION TRACK LINES USED IN DETERMINING SEAFLOOR GEOLOGY, SEDIMENT THICKNESS, AND MAJOR DEEP STRUCTURES IN THE STRAIT OF JUAN DE FUCA AREA, WASHINGTON, U.S.A. AND BRITISH COLUMBIA, CANADA.

Screened bathymetry from Canadian Hydrographic Service Map 15783-A.

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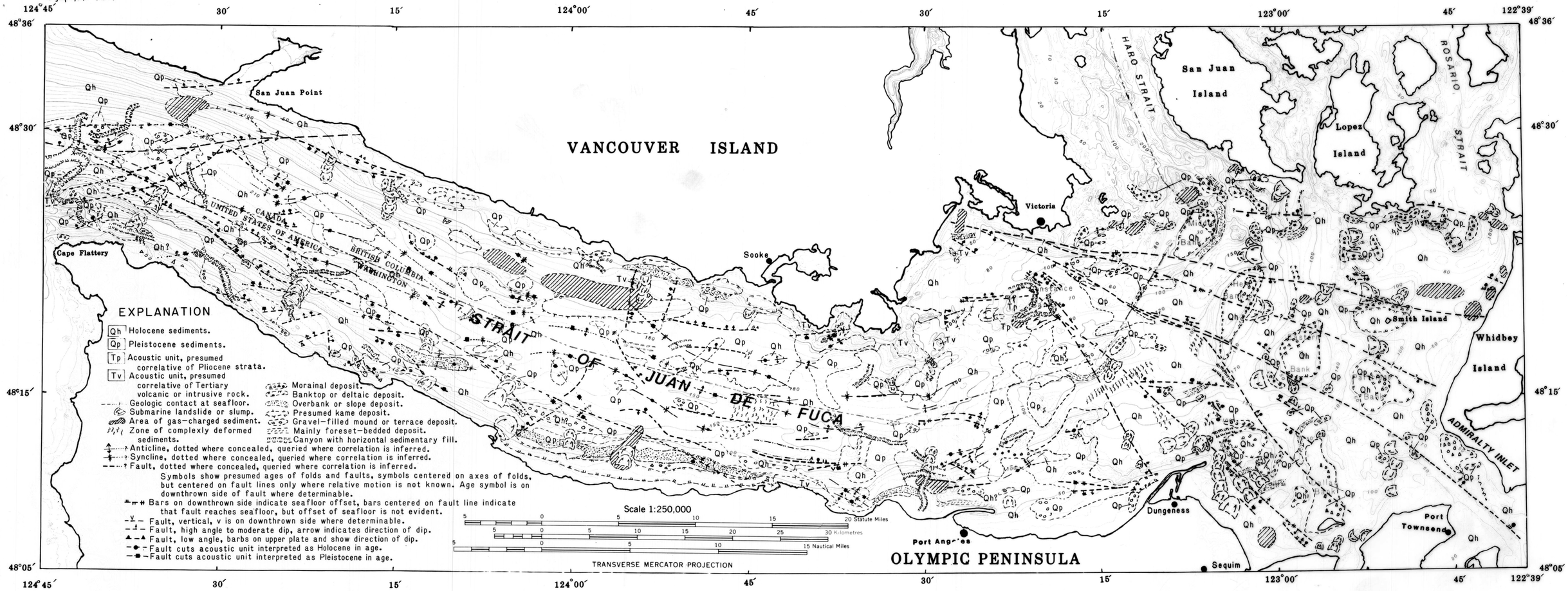

PLATE 3. MAP SHOWING SEAFLOOR GEOLOGY IN THE STRAIT OF JUAN DE FUCA AREA, WASHINGTON, U.S.A. AND BRITISH COLUMBIA, CANADA.

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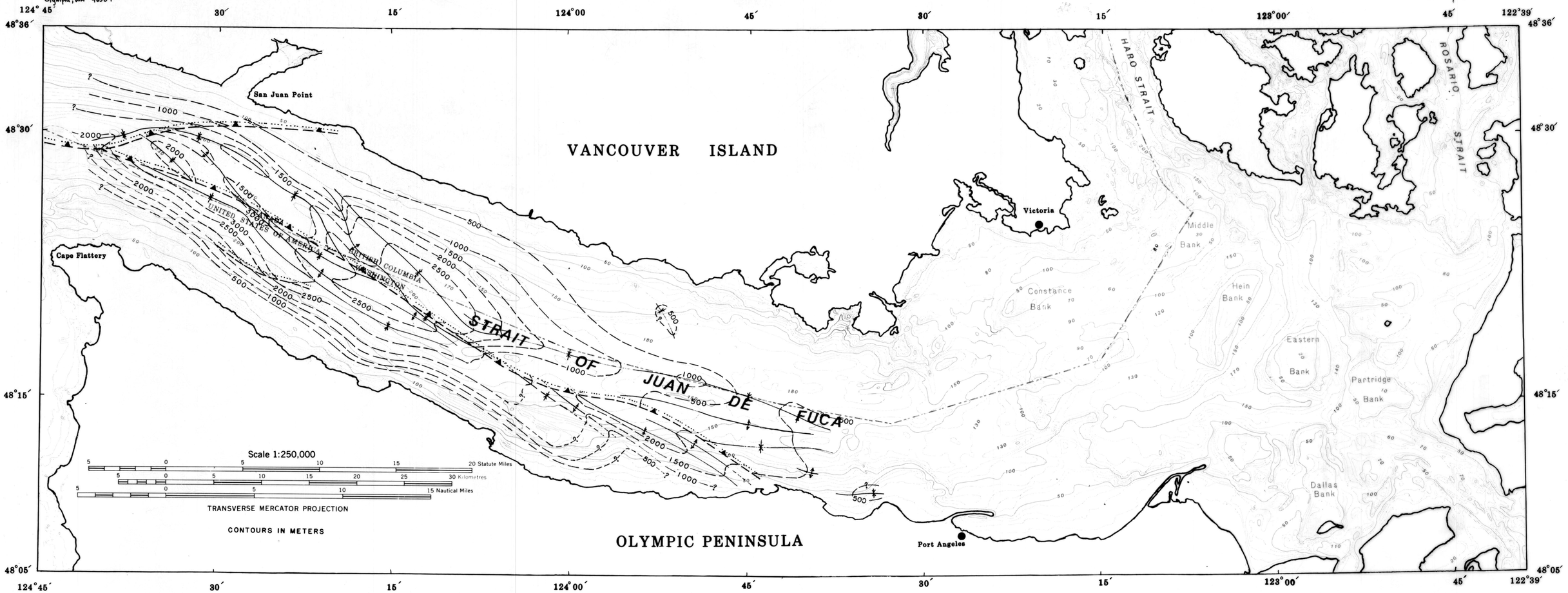

PLATE 4. MAP SHOWING GENERALIZED THICKNESS OF SEDIMENT ABOVE THE LATE MIOCENE UNCONFORMITY IN THE STRAIT OF JUAN DE FUCA AREA, WASHINGTON, U.S.A. AND BRITISH COLUMBIA, CANADA. Screened bathymetry from Canadian Hydrographic Service Map 15783-A.

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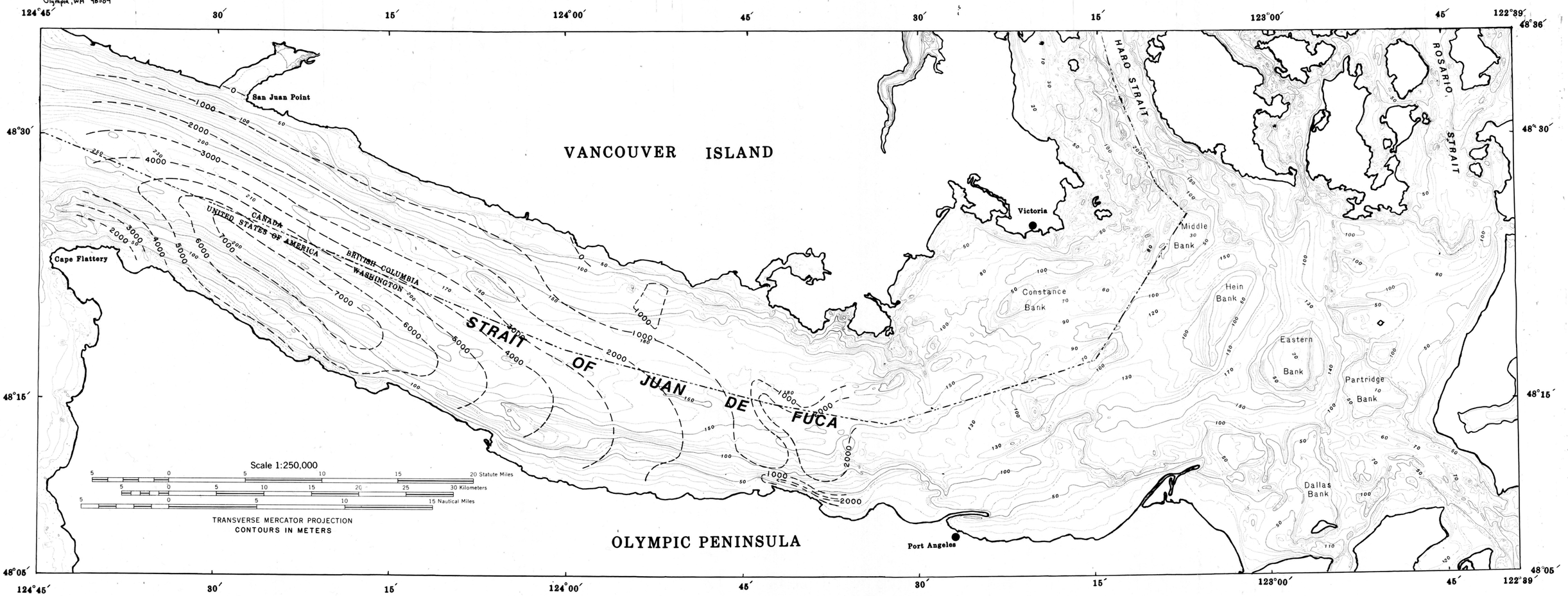

PLATE 5. GENERALIZED MAP SHOWING ESTIMATED TOTAL THICKNESS OF SEDIMENTS ABOVE THE LOWER AND MIDDLE EOCENE BASALT IN THE STRAIT OF JUAN DE FUCA AREA, WASHINGTON, U.S.A. AND BRITISH COLUMBIA, CANADA. Screened bathymetry from Canadian Hydrographic Service Map 15783-A.

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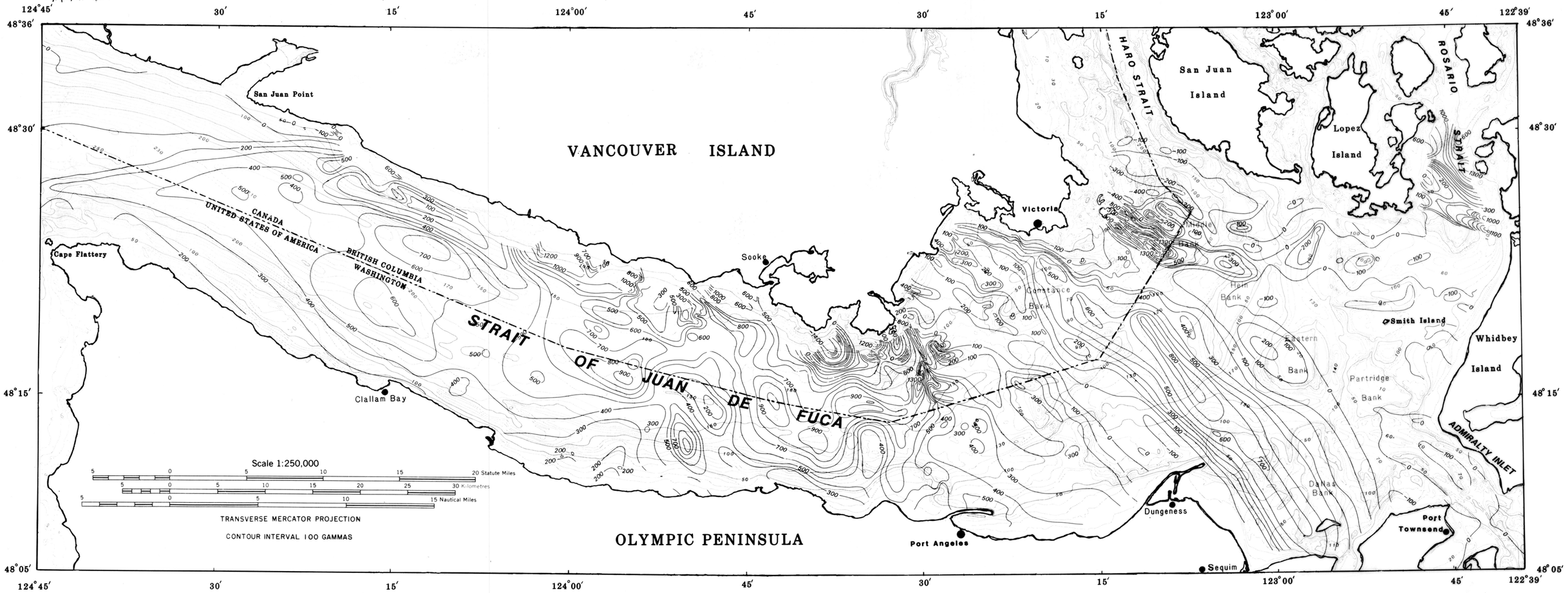

PLATE 6. MAP SHOWING MAGNETIC FEATURES IN THE STRAIT OF JUAN DE FUCA AREA, WASHINGTON, U.S.A. AND BRITISH COLUMBIA, CANADA.

Magnetic contours from Canadian Hydrographic Service Map 15783-E.

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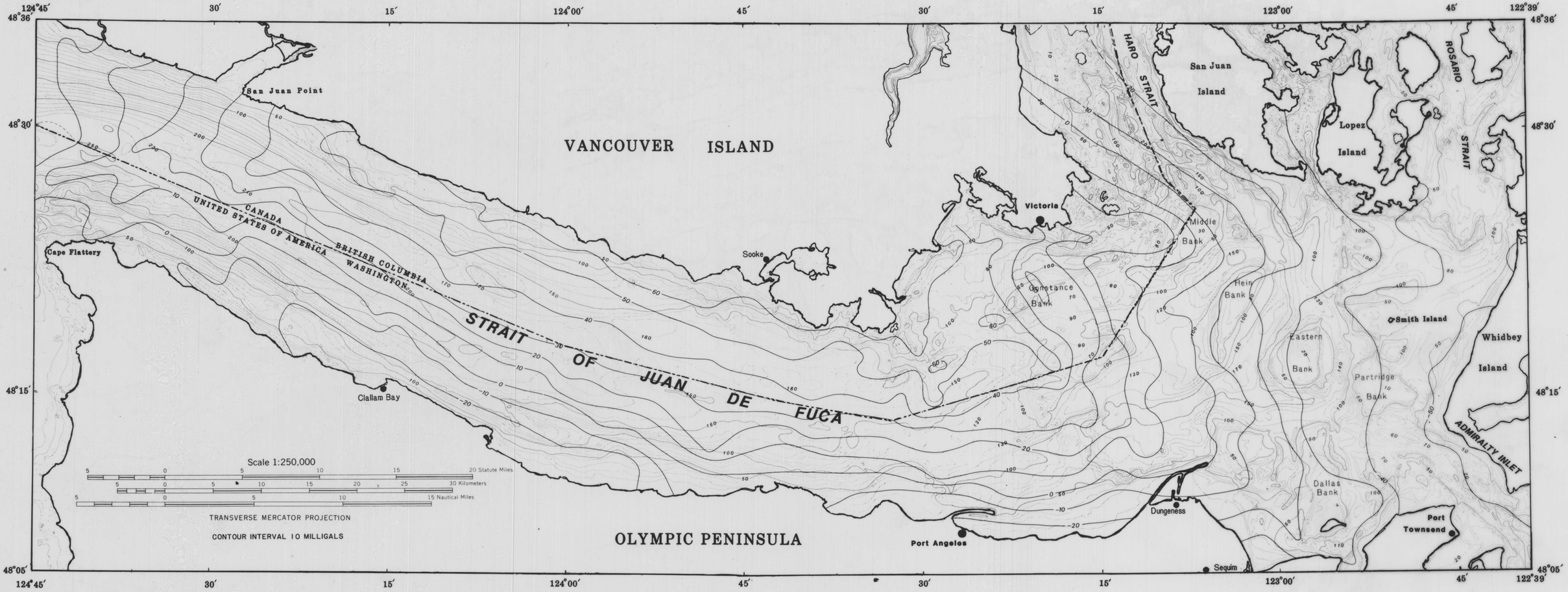

PLATE 7. MAP SHOWING GRAVITY FEATURES IN THE STRAIT OF JUAN DE FUCA AREA, WASHINGTON, U.S.A. AND BRITISH COLUMBIA, CANADA.

Gravity contours from Canadian Hydrographic Service Map 15783-D.

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