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PRELIMINARY REPORT ON THE GEOLOGY OF THE CONTINENTAL SLOPE ADJACENT TO OCS LEASE SALE 55, EASTERN GULF OF ALASKA: PETROLEUM RESOURCE IMPLICATIONS

By

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This report is preliminary and has not been reviewed for conformity with U.S. Geological Survey editorial standards and stratigraphic nomenclature

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CONTENTS

	Page
Abstract	1
Introduction	3
Methods	5
Acknowledgments	6
Regional tectonic setting	7
Rock units	7
Stratigraphic summary	11
Unit A: Pre-Tertiary rocks	36
Unit B: Eocene(?) and Paleocene(?) rocks west of Yakutat Seavalley	36
Unit C: Eocene basaltic rocks	37
Unit D: Eocene sedimentary and volcanic rocks	42
Unit E: Eocene and Oligocene? sedimentary rocks	43
Unit F: Oligocene sedimentary rocks	44
Unit G: Miocene and younger sedimentary rocks	45
Discussion	46
Source rocks	47
Organic carbon and hydrocarbon content	47
Visual kerogen assessment	51
Vitrinite reflectance and thermal alteration index	51
Extraction and chromatography	54
Thermal analysis	55
Discussion	57

CONTENTS--(Continued)

	Page
Sandstone reservoir characteristics	57
Composition	57
Texture and physical properties	59
Discussion	63
Hydrocarbon traps	64
Drape structures	65
Fault blocks and faults	65
Basin margin traps	65
Discussion	66
Conclusions	67
References cited	69

ILLUSTRATIONS

Page

Figure 1. Index map showing dredge sample localities relative to area of proposed OCS Lease Sale 55 ---------- 4

2. Map model showing crustal blocks in southern Alaska and their rate and direction of motion ---------- 8

3. Generalized geologic map of the region surrounding area of proposed OCS Lease Sale 55 ---------- 9

4. Diagrammatic continental slope section showing dredge haul sample intervals ---------- 10

5. Map showing U.S. Geological Survey ship tracklines in the region of proposed OCS Lease Sale 55 ---------- 19

6-20. Seismic line interpretations and true scale bathymetry profiles:

6. Near dredge locality 2 ---------- 20

7. Near dredge localities 3 and 4 ---------- 21

8. Near dredge localities 6 and 8 ---------- 22

9. Near dredge localities 9-11 ---------- 23

10. Near dredge localities 12-14 ---------- 24

11. Near dredge localities 15-17 ---------- 25

12. Near dredge localities 20-2 ---------- 26

13. Near dredge locality 24 ---------- 27

ILLUSTRATIONS--Continued

		Page
Figure	14. Near dredge localities 25-28	28
	15. Near dredge locality 29	29
	16. Near dredge localities 30 and 31	30
	17. Near dredge localities 32 and 33	31
	18. Near dredge localities 34-36	32
	19. Near dredge localities 37, 38, and 40	33
	20. Near dredge locality 39	34
	21. Diagram showing total organic carbon vs. extractable hydrocarbons for shale samples	52
	22. Diagram showing vitrinite reflectance values of kerogen in dredge shale samples relative to values of hydrocarbon generation zones from Dow (1977)	53
	23. Ternary diagrams comparing compositions of dredged samples and the mean compositions of probably coeval onshore rocks	58

TABLES

		Page
Table 1.	Location and description of dredged pre-Quaternary outcrop samples	12
2.	Potassium-argon age data for basaltic rocks	38
3.	Magnetic susceptibility of volcanic rocks	41
4.	Organic carbon and visual kerogen assessment	48
5.	Vitrinite reflectance summary (R-33)	49
6.	Organic carbon content and Rock-Eval pyrolysis data for selected dredge samples	50
7.	Sandstone reservoir characteristics	62

Preliminary report on the geology of the continental slope adjacent to OCS Lease Sale 55, eastern Gulf of Alaska: Petroleum resource implications

By George Plafker, Gary R. Winkler, Warren L. Coonrad, and George Claypool

Abstract

Forty samples of Tertiary and Cretaceous outcrop or suspected outcrop were dredged along the 250-km-long northwest-trending continental slope between long 138°00' W. and 142°30' W. These samples, from water depths of 3,150 m to 200 m, combined with seismic reflection data, identify seven rock units in apparently normal stratigraphic position. From oldest to youngest they are: Unit A: Hard graywacke, argillite, and possible intrusive rocks of inferred Late Cretaceous age that crop out in the eastern part of the slope and probably underlie much of the Fairweather Ground. Unit B: At least 900 m of sandstone, conglomerate, shale, and subordinate basaltic volcanic rocks west of Yakutat Seavalley between 142° W. and 143° W. that is not dated but is probably of late Paleocene to early Eocene age. Unit C: 1,300 m of basaltic flow and pyroclastic rocks with associated clastic marine sedimentary rocks that makes up much of the rugged lower slope throughout the area. This sequence is largely, or entirely, of early Eocene age. Unit D: Up to 2,100 m of early and middle Eocene sandstone, conglomerate, siltstone, and tuffaceous organic-rich shale that partly overlies, and partly intertongues with, the volcanic unit. Unit E: 800 m of early to late Eocene and early Oligocene(?) organic-rich shale, tuffaceous shale, siltstone, and sandstone that partly intertongues with, and partly overlies units C and D. Unit F: 300+ m of siltstone, at least in part of late Oligocene age, that crops out locally

along the upper slope where it unconformably overlies Unit E. Unit G: Up to 2,000 m of late Cenozoic (middle Miocene? and younger) clastic sedimentary rocks including abundant glaciomarine deposits that unconformably overlie all the older units.

The early Tertiary sequence sampled on the continental slope differs strikingly in lithology and structure from coeval rocks exposed onshore or penetrated in unsuccessful exploratory wells on the adjacent mainland. Units B, D, and E include abundant source rocks that have undergone a thermal history resulting in local generation of hydrocarbons. Sandstones from Units D and E locally have secondary porosities up to 31 percent and permeabilities to 36 md. Seismic reflection data indicate that the sequence with the most favorable source and reservoir potential (Units B, D, E) dips northeastward beneath OCS Lease Sale 55 where it could be a favorable exploratory target if involved in suitable traps. Young anticlinal folds are not present, but other important traps are likely to include drape structures, horsts, and faults within the early Tertiary sequence and pinchouts, fault traps, or combination structural/stratigraphic traps along the northeastern margin of the early Tertiary basin.

Introduction

Bedrock outcrops along the continental slope adjacent to the Yakutat shelf were sampled in 1977, 1978, and 1979 as part of the U.S. Geological Survey's program for evaluation of the geologic framework and petroleum potential of the outer continental shelf (OCS) in the eastern Gulf of Alaska (fig. 1). The samples were collected in water depths between 3,180 m and 250 m to provide geologic control on the seaward margin of the Gulf of Alaska Tertiary Province, a major sedimentary basin on the continental margin that has long been of interest for petroleum exploration and to further understanding of the tectonics of this active plate margin.

Between 1954 and 1961, 25 exploratory wells were drilled onshore and one unsuccessful well was drilled offshore in State of Alaska waters near Middleton Island (Plafker, 1971). Part of this basin on the outer continental shelf (OCS), between Kayak Island and Icy Bay, was leased in April 1976, following which 10 dry, deep exploratory wells were drilled for petroleum from 1976 to early 1978 (Plafker and others, 1978a; Bruns, 1979). A second lease sale (Sale 55) has been scheduled for October 1980 in the segment of the continental shelf lying between Icy Bay and Alsek River, herein referred to as the Yakutat shelf (fig. 1).

This paper outlines sample data derived from the segment of continental slope adjacent to the area of proposed OCS Lease Sale 55 and presents a preliminary evaluation of the sample data with respect to its petroleum resource potential. Some of the data on samples collected in 1977 and 1978 were summarized in previous reports by Plafker and Claypool (1979) and Plafker and others (1978C, 1979).

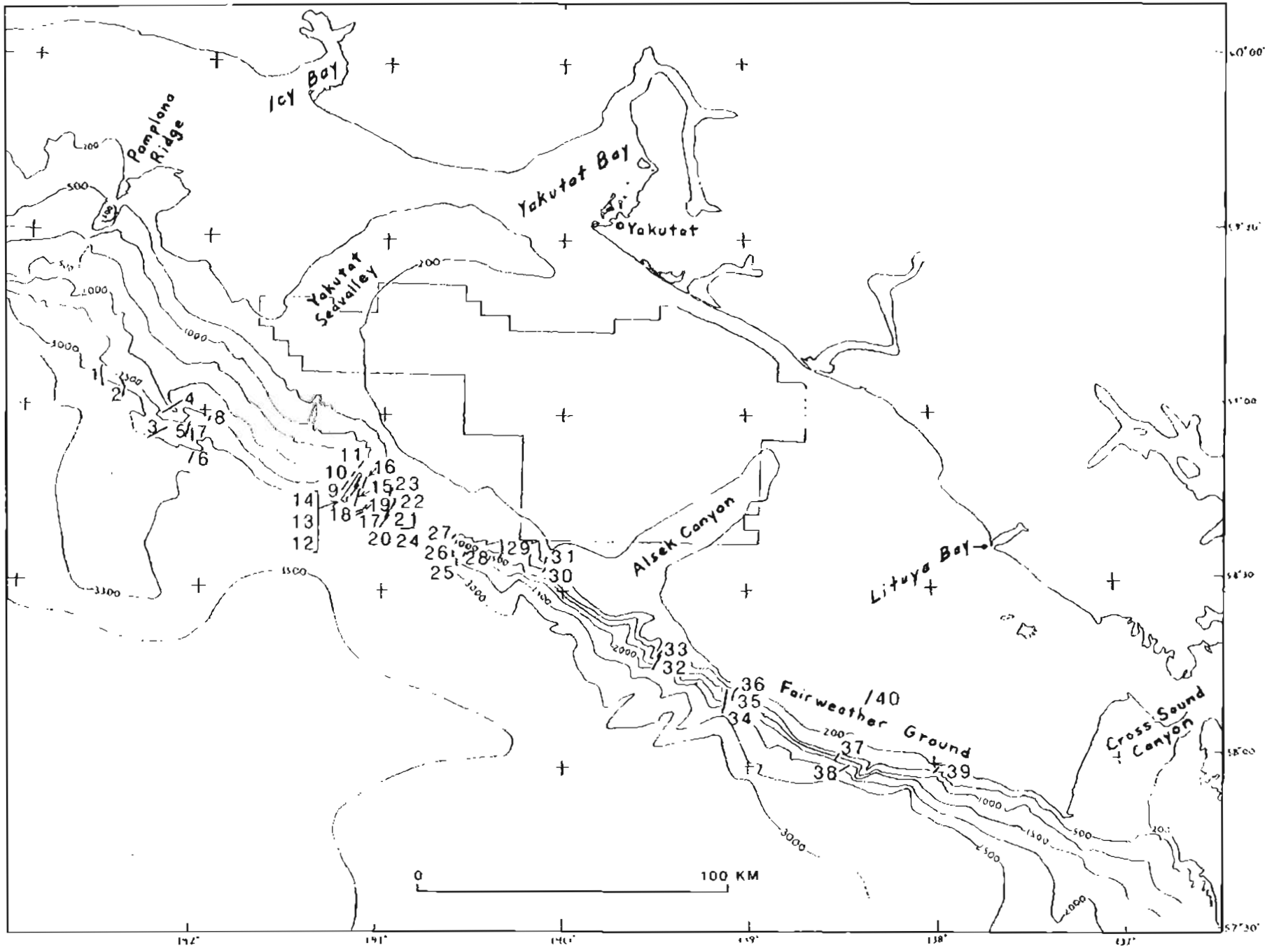


Figure 1.--Index map showing locations of dredged outcrop samples described in tables and text. Area outlined on continental shelf is the proposed OCS Lease Sale No. 55.

Methods

Outcrop samples on the continental slope (and one on the shelf) were collected with a Benthos chain-bag dredge designed for heavy-duty deep-sea work. The dredge mouth is rectangular and is constructed of 4.4-cm-thick steel plate jaws 22 cm wide by 70 cm long connected at the ends by 1.25 cm steel plate 13 cm wide. The dredge mouth is 46 cm by 61 cm at the top and tapers to an opening of 25 cm by 61 cm at the bottom. Samples are caught in a chain link bag approximately 112 cm long that is attached to the bottom of the rectangular steel plate dredge mouth. Link openings are approximately 5 cm in diameter, which permits mud and smaller rock fragments to wash out of the bag. When full, the bag has a capacity of about 1/4 cubic meter or roughly 455 kg of broken sedimentary rocks. The dredge is connected to the towing cable by a steel A-frame hinged yoke designed so that pull on the yoke causes whichever jaw is on the bottom to dig into the surface over which it is dragged. The dredge was connected to a 1.4 cm cable (9/16 inch) by a 1.1 cm (7/16 inch) weak link having a breaking strength of about 8,200 kg.

Sampling was accomplished by towing the dredge over the bottom at speeds of approximately 2.8 to 3.7 km/hr (1-1/2 to 2 knots) with a cable length roughly 25 to 50 percent greater than the water depth. The pull registered by a dynamometer on the cable indicated when the dredge was on bottom, the general nature of the bottom, and when outcrop samples were being broken off. A time-depth recorder was installed on the cable for most hauls made during the 1979 cruise in order to better locate the outcrop "bites" and samples.

The dredge attempts were commonly located along seismic profiles obtained simultaneously with the R/V Sea Sounder's single-channel 160 kiloJoule sparker system as well as 3.5 and 12 kiloHertz systems. Several of the samples and profile lines are also located along 24 channel CDP reflection lines taken by

the R/V Lee or R/V Cecil Green. The seismic profiles were used to facilitate correlation of the outcrop sampling with seismic reflectors.

Locations were provided by a Magnavox integrated satellite/Loran navigation system and are normally accurate to within 1/2 km. Problems with the system's Loran and timing clock in 1978 probably resulted in increased sample location errors; the amount of these errors is unknown, but could be up to 2 km in some cases.

Dredge localities are numbered consecutively for the 1977, 1978, and 1979 hauls and samples are assigned the dredge locality number followed by letters. Prefixes that identify these cruises are as follows: 1977, S2-77-EG; 1978, S5-78-EG; and 1979, S10-79-EG. "S" indicates R/V Sea Sounder, the numeral that follows indicates the cruise leg, the two-digit number refers to the year, and EG indicates the area (Eastern Gulf of Alaska). For brevity in this paper the prefixes have been shortened so that references to dredge localities and samples are referred to only by year and number (i.e., locality 78-44, sample 78-44A).

Acknowledgments

Collection of the samples was made possible by the outstanding cooperation and seamanship of the officers and crew of the R/V Sea Sounder and the dedicated efforts of the scientific and technical staffs that participated in all three eastern Gulf of Alaska cruises. Plafker was co-chief scientist with Gary Winkler in 1977, with Paul Carlson in 1978, and with Terry Bruns in 1979.

Age assignments for the dredged samples are based largely on studies of the contained nannoplankton by David Bukry, the foraminifers by Weldon W. Rau and Richard Poore, the siliceous micro-organisms by John Barron, and the palynomorphs by Anderson-Warren and Associates, Inc.

REGIONAL TECTONIC SETTING

The segment of the continental slope sampled in this study, together with the adjacent OCS, is part of a relatively small triangular crustal plate that has been informally named the Yakutat block (fig. 2, Plafker and others, 1978b; Rodgers, 1978). Available earthquake, geologic, and marine seismic data suggest that most of the approximately 5.8 cm/yr relative motion between the Pacific and North American plates is presently being taken up along the Fairweather transform fault and Pamplona zone of thrust faults and folds. Relative motion between the Pacific plate and Yakutat block is small--perhaps on the order of 0.4 cm/yr (Lahr and Plafker, in press) and occurs mainly on a system of inferred faults (the Transition fault zone) at or near the base of the continental slope. Offshore parts of the Yakutat block are characterized by an asymmetric, deep shelf basin containing middle(?) and late Cenozoic sedimentary rocks, and a general absence of compressional deformation in the post-Paleocene Cenozoic section (Plafker and others, 1978a; Bruns, 1979). These features suggest that the Yakutat continental slope has been a trailing or strike-slip margin--rather than a zone of convergence--throughout much of the Cenozoic. In this respect, the continental shelf and slope of the Yakutat block differ strikingly from the Yakataga area to the northwest where seaward-verging thrust faults and folds reflect pervasive late Cenozoic compression due to high rates of underthrusting along the Aleutian Trench and Pamplona zone.

ROCK UNITS

The approximate distribution of rock units along the continental slope is shown in figures 3 and 4. Also shown in figure 3 are the stuctural boundaries of the Yakutat block, the limits of pre-Tertiary outcrop along the coast, the location of exploratory wells, the axis of the late Cenozoic basin, and the

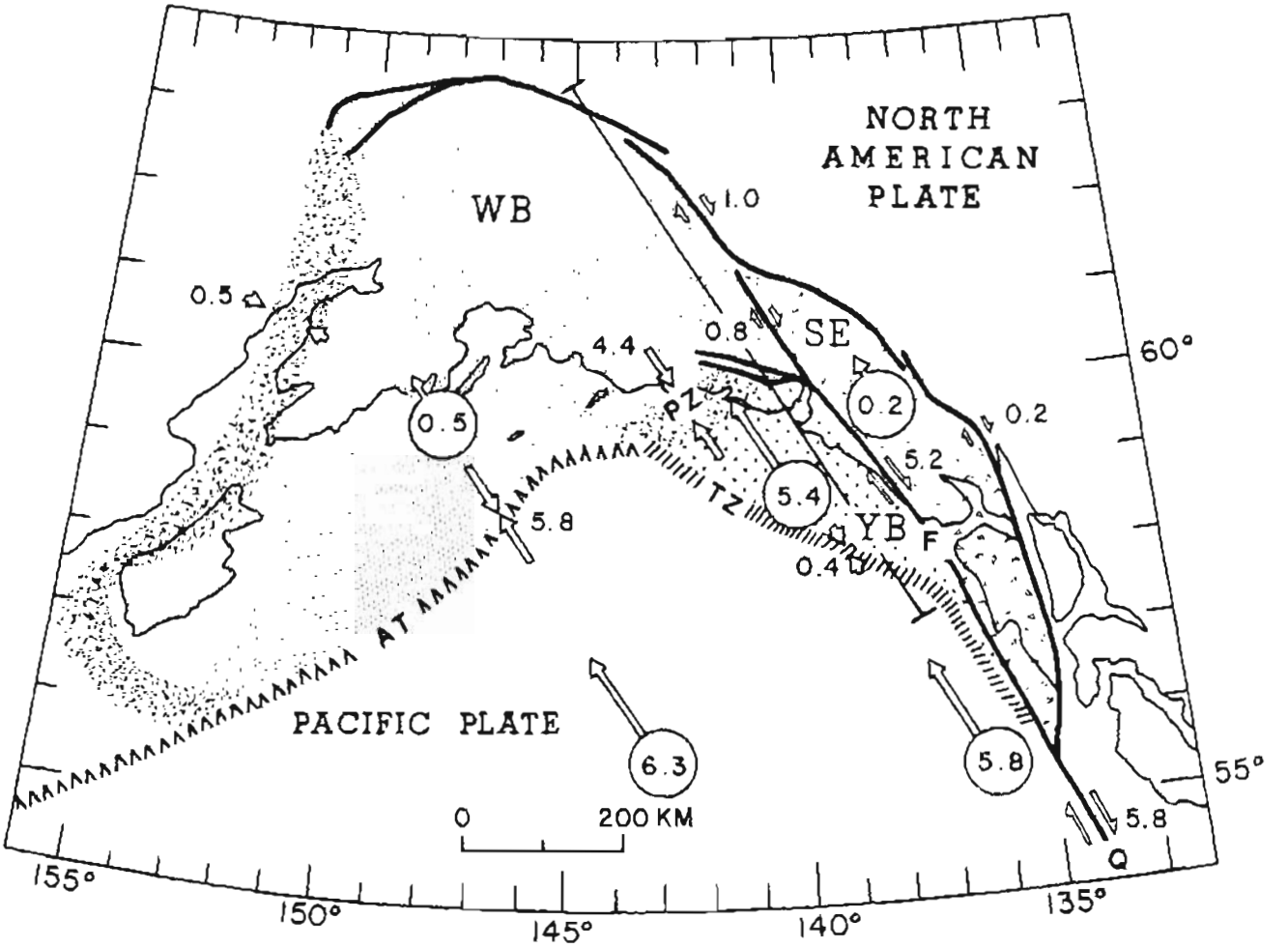


Figure 2.--Model showing inferred relationship of the Yakutat block (YB) to other crustal blocks in southern Alaska (Lahr and Plafker, in press). Circled numbers give rate of motion (cm/yr) of the Yakutat block, Pacific plate, Saint Elias block (SE), and Wrangell block (WB) relative to the North American plate. Numbers next to paired vectors give rate of motion across indicated zone. PZ, Pamplona zone; TZ, Transition fault zone; F, Fairweather fault; Q, Queen Charlotte fault; AT, Aleutian Trench.

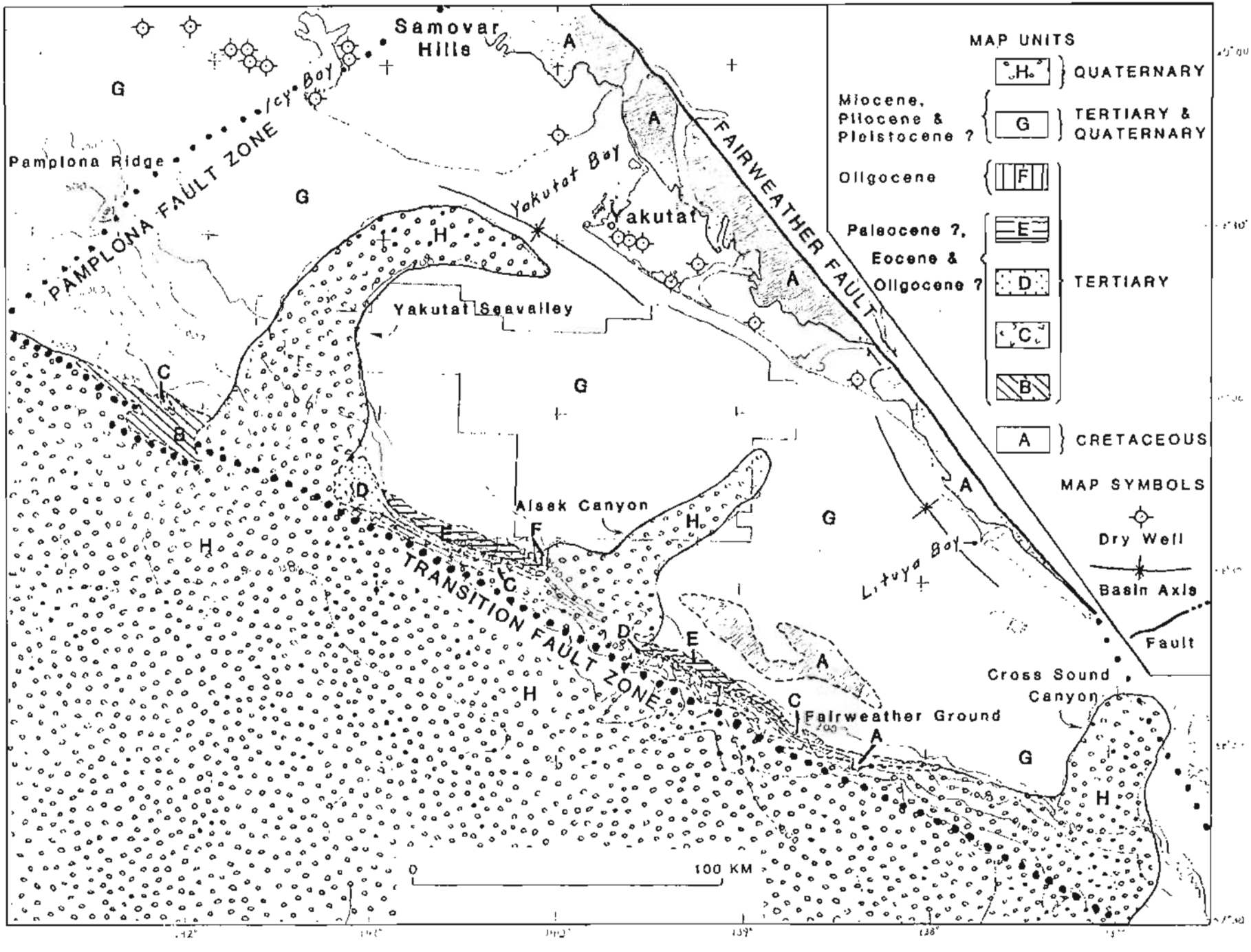


Figure 3.--Generalized geologic map showing bedrock outcrop distribution on the Yakutat continental slope and shelf, the outcrop area of pre-Tertiary rocks onshore, areas of thicker unconsolidated deposits, major structural features, onshore wells, and proposed OCS Lease Sale No. 55. See text for description of map units.

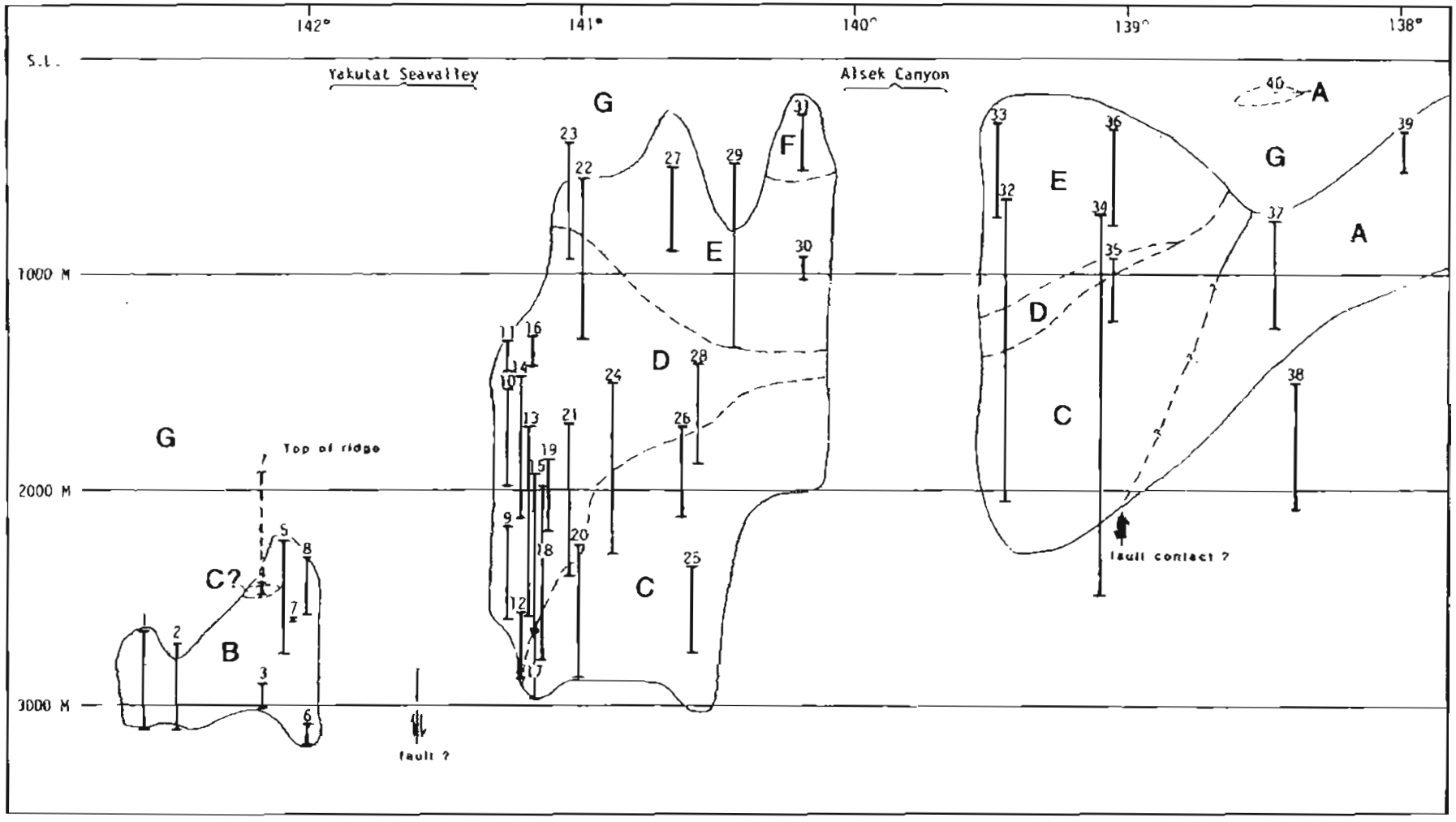


Figure 4.--Section parallel to the continental slope between 138° W. and 143° W. showing depth intervals sampled by dredge hauls (table 1) and the distribution of lithologic units A through G deduced from the dredge and (or) seismic data.

distribution of thick unconsolidated Quaternary deposits. Dredge samples on which the map and section are largely based are described in table 1 and their locations are shown in figure 1. Figures 6 through 20 are marine seismic profiles oriented approximately perpendicular to the slope that show the topographic and structural settings for many of the dredge samples. Profile locations are shown on figure 5.

Because the geologic map and section (figs. 3 and 4) were constructed from dredge samples whose precise depth is unknown and because the seismic profiles are widely spaced, the exact location of contacts is generally uncertain. Bedded clastic sequences of Eocene and younger age commonly show well-defined continuous interval reflections in areas of gentle slope, but these are invariably masked by diffractions in the more topographically rugged areas. Eocene volcanic rocks and the Late Cretaceous "basement" rocks lack coherent reflectors and cannot be differentiated on our seismic profiles.

Stratigraphic Summary

Seven rock units of pre-Quaternary age have been tentatively delineated on the continental slope and adjacent shelf in the Yakutat block. From oldest to youngest they are:

Unit A) "Basement" rocks probably correlative with the Late Cretaceous Yakutat Group onshore.

Unit B) 900 m+ of clastic sedimentary rocks and basalt of unknown, but probable late Paleocene or early Eocene age.

Unit C) 1,300+ m of basalt and probably minor sedimentary rocks of late early to middle Eocene (Penutian and Ulatisian stages) age.

Unit D) Up to 2,100 m of heterogeneous sedimentary and pyroclastic rocks with some basalt of middle to late Eocene (Penutian and Narizian stages) age.

Table 1.--Location and description of dredged pre-Quaternary outcrop or probable outcrop samples

[Fossil identifications and age assignments by D. Bukry (nannofossils), W. W. Rau and R. Z. Poore (foraminifers), Anderson-Warren Associates (palynomorphs), J. A. Barron and D. Bukry (diatoms and silicoflagellates]

Map No. (Fig. 1)	Dredge No.	Location (Depth and coordinates are given for start and finish of dredge casts)			Estimated Recovery (kg)	Sample Designation (Underline indicates thin section available)	Lithology (Listed in order of relative abundance in dredge sample)	Fossils	Comments
		Water depth (m)	Latitude (N.)	Longitude (W.)					
1	79-16	3105- 2650	59°04.58' 59°03.78'	142°33.37' 142°34.22'	125	79-16A, 16B, 16C, 16D, 16E	Sandstone, feldspatholithic, highly micaceous, hard, medium-light-gray to medium-dark-gray, fine- to medium-grained, moderately well sorted, in part calcareous and cut by calcite veinlets, local laminae of carbonized plant material, in part sheared, and brecciated.	None	
						79-16F, 16G, 16H, 16I, 16J	Shale, silty, hard, brownish-black with interbedded sandstone and partings of wispy black plant? material. Sandstone laminae 2 mm to 35 cm thick, medium-gray to yellow-gray, very fine to medium-grained, in part graded and cross-laminated.		
2	78-41	3110- 2700	59°02.94' 59°05.02'	142°26.51' 142°24.17'	20	78-41A, 41B, 41C	Pebbly and sandy mudstone, hard, light-gray, rusty-brown-weathering, attached to cobble-size gabbro clast.	Pliocene-Quaternary foraminifers Tertiary palynomorphs Late Miocene to Holocene diatoms	Mudstone-matrix conglomerate or diamictite in Yakataga Formation?
						78-41D through 41Z	Cobbles and boulders, loose, polymictic, subangular to rounded, largest is 18 x 15 x 12 cm. Includes graywacke, gabbro, gneiss, schist, altered basalt, quartz diorite, granodiorite, aplite, etc.		Diorite clast minimum age is 33.3±2.5 m.y. based on whole rock K/Ar date
3	78-23	2890- 3010	58°55.96' 58°54.66'	142°10.78' 142°14.41'	2	78-23A	Sandstone, feldspatholithic, hard, dense, light-gray, medium-grained, subangular to subrounded, poorly sorted, tightly compacted, slightly calcareous.	---	May be erratic or Eocene? outcrop
4	78-22	2470- 2430	59°00.44' 58°57.63'	142°08.55' 142°09.39'	300	78-22C1, 22C2, 22C3	Sandstone, feldspatholithic, hard, light-gray to gray and greenish-gray, very fine- to coarse-grained, in part laminated and graded, highly micaceous, veins of prehnite and carbonate.		
						78-22B2, 22B3	Siltstone, hard, black, carbonaceous, in part with laminae of greenish-gray, graded, and channeled very fine grained sandstone.		
						78-22D1, 22D2, 22D3, 22D4	Shale, medium-gray, light-brownish-gray, and dark-brown, waxy, organic-rich, massive.	Pre-Pliocene foraminifers Small pelecypods	
						78-22A1, 22A2, 22A3, 22A4, 22A5, 22A6, 22A8	Basalt and diabase, angular to subangular blocks (possibly talus), very hard, green, gray-green, and dark-green, in part porphyritic, amygdaloidal, veined, in part agglomeritic.		
						78-22A5	Basalt, hard, dark-green, hyaloolitic, minor chlorite and slightly altered plagioclase laths, abundant dusty iron ores.		Basalt minimum age 55.2±7.1 m.y. based on whole rock K/Ar date
						78-22A7	Basalt, hard, dark-green, fine-grained, intergranular, fresh plagioclase and augite, abundant iron ore.		Basalt minimum age 33.6±3.9 m.y. based on whole rock K/Ar date
5	79-28	2760- 2225	58°56.16' 58°55.20'	142°05.94' 142°06.78'	25	79-28A	Sandstone, moderately indurated, friable, massive, pale-yellow-brown-weathering, medium- to coarse-grained with scattered very coarse grains, micaceous.		
6	77-20	3180- 3080	58°53.17' 58°54.28'	142°03.21' 142°02.90'	75	77-20A	Sandstone-matrix conglomerate, hard, fresh, polymictic, clast size from pebbles to blocks (35 x 25 x 20 cm), pebbles well rounded and smooth, coarser clasts rounded to subrounded, matrix dirty, calcareous, medium grained, lithofeldspathic.		
						77-20B	Shale, hard, dark-gray, slightly calcareous, abundant finely divided pyrite.		
7	77-21	2600- 2610	58°55.83' 58°52.31'	142°06.57' 142°03.39'	140	78-21D4, 21D5	Sandstone, feldspathalithic, moderately hard to hard, sheared, massive, light-gray to gray, medium- to coarse-grained, very poorly sorted, angular to subangular, in part pebbly with abundant shale chips.		
						78-21A, 21B, 21C	Shale, moderately hard, black, carbonaceous, in small fragments within sandstone.		

Table 1.--Location and description of dredged pre-Quaternary outcrop or probable outcrop samples (Continued)

Map No.	Dredge No.	Location: Depth	Location: Latitude	Location: Longitude	Estimated Recovery (kg)	Sample Designation	Lithology	Fossils	Comments
8	77-22	2575-2300	58°58.60' 58°59.77'	141°59.68' 141°58.46'	50	77-22A	Sandstone, moderately hard, friable, massive, slightly weathered, pale-yellowish-gray, fine-grained, micaceous, sparse glauconite, very dirty with moderate secondary porosity.	Tertiary arenaceous foraminifers	
						77-22B	Shale, soft to moderately hard, medium-light-gray, micaceous and carbonaceous.		
9	79-42	2600-2160	58°47.10' 58°48.44'	141°12.25' 141°10.71'	25	79-42A, 42B	Sandstone, feldspatholithic, slightly indurated and friable, in part calcareous and hard, medium-gray, medium-grained, moderately well sorted, angular to subrounded, micaceous, commonly massive but in part with dark-gray laminae of carbonaceous and micaceous siltstone.	Middle Eocene to early Oligocene nannofossils Eocene? foraminifers Eocene palynomorphs	
						79-42C, 42D, 42E	Shale, moderately indurated to hard, brownish-gray to dusky-brown, massive, abundant kerogen, microfossils, and carbonized plant remains.		
10	79-43	1980-1518	58°48.55' 58°50.03'	141°10.51' 141°08.85	75	79-43A, 43B, 43D, 43E	Shale, soft, locally calcareous and moderately indurated, massive, grayish-brown to brownish-gray, abundant kerogen and microfossils, highly micaceous, local dusky-yellow-brown very hard calcareous "cannonball" concretions.	Early Eocene nannofossils Late early to early middle Eocene (Penutian to Ulatisian) foraminifers Late Eocene palynomorphs	
						79-43C	Sandstone, lithofeldspathic, hard, massive, medium-gray, moderately well sorted, angular to subangular, abundant carbonate and minor clay cement.		
11	79-44	1450-1312	58°51.11' 58°52.48'	141°07.81' 141°06.23'	10	79-44A, 44B, 44C	Shale, slightly indurated, massive, dusky-brown, abundant kerogen, minor microfossils.	Probable late Eocene palynomorphs	
12	79-37	2870-2560	58°44.91' 58°46.80'	141°12.33' 141°10.24'	375	79-37A, 37B, 37C	60% Shale, slightly to moderately indurated, massive, grayish-brown to dusky-brown, in part carbonaceous, common microfossils, large calcareous concretions.	Middle Eocene to early Oligocene (possibly early or middle Eocene) nannofossils Late Eocene (Narizian) foraminifers Eocene palynomorphs	
						79-37F	35% Sandstone, feldspatholithic, hard, massive, medium-light-gray, medium-grained, angular to subrounded, well sorted, 30%-35% calcite cement, micaceous.		
						79-37D	Palagonitic vitric crystal tuff, massive, hard, grayish-blue, very fine grained with angular to rounded green, gray, and violet clasts to 1 cm across of palagonite containing plagioclase, opaque crystals, and minor clear glass fragments. Vesicles and veinlets infilled with zeolites and minor hematite.		
						79-37E	Siltstone, slightly indurated, massive, medium-dark-gray, highly micaceous, abundant coarse carbonized plant material.		
13	79-38	2510-1700	58°46.89' 58°47.90'	141°09.99' 141°08.44'	5	79-38A, 38B, 38C	Shale, slightly indurated to moderately indurated, massive, grayish-brown to dusky-brown.	Middle Eocene to early Oligocene nannofossils Late Eocene (Upper Narizian) foraminifers Eocene palynomorphs Fish scales, one small gastropod	
14	79-39	2125-1467	58°47.26' 58°48.79'	141°09.70' 141°07.62'	500	79-39D, 39E, 39F, 39G	Shale, slightly indurated to hard, massive to laminated, medium-gray to medium-dark-gray and dusky-brown, in part calcareous, locally abundant carbonized plant material.	Middle Eocene to early Oligocene (possibly middle Eocene?) nannofossils Late Eocene (Narizian) foraminifers Eocene palynomorphs One small clam in shale	
						79-39A	Sandstone, bioclastic and volcaniclastic, hard, bedded, medium-gray, coarse-grained. Clasts predominantly a calcareous reef hash with subordinate rounded basaltic rock fragments in a calcite matrix.	Tropical reef assemblage in sandstone including Amphistegina, pelagic foraminifers, coral, coralline algae, bryozoans, echinoids, etc.	
						79-39B	Interbedded shale and sandstone, moderately indurated laminated brownish-gray organic-rich shale and medium-light-gray, medium-grained feldspatholithic sandstone.		
						79-39C	Siltstone, moderately indurated, laminated, medium-dark-gray, highly micaceous and carbonaceous.		

Table 1.--Location and description of dredged pre-Quaternary outcrop or probable outcrop samples (Continued)

Map No.	Dredge No.	Location: Depth	Location: Latitude	Location: Longitude	Estimated Recovery (kg)	Sample Designation	Lithology	Fossils	Comments
15	78-43	2640-1915	58°45.60' 58°47.50'	141°12.64' 141°10.48'	300	78-43E, 43F	Siltstone, moderately hard, massive, light-greenish-gray, slightly calcareous.	Early Eocene (D. Lodogensis zone) nannofossils Late early Eocene to early Eocene (Penutian-Ulatisian) foraminifers Late Eocene palynomorphs	Some slickensides in siltstone
						78-43A	Palagonitic basaltic tuff, hard, dark-green with white analcite amygdule and pore fillings.		
						78-43B	Limestone, very hard, massive, light-gray concretions or beds.		
16	78-44	1415-1270	58°45.90' 58°46.84'	141°08.49' 141°07.45'	450	78-44D, 44E, 44F	Shale, soft to moderately hard, finely laminated, dark-olive-gray to dusky-yellowish-brown, abundant microfossils and fish scales, minor glauconite?.	Middle or late Eocene nannofossils Middle to late Eocene (Narizian) foraminifers Eocene palynomorphs Rare thin-shelled small pelecypods and abundant fish scales in shale	Abundant slickensides
						78-44A	Sandstone, lithofeldspathic, moderately hard, friable, gray, fine- to medium-grained, angular to subangular, dirty.		
						78-44B	Sandstone, volcaniclastic, moderately hard, grayish-green, very fine- to medium-grained, angular to rounded, clasts mostly altered basaltic glass, plagioclase, glauconite, and zeolites, abundant carbonized plant material on bedding planes.		
						78-44C	Devitrified basalt?, hard, mottled brown and gray, vesicular, chloritic volcaniclastic rock with abundant disseminated pyrite.		
17	78-45	2955-2625	58°42.40' 58°43.83'	141°07.18' 141°03.58'	5	78-45A, 45B	Volcaniclastic pebbly sandstone, hard, massive, dark-purplish-gray to reddish-black, subangular to rounded vesicular chloritized basaltic glass clasts with intersertal texture to 12 cm maximum diameter in vitric tuff matrix.	Early Eocene nannofossils Early to middle Eocene (Penutian-Ulatisian) foraminifers Late Eocene palynomorphs	
						78-45C	Siltstone, soft, massive, waxy, gray.		
18	79-40	2780-1980	58°42.61' 58°44.08'	141°07.74' 141°05.90'	10	79-40A, 40C, 40D	Basalt and olivine basalt, hard, massive, commonly amygdaloidal, medium-bluish-gray to brownish-gray; intersertal, hyalopilitic, hyalo-ophitic, and intersertal subophitic porphyritic textures; glass commonly altered to chlorophaeite or nontronite; plagioclase, augite, iron ore, altered olivine, abundant zeolite- and chlorite-filled amygdules.		Basalt minimum age is 29.7± 3.6 m.y. based on whole rock K/Ar date
						79-40B	Volcaniclastic pebbly sandstone, hard, massive, olive-gray, subangular to subrounded basalt and zeolite clasts to 25 mm maximum diameter in tuffaceous matrix.		
						79-40E	Silty shale, slightly indurated, weathered light-olive-brown.		
						79-40F	Calcareous shale, moderately hard, massive, light-yellowish-brown.	Early Eocene (D. Lodogensis zone?) nannofossils Late Eocene palynomorphs One small gastropod	
19	79-41	2170-1850	58°43.36' 58°44.43'	141°06.08' 141°05.04'	25	79-41A, 41B	Shale, moderately indurated, massive, light-brownish-gray, calcareous, abundant kerogen and microfossils.	Early Eocene nannoplankton Early to middle Eocene (early Ulatisian to early? Penutian) foraminifers Middle to late Eocene palynomorphs	
						79-41C	Shale, very hard, massive, medium-bluish-gray, siliceous, abundant kerogen and microfossils.		
						79-41D	Basaltic lapilli tuff, hard, mottled yellow, gray, and pink, devitrified palagonitized lapilli with plagioclase microlites and amygdules of chlorite and calcite in tuff and calcite matrix.		

Table 1.--Location and description of dredged pre-Quaternary outcrop or probable outcrop samples (Continued)

Map No.	Dredge No.	Location: Depth	Location: Latitude	Location: Longitude	Estimated Recovery (kg)	Sample Designation	Lithology	Fossils	Comments
20	79-33	3020-1778	58°40.17' 58°42.41'	141°00.67' 140°56.63'	125	79-33A	Palagonitic basaltic lapilli tuff, hard, massive, greenish-black, amygdaloidal, microlitic basaltic glass extensively altered to palagonite, clay, and chlorophaeite with abundant zeolite in amygdules and interstices. Violet, pale-green, and pale-reddish-purple lapilli to 25 mm maximum size. In part veined with coarsely crystalline calcite.		
						79-33G	Basalt, very hard, massive, dark-gray, amygdaloidal intersertal porphyritic texture. Microphenocrysts of clinopyroxene and plagioclase, one altered plagioclase phenocryst, intersertal clear glass groundmass with some replacement by chlorite. Amygdules have chlorite rims and are filled with zeolites and minor smectite.		
						79-33H	Basalt, hard, massive, dark-gray, intersertal porphyritic texture, phenocrysts of plagioclase and chlorophaeite after olivine, groundmass of plagioclase, clinopyroxene, abundant iron sulfides, and chlorophaeite?.		Minimum basalt age 26.2±3.0 m.y. based on whole rock K/Ar date
						79-33B, 33C, 33D, 33E, 33F	Banded calcite, wavy bands of vuggy, coarsely crystalline, grayish-orange-pink to amber-brown with thin layers of light-greenish-gray, fine-grained calcite in massive chunks to 35 x 30 x 22 cm. Occurs interbedded with thin layers of palagonitized basaltic tuff from 3-15 mm thick, as matrix cementing basaltic lapilli, or with included basaltic rock fragments.		
						79-33I	Sandstone, lithofeldspathic, hard, massive, medium-gray, medium-grained, angular to subrounded, well sorted with approximately 40% primary calcite matrix.		
						79-33J, 33K	Glauconitic siltstone, soft, medium-gray-weathering, 30% pellets glauconite, abundant biotite, finely disseminated pyrite?, rare sand-size quartz grains, abundant opaline skeletal fragments.		Possibly middle or late Cenozoic?
21	79-34	2405-1679	58°41.13' 58°42.53'	140°58.80' 140°56.49'	75	79-34B	Olivine basalt, hard, fractured and veined, dusky-brown, porphyritic variolitic amygdaloidal texture. Olivine phenocrysts altered to smectite, zeolite and some iddingsite; matrix is plagioclase varioles, opaques, and greenish-brown palagonite cut by veins of green nontronite, zeolite, and yellow clay.		
						79-34C, 34E	Amygdaloidal basalt, hard, medium-bluish-gray, very fine grained intersertal porphyritic texture. Plagioclase and orthopyroxene phenocrysts in groundmass of plagioclase, chloritized clinopyroxene, and opaques. Amygdules filled with chlorite and zeolites.		
						79-34F	Volcaniclastic sandstone, very hard, massive, medium-gray, medium- to very coarse grained, moderately well sorted. Mainly basaltic rock fragments and subordinate bioclastic detritus in a calcareous matrix	foraminifers and bioclastic detritus including large foraminifers (Amphistogina?)	
						79-34A	Pebbly mudstone, crumbly, massive, medium-dark-gray, waxy, with angular to subangular volcanic clasts to 6 cm in maximum size.	Middle Eocene (upper Ulatisian) foraminifers including Amphistogina Eocene palynomorphs	
22	79-35	1300-560	58°42.70' 58°44.37'	140°56.50' 140°54.92'	75	79-35B	Amygdaloidal basalt, hard, medium-bluish-gray, fine-grained amygdaloidal intersertal texture. Groundmass of altered plagioclase, orthopyroxene, olivine, and opaques in devitrified glass matrix. Amygdules filled with radial smectite and zeolites.		
						79-35A	Basaltic lapilli tuff, hard, massive, grayish-blue, palagonitized basaltic lapilli to 5½ cm maximum size in matrix of smectite, nontronite, calcite, and opaques.		
						79-35C	Silty shale, moderately indurated, massive, brownish-gray, abundant kerogen.		
						79-35D, 35E	Siltstone, moderately indurated, massive, brownish-gray, abundant microfossils and kerogen, in part calcareous.	Middle to late Eocene palynomorphs	

Table 1.--Location and description of dredged pre-Quaternary outcrop or probable outcrop samples (Continued)

Map No.	Dredge No.	Location: Depth	Location: Latitude	Location: Longitude	Estimated Recovery (kg)	Sample Designation	Lithology	Fossils	Comments
23	79-36	930-390	58°44.14' 58°46.11'	140°58.77' 140°55.24'	475	79-36A, 36B, 36C, 36D	Organic-rich shale, slightly to moderately indurated. Laminated to massive, dusky-yellowish-brown, abundant microfossils and kerogen, mica and fish scales commonly on bedding planes, one large piece of carbonized wood 15 cm long, in part calcareous (concretions?), in part with beds to 1 cm thick of fine-grained, greenish-gray volcaniclastic, highly fossiliferous sandstone.	Middle or late Eocene nannofossils Late Eocene (upper Narizian) foraminifers including Amphistegina and Discocyclina Eocene, (late Eocene?) palynomorphs Siliceous sponge remains	
						79-36E	Volcaniclastic sandstone, hard, massive, mottled grayish-blue, medium- to very coarse-grained (2 cm), mainly basaltic rock fragments and minerals, abundant megafossil fragments and large foraminifers, calcareous matrix.	Amphistegina sp. and Discocyclina sp.	
						79-36G	Basaltic lapilli tuff, hard, grayish-purple angular lapilli to 4 cm in green altered tuff matrix.		
24	79-26	2300-1500	58°40.70' 58°41.06'	140°55.98' 140°52.07'	170	79-26C, 26I, 26F, 26G, 26K, 26L	Amygdaloidal basalt, hard, massive, gray-black, brown, medium-dark-gray, and olive-gray, very fine grained intersertal porphyritic texture. Phenocrysts to 0.7 mm include fresh clinopyroxene and fresh to altered plagioclase; groundmass is clinopyroxene, plagioclase, and opaques with interstitial palagonite or chlorophaeite; amygdules of zeolite and chlorite.		Some basalt blocks are sheared and fractured. Minimum age 38.9±2.8 m.y. based on basalt whole rock K/Ar date
						79-26I	Amygdaloidal olivine basalt, hard, massive, medium-dark-gray, fine-grained, intersertal porphyritic texture. Phenocrysts (to 5 mm) plagioclase partly altered to zeolites and clay, clinopyroxene, and olivine altered to chlorite? and iddingsite. Groundmass is partly altered plagioclase and pyroxene, iron ore and interstitial chlorophaeite after palagonite. Approximately 25% zeolite, chlorite, and clay-filled amygdules.		
						79-26A, 26B	Bioclastic sandstone, very hard, white or weathered moderate red, angular to rounded calcareous clasts to 14 mm in medium-dark-gray or greenish-gray, fine- to medium-grained matrix of calcite-cemented bioclastic material and basaltic detritus. Bioclastic detritus consists mainly of calcareous algae, coral, bryozoans, large foraminifers, and shell fragments	Foraminifers, including Eocene Amphistegina sp. and Discocyclina sp.	
						79-26J	Bioclastic volcaniclastic sandstone, very hard, massive, fine- to medium-grained, angular to rounded reef detritus, foraminifers, and mafic volcanic rock and mineral fragments in calcite matrix. Rare silt-size quartz grains.		
25	77-8	2750-2350	58°35.61' 58°36.32'	140°38.40' 140°38.77'	2	77-8	Spilitized tholeiitic basalt, hard, dark-green, calcite-veined, very fine grained intersertal porphyritic amygdaloidal texture. Zoned andesine phenocrysts (to 1.5 mm) in groundmass of labradorite laths, opaques, and dark devitrified glass. Chlorite occurs as replacements of femic minerals, veinlets, and vesicle fillings, abundant carbonate as veins, patches in groundmass, and vesicle fillings. Some secondary opaline? silica.		Slickensided fractures
26	77-9	2125-1700	58°37.61' 58°38.87'	140°38.92' 140°38.59'	3	77-9	Amygdaloidal spilitized basalt, hard, dark-green, strongly vesiculated and possibly brecciated, thoroughly altered. Very fine intergranular texture with abundant zeolite and chlorite-filled amygdules.		Sheared
27	77-11	890-500	58°39.16' 58°39.69'	140°36.89' 140°36.03'	25	77-11A, 11B	Siltstone, moderately well indurated, slabby, light-olive-gray to dark-gray, abundant kerogen, moderately abundant microfossils, sparse pyrite, carbonaceous plant remains, and glauconite, in part sandy.	Eocene or Oligocene nannofossils Late Eocene (Refugian) foraminifers Eocene palynomorphs	
						77-11C	Sandstone, feldspatholithic, moderately well indurated, slabby, gray, medium-grained, angular to subrounded, well sorted, 23% carbonate matrix.		
28	77-10	1875-1400	58°37.39' 58°38.11'	140°35.71' 140°35.29'	75	77-10A, 10B	Siltstone, soft to moderately indurated, slabby, gray, greenish-gray, or dark-gray, waxy, minor pyrite and glauconite?.	Late Eocene to Oligocene foraminifers Eocene palynomorphs	
						77-10C	Sandstone, feldspatholithic, friable, blocky, gray, fine- to medium-grained, angular to subrounded, pervasive siliceous cement and trace of calcite cement. Moderate secondary porosity.		

Table 1.--Location and description of dredged pre-Quaternary outcrop or probable outcrop samples (Continued)

Map No.	Dredge No.	Location: Depth	Location: Latitude	Location: Longitude	Estimated Recovery (kg)	Sample Designation	Lithology	Fossils	Comments
29	79-24	1340-480	58°35.70' 58°38.33'	140°21.66' 140°20.47'	100	79-24A, 24B, 24C, 24D	Shale, slightly indurated, finely laminated, dusky-brown, abundant microfossils, kerogen, and mica, in part calcareous and moderately indurated, rare fine-grained sandstone laminae.	Late to late middle? Eocene nannoplankton Late Eocene (Narizian?) foraminifers Middle to late Eocene palynomorphs	
						79-24E	Sandstone, feldspatholithic, very hard, massive, light-gray, medium-grained, clean, calcareous cement, abundant carbonaceous plant fragments and mica.		
30	77-17	1025-925	58°32.62' 58°33.02'	140°06.66' 140°06.49'	75	77-17B, 17C, 17D, 17E	Shale, soft to moderately hard, laminated to massive, grayish-orange, brownish-gray, and medium-gray, waxy, abundant microfossils, kerogen, mica, carbonaceous plant fragments, in part silty and interbedded with laminae of medium-gray siltstone or fine-grained highly micaceous sandstone.	Late Eocene or Oligocene (Refugian or Zemorrian) foraminifers Eocene palynomorphs Eocene? diatoms and silicoflagellates	
						77-17A	Sandstone, lithofeldspathic, moderately hard, friable, light-gray, medium-grained, subangular to subrounded, highly micaceous, siliceous cement, secondary porosity.		
31	77-18	510-250	58°34.72' 58°35.92'	140°05.46' 140°04.67'	275	77-18A, 18B	Silty shale, soft to moderately indurated, blocky, laminated in part, tan to light-gray and yellowish-gray, abundant siliceous microfossils and mica, sparse pyritic micronodules and glauconite.	Eocene palynomorphs Late Oligocene diatoms and silicoflagellates	Abundant slickensides and iron-oxide-coated fractures
32	79-20	2040-650	58°16.48' 58°19.24'	139°32.42' 139°28.37'	400	79-20B, 20D, 20E, 20I	Shale, slightly to moderately indurated, massive, medium-dark-gray, locally abundant microfossils, mica, carbonaceous plant material, and fish scales, in part with very hard, light-gray calcareous concretions.	Early? Eocene nannoplankton Early to middle? Eocene (upper Penutian to lower? Ulatisian) foraminifers Eocene, possibly early Eocene palynomorphs	Abundant slickensides
						79-20H	Sandstone, volcaniclastic and bioclastic, very hard, medium-gray, fine- to coarse-grained, angular to subrounded; clasts are predominantly basaltic volcanic rock and mineral fragments with subordinate quartz, potash feldspar, chert, and other nonvolcanic detritus, and minor shelly material, calcareous cement.	Abundant Amphistegina	
						79-20F, 20G	Sandstone and siltstone, hard, bedded, fissile, medium-dark-gray, fine- to medium-grained, feldspatholithic sandstone alternating with dark-gray to black, inch- to millimeter-scale laminae of carbonaceous and micaceous siltstone.		
						79-20A, 20C	Claystone, slightly indurated, massive, low density, yellowish-gray, abundant siliceous microfossils, very fine grained mica, carbonaceous plant fragments.	Late Oligocene to Recent diatoms	
33	79-21	735-300	58°19.00' 58°20.16'	139°28.80' 139°27.10'	300	79-21A	Sandstone, feldspatholithic, hard, friable, massive, medium-grained, angular to subrounded, abundant basaltic detritus.		Some blocks are slickensided
						79-21B, 21C, 21D, 21E, 21F	Shale, slightly to moderately indurated, medium-dark-gray to dark-gray, coarse microfossils, disseminated carbonaceous plant material, some small trails, or burrows; in part very hard and calcareous (concretions?).	Late to late middle? Eocene nannofossils Late Eocene (Narizian) foraminifers Middle to late Eocene palynomorphs	
34	79-17	2480-710	58°09.62' 58°13.10'	139°06.91' 139°05.73'	1	79-17B	Amygdaloidal basalt, hard, massive, greenish-black, medium-grained intersertal with roughly 50% amygdules; groundmass is altered plagioclase, fresh augite, minor orthopyroxene, and opaques in a brown palagonite matrix; amygdules filled with zeolite and brown clay.		
35	79-18	1220-930	58°11.27' 58°11.94'	139°05.10' 139°04.10'	170	79-18C, 18E, 18F	Amygdaloidal basalt, hard, massive, medium-dark-gray to dark-gray, fine- to medium-grained hyalo-ophitic amygdaloidal texture; altered plagioclase laths, fresh clinopyroxene, rare orthopyroxene, and opaques in palagonitized glass or chlorophaeite matrix. Amygdules filled with zeolite, chlorite, and minor clay.		All basalt except for two chunks of sedimentary rock Probably early Eocene on basis of 50.7-5.2 m.y. basalt K/Ar age
						79-18D	Basalt, hard, massive, medium-grained, subophitic texture. Fresh plagioclase, clinopyroxene and opaques in altered glass matrix.		
						79-18A	Shale, moderately indurated, homogeneous, medium-dark-gray	Tertiary palynomorphs	
						79-18B	Siltstone, slightly indurated, deeply weathered to moderate-yellow-brown, medium-gray, abundant finely divided mica.		May be late Cenozoic

Table 1.--Location and description of dredged pre-Quaternary outcrop or probable outcrop samples (Continued)

Map No.	Dredge No.	Location			Estimated Recovery (kg)	Sample Designation	Lithology	Fossils	Comments
		Depth	Latitude	Longitude					
36	79-19	780-320	58°11.56' 58°13.24'	139°04.09' 139°02.40'	125	79-19A, 19B, 19C	Siltstone, crumbly to moderately indurated, massive, medium-dark-gray, highly micaceous, sparse fish scales and small megafossils	Eocene palynomorphs	
37	77-3	1250-750	58°00.62' 58°00.92'	138°28.04' 138°27.40'	250	77-3A	Feldspatholithic sandstone, volcaniclastic, very hard, blocky, greenish-gray, in part pebbly.		
						77-3B	Argillite, hard, grayish-black.		
38	77-2	2090-1500	57°58.99' 57°59.59'	138°28.76' 138°26.88'	290	77-2A	Siltstone, slightly indurated, dark-gray, sandy with floating pebbles.	Quaternary? nannofossils Pleistocene or Holocene foraminifers	
						77-2B	Siltstone, hard, light-gray, calcareous minor glauconite	Early Pliocene diatoms Tertiary palynomorphs	
39	78-14	510-340	57°54.31' 57°54.57'	138°02.45' 138°01.23'	50	78-14B, 14C	Sandstone, lithic wacke, hard, slabby, medium-gray, medium-grained, angular to subangular, poorly sorted, micaceous, in part with calcite cement.		Sandstone intensely sheared
						78-14A	Siltstone, soft, weathered light-brown, waxy, abundant biotite, diatomaceous.	Late Pliocene to Holocene with reworked Miocene diatoms	
40	77-6	157-150	58°11.55' 58°12.15'	138°23.44' 138°23.12'	30	77-6A	Metasandstone, lithofeldspathic, hard, gray to greenish-gray, fine- to medium-grained, angular to subangular, poorly sorted, laumontite in patches and veinlets.	None	Rocks intensely sheared

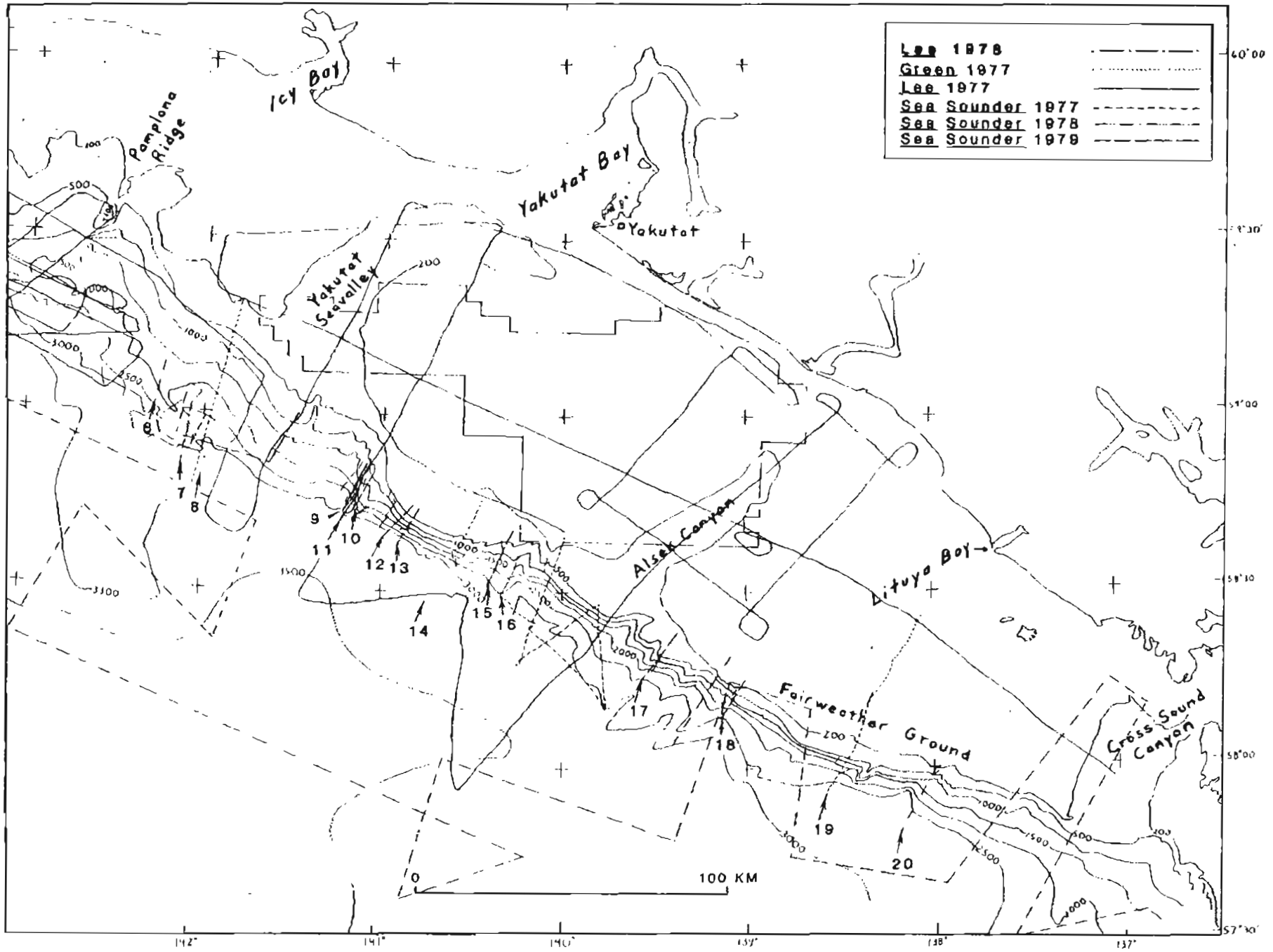


Figure 5.--Map showing U.S. Geological Survey multichannel seismic lines for the Yakutat shelf and multichannel and single channel lines for the slope and adjacent areas. The 1977 Green and 1977 and 1978 Lee lines are multichannel; Sea Sounder lines are single-channel sparker. Numbers refer to profiles across the continental slope shown in figures 6 through 20.

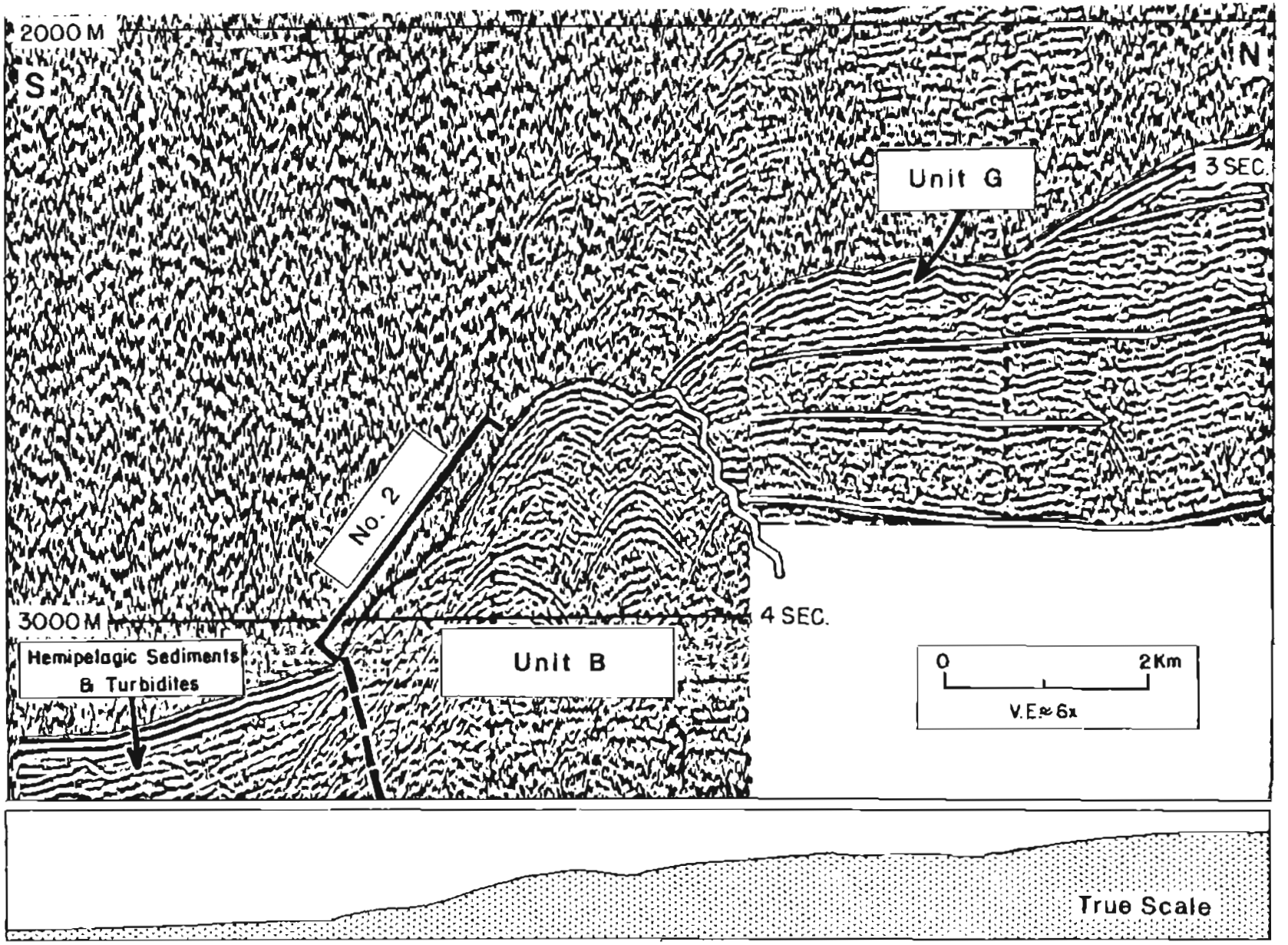


Figure 6.--Sparker seismic line and true scale bathymetry across the continental slope near dredge locality 2. Subhorizontal Yakataga Formation (Unit G) overlaps a ridge of probable late Paleocene to early Eocene rocks delineated by hyperbolic reflectors (Unit B). The heavy black line shows the approximate location of the Transition fault zone and the uniform reflectors seaward of this zone are from late Cenozoic deep-sea deposits (Unit H). Dredge locality 2 lies north of the seismic line where the ridge is lower and sampled only Unit G.

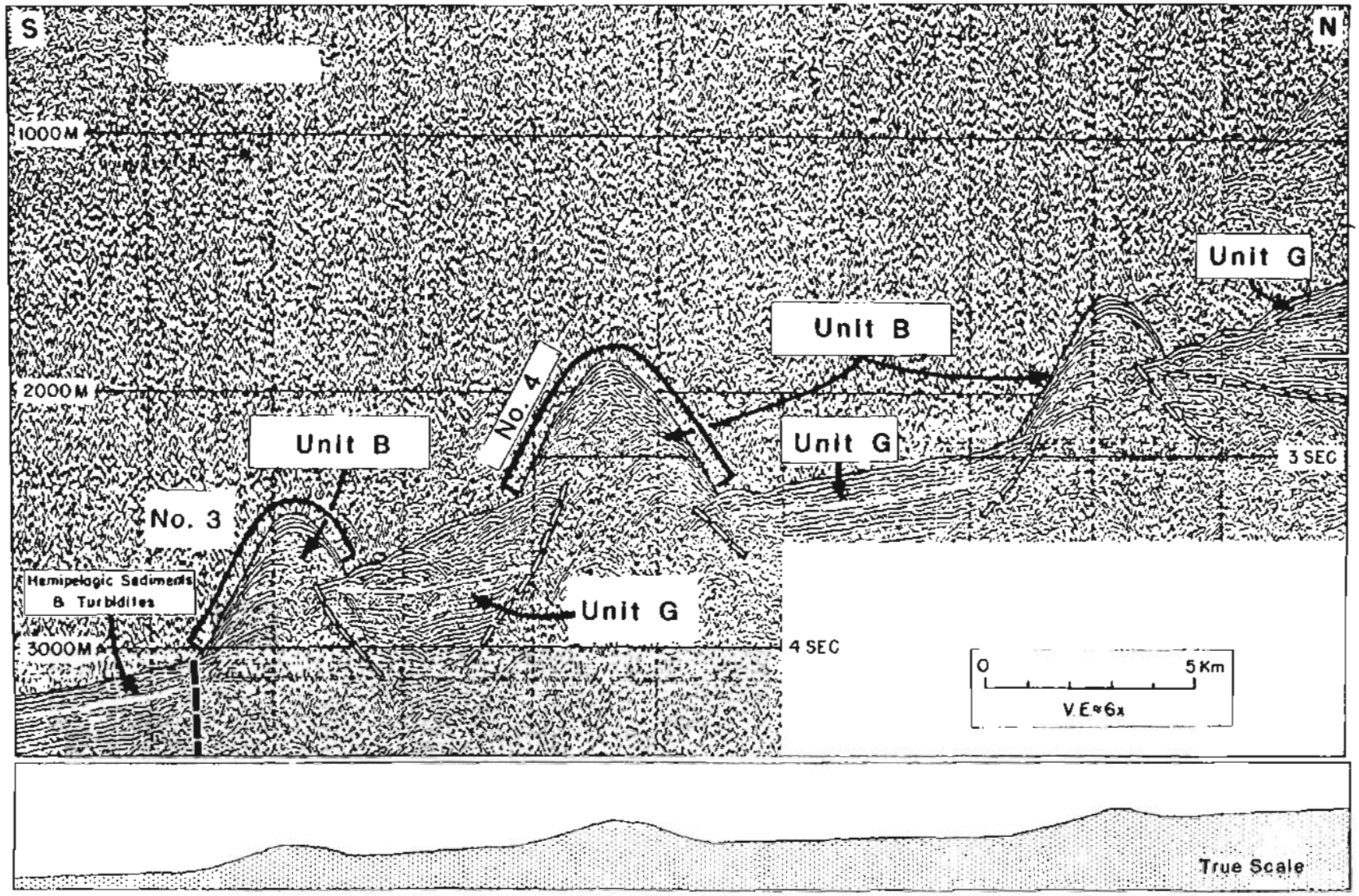


Figure 7.--Sparker seismic line and true scale bathymetry across the continental slope near dredge localities 3 and 4. Ridges of Paleogene rocks (Unit B) are partially buried by Yakataga Formation (Unit G).

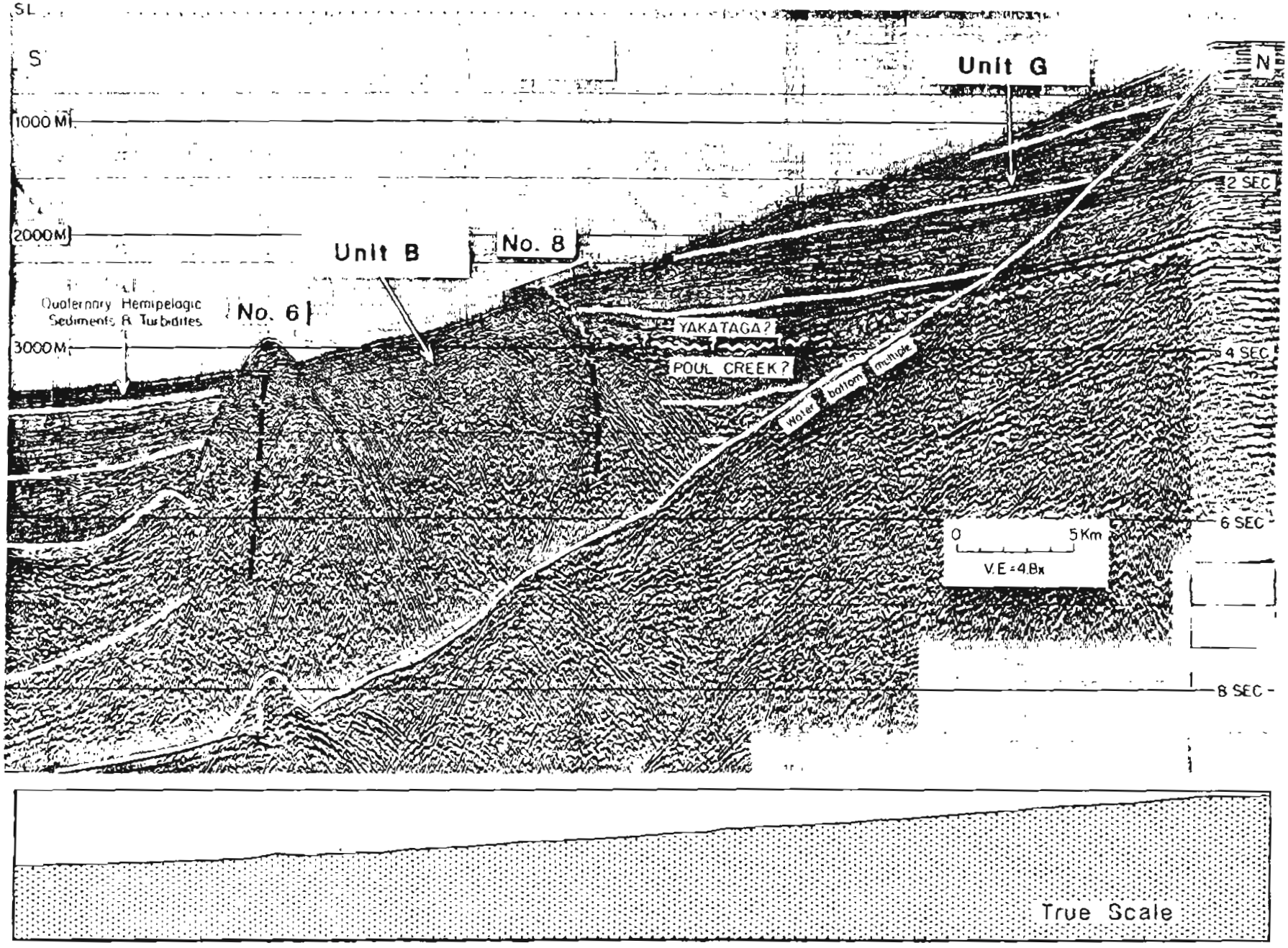


Figure 8.--Multichannel seismic line across the continental slope near dredge localities 6 and 8. The unconformity within the sequence of coherent reflectors separates strata inferred to be correlatives of the Yakataga Formation (Unit G) from the Poul Creek Formation (Unit F).

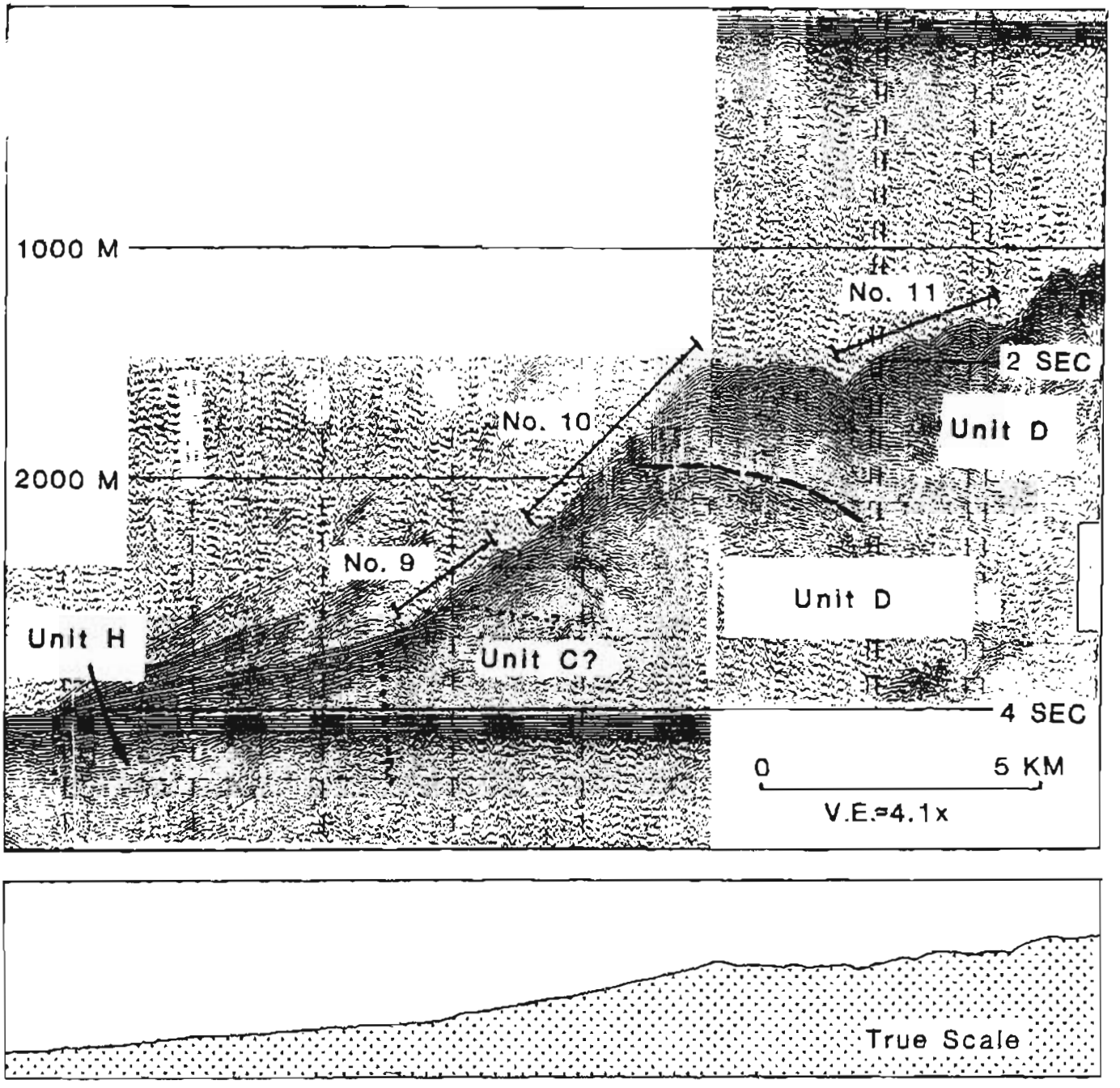


Figure 9.--Sparker seismic line and true scale bathymetry across the continental slope near dredge localities 9-11.

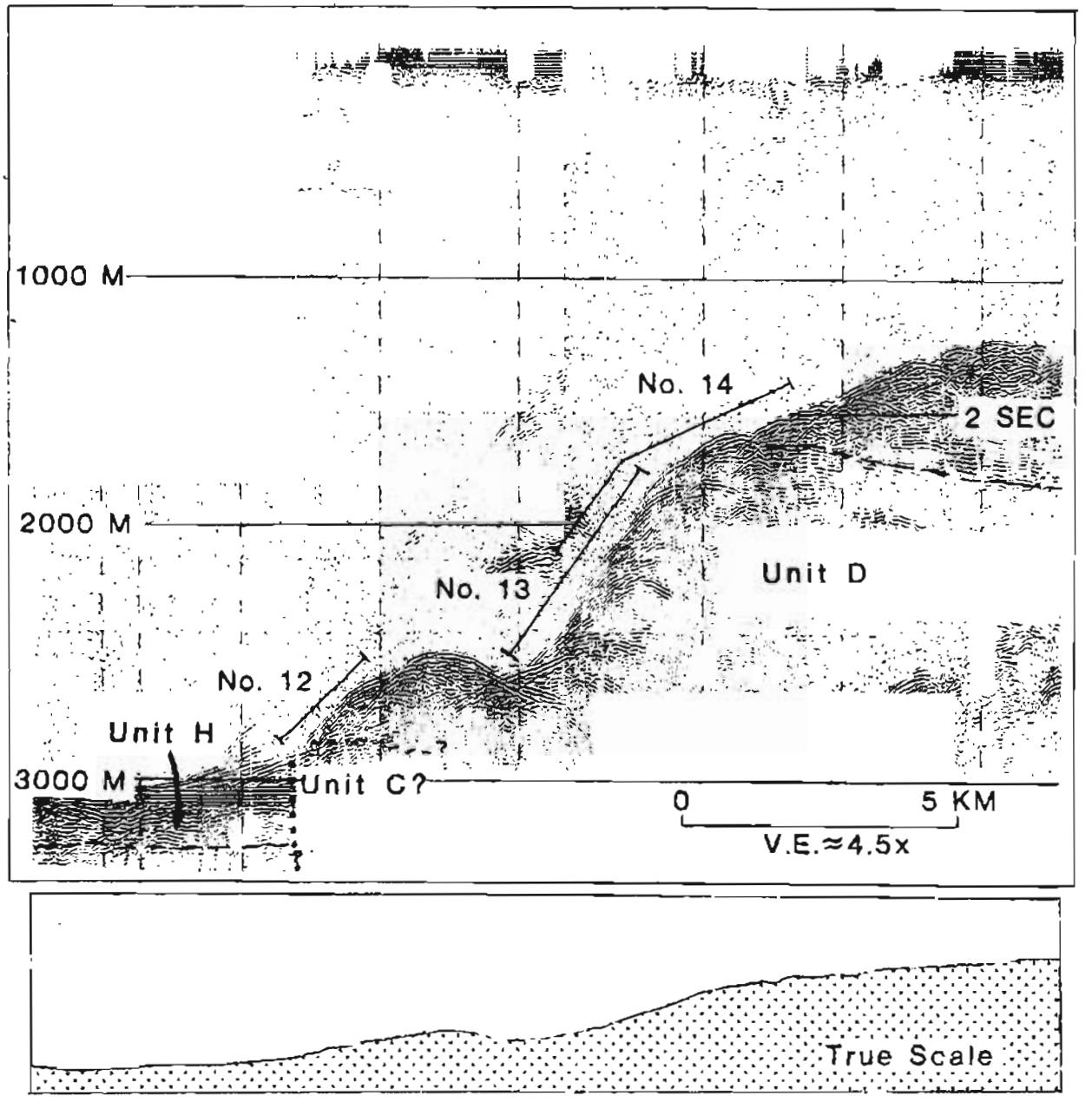


Figure 10.--Sparker seismic line and true scale bathymetry across the continental slope near dredge localities 12-14.

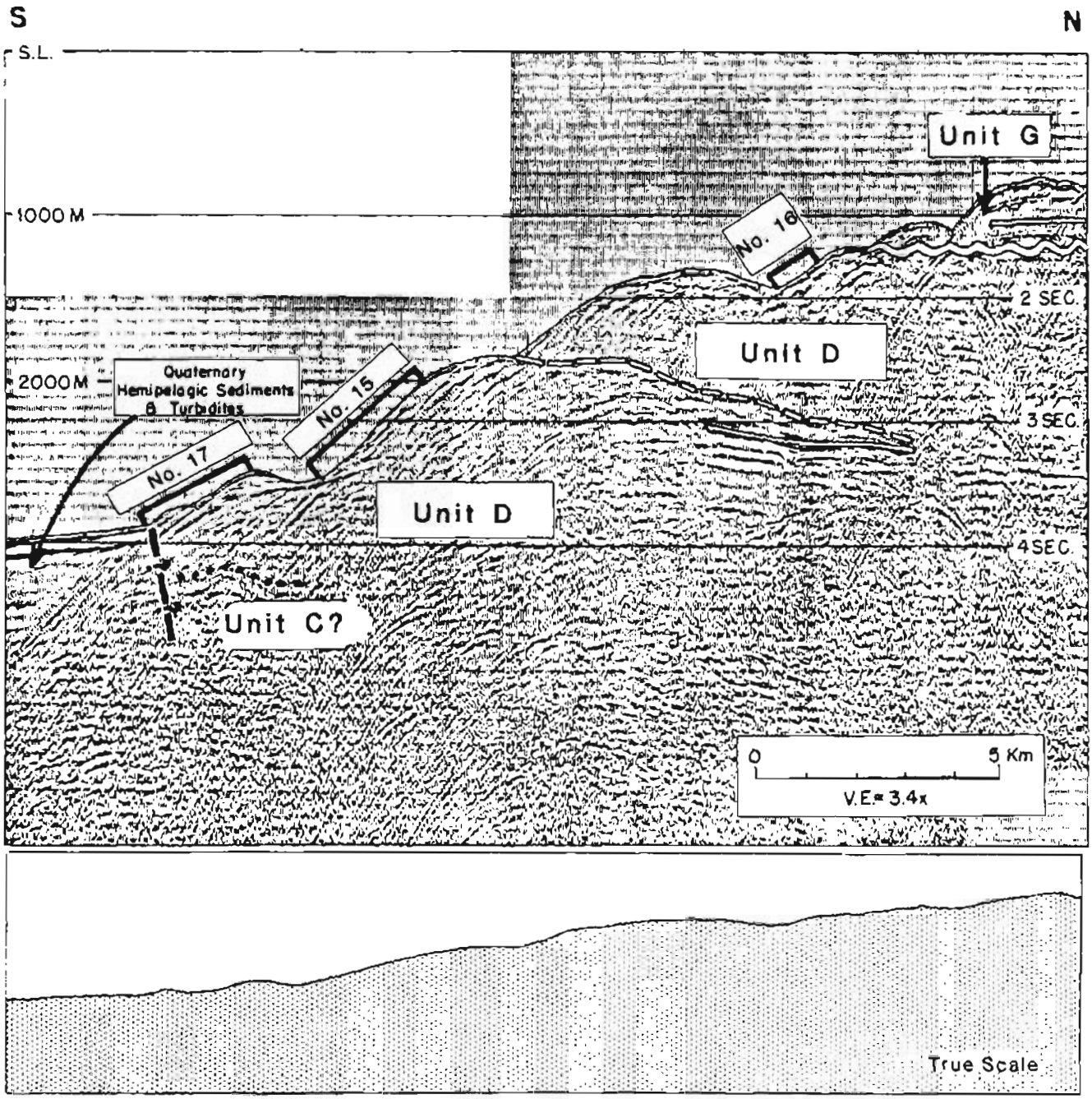


Figure 11.--Multichannel seismic line and true scale profile across the continental slope near dredge localities 15-17.

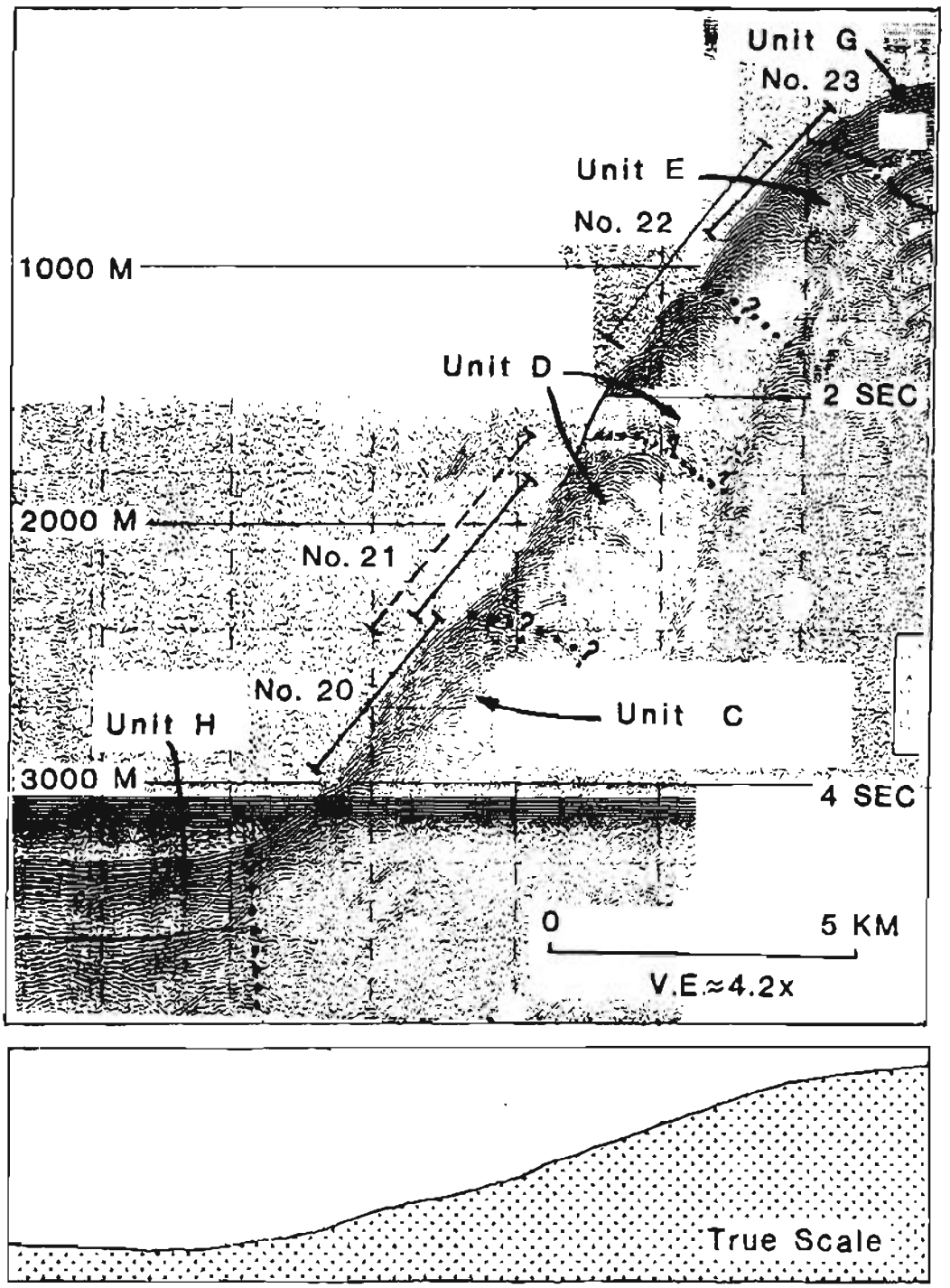


Figure 12.--Sparker seismic line and true scale bathymetry across the continental slope near dredge localities 20-23. Dashed line indicates dredge cast with no bedrock recovery.

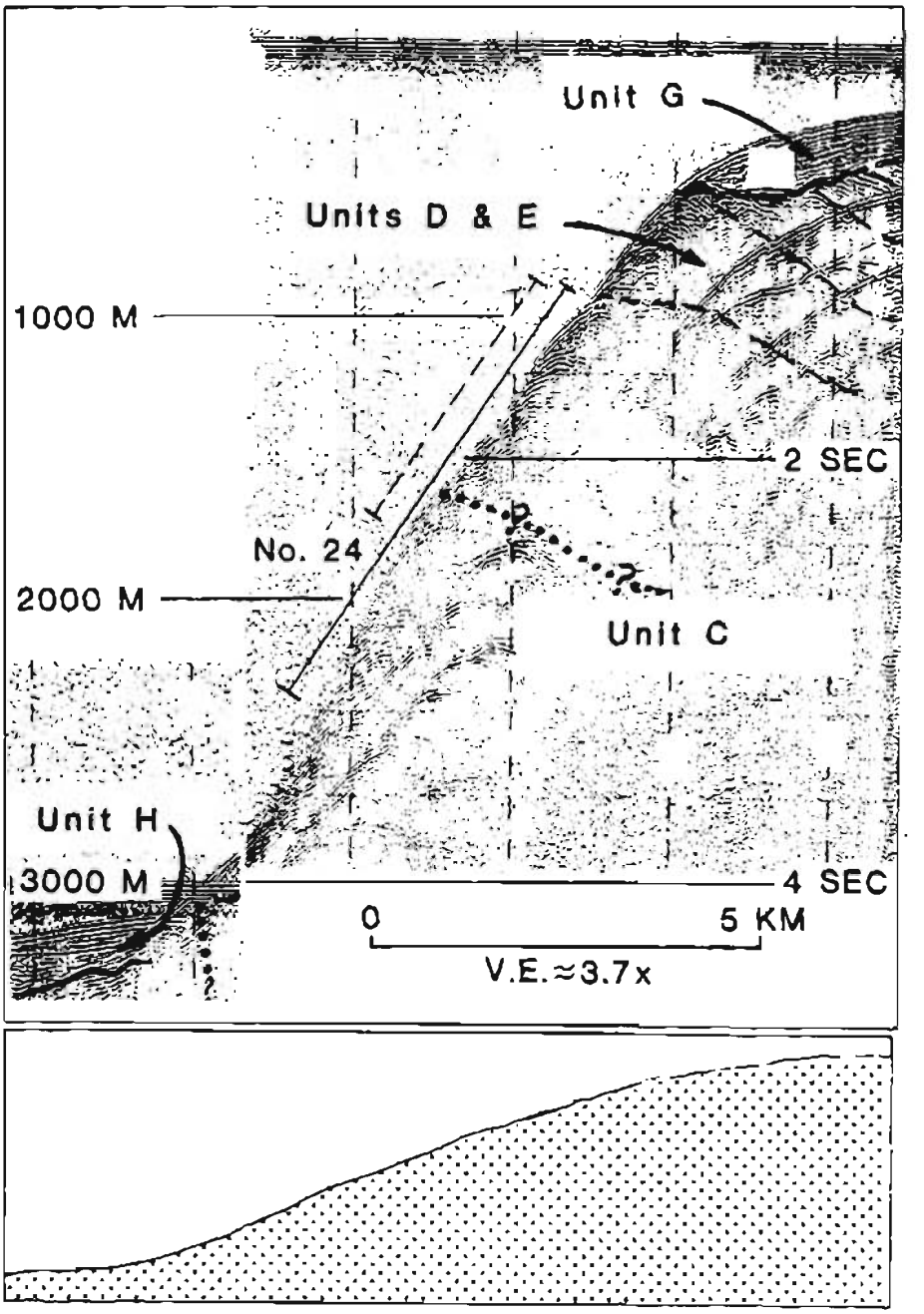


Figure 13.--Sparker seismic line and true scale bathymetry across the continental slope near dredge locality 24. Dashed line indicates dredge cast with no bedrock recovery.

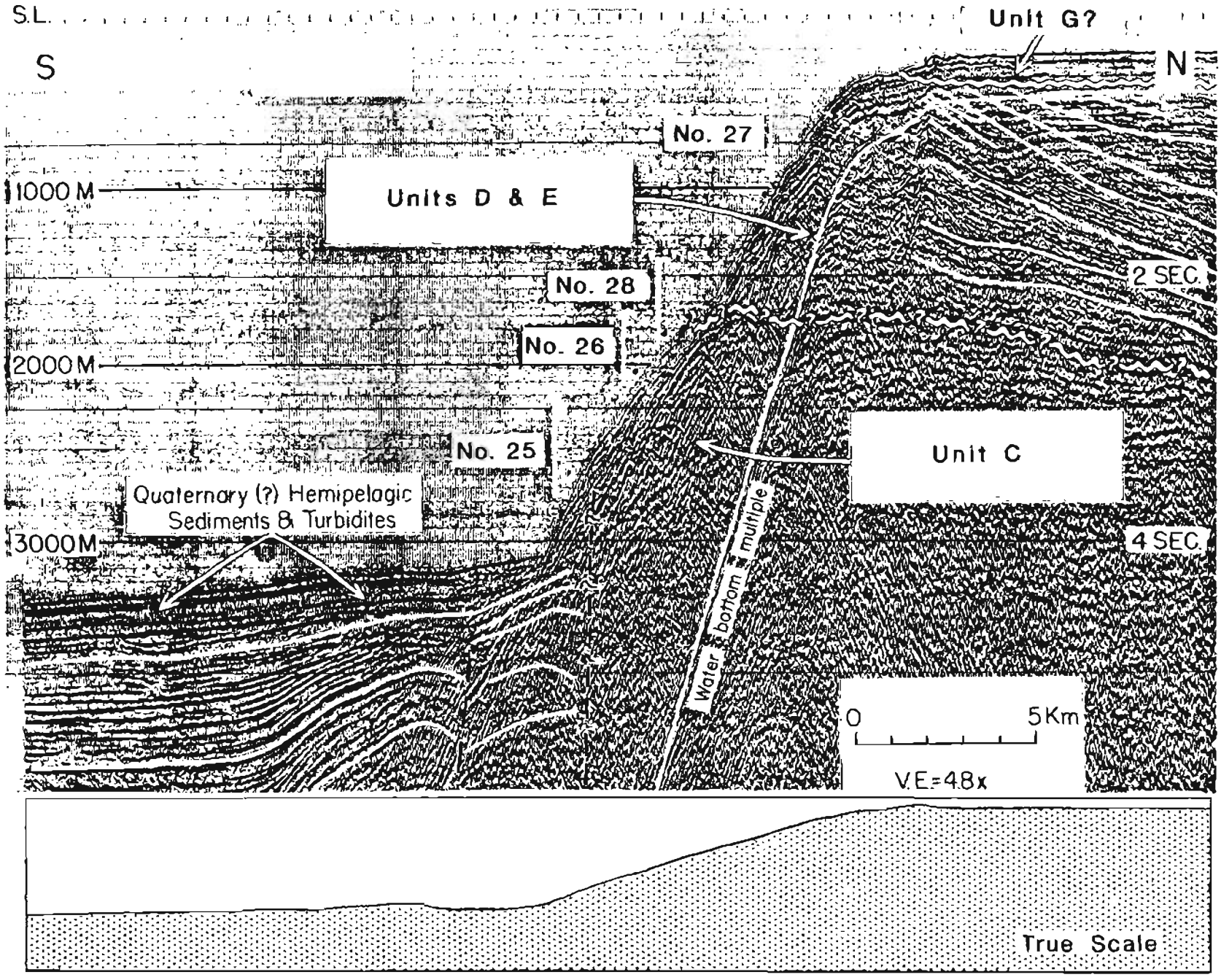


Figure 14.--Multichannel seismic line and true scale bathymetry across the continental slope near dredge localities 25-28.

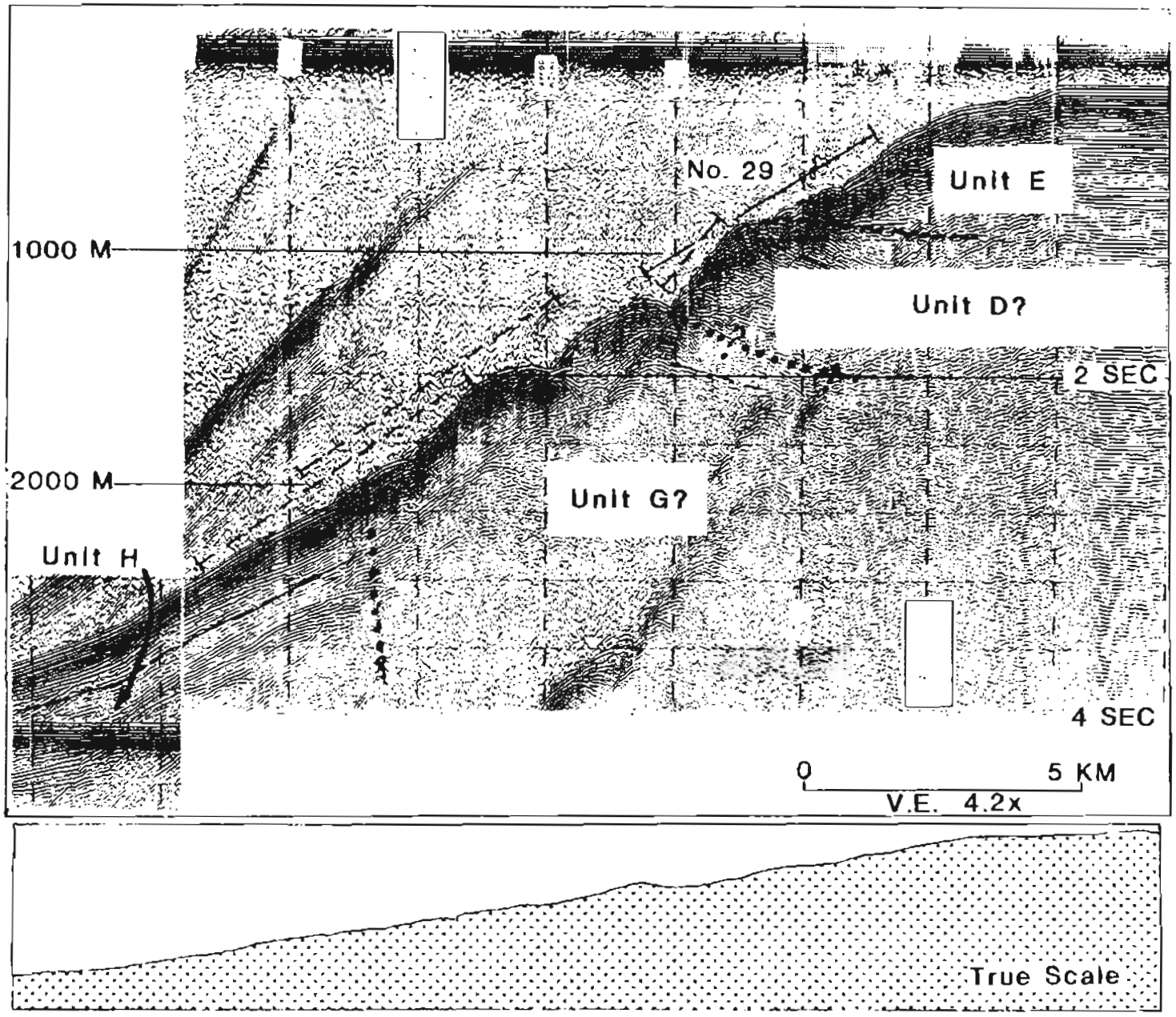


Figure 15.--Sparker seismic line and true scale bathymetry across the continental slope near dredge locality 29. Dashed lines indicate dredge casts with no bedrock recovery.

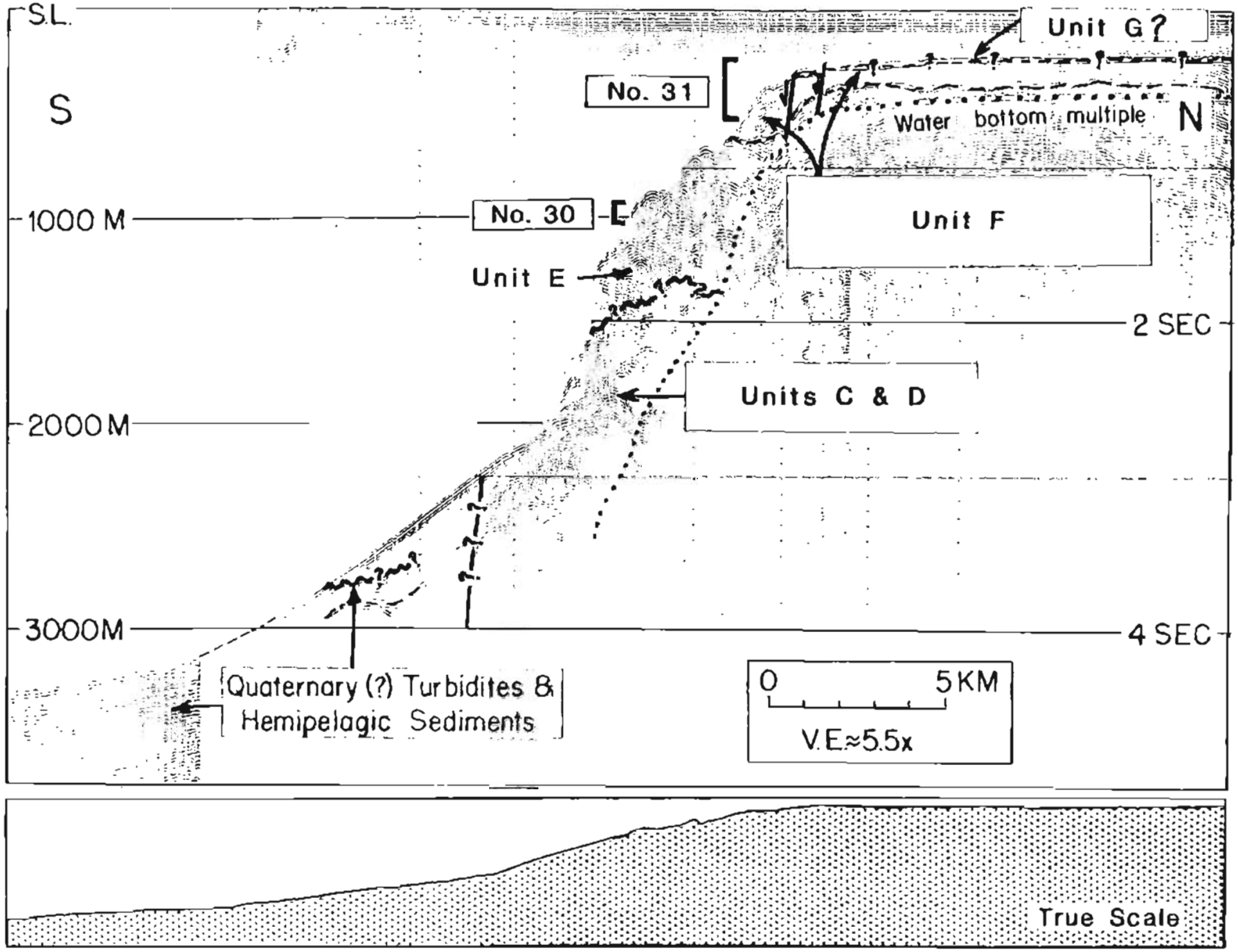


Figure 16.--Sparker seismic line and true scale bathymetry across the continental slope near dredge localities 30 and 31.

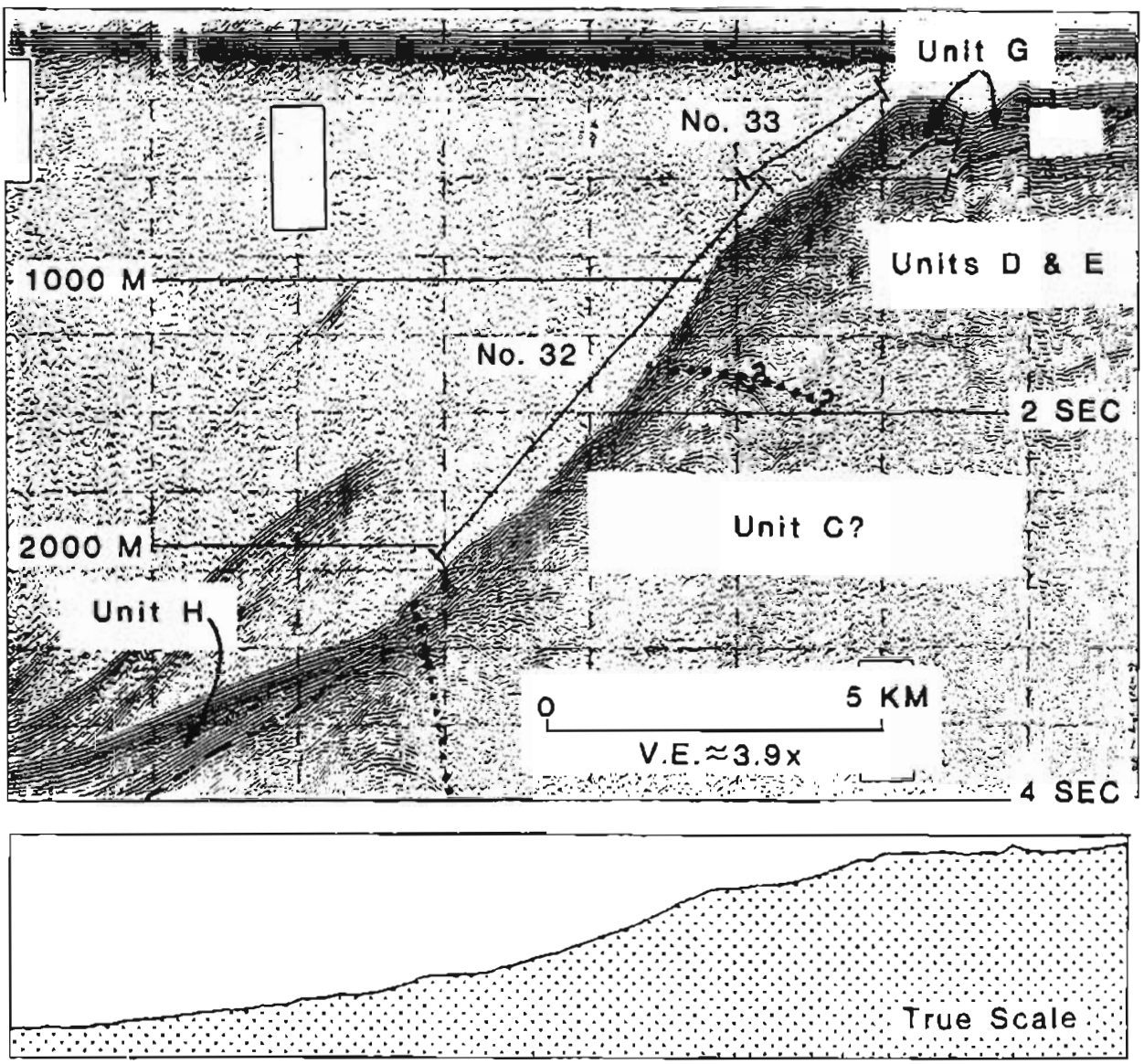


Figure 17.--Sparker seismic line and true scale bathymetry across the continental slope near dredge localities 32 and 33.

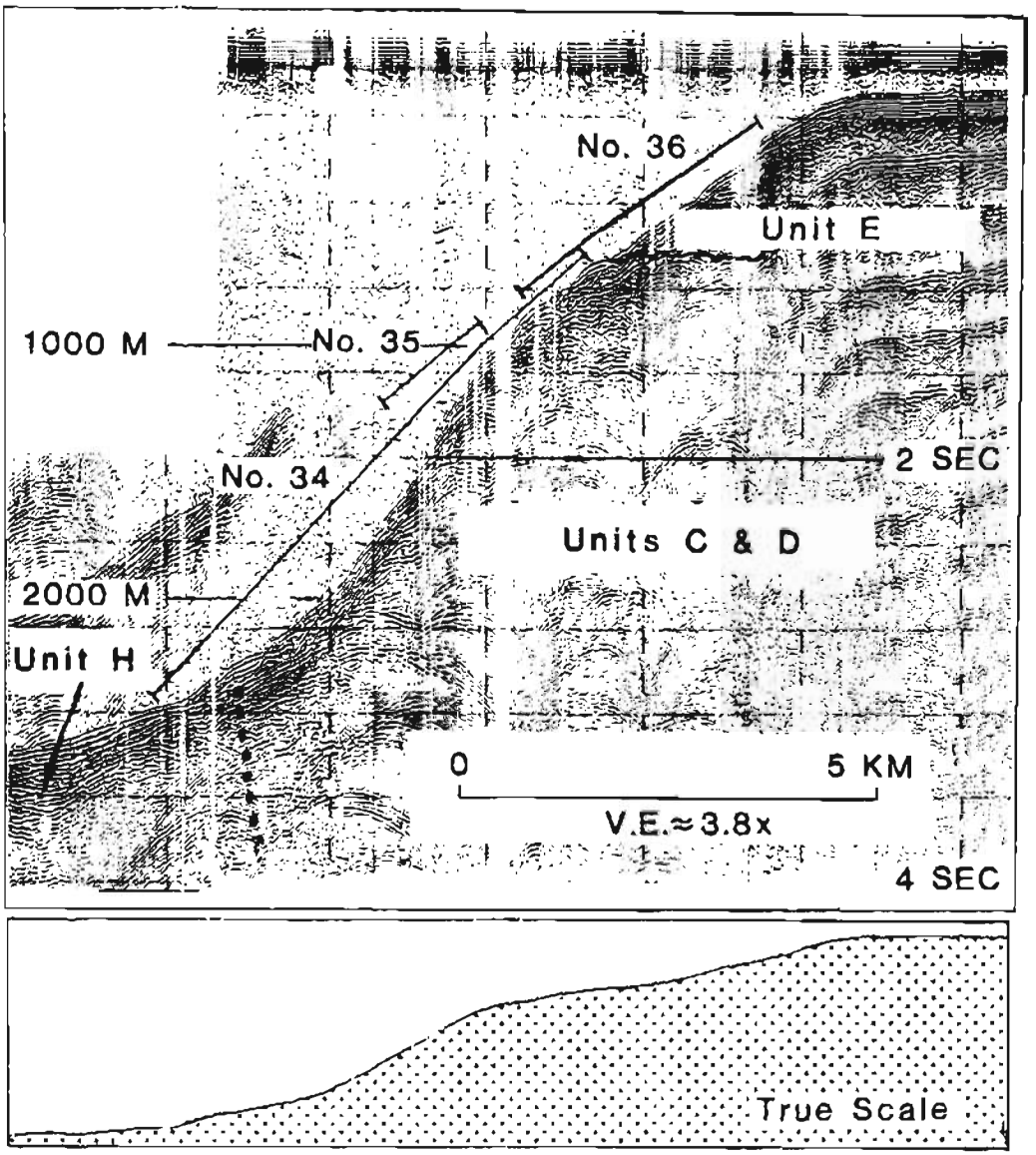


Figure 18. Sparker seismic line and true scale bathymetry across the continental slope near dredge localities 34-36.

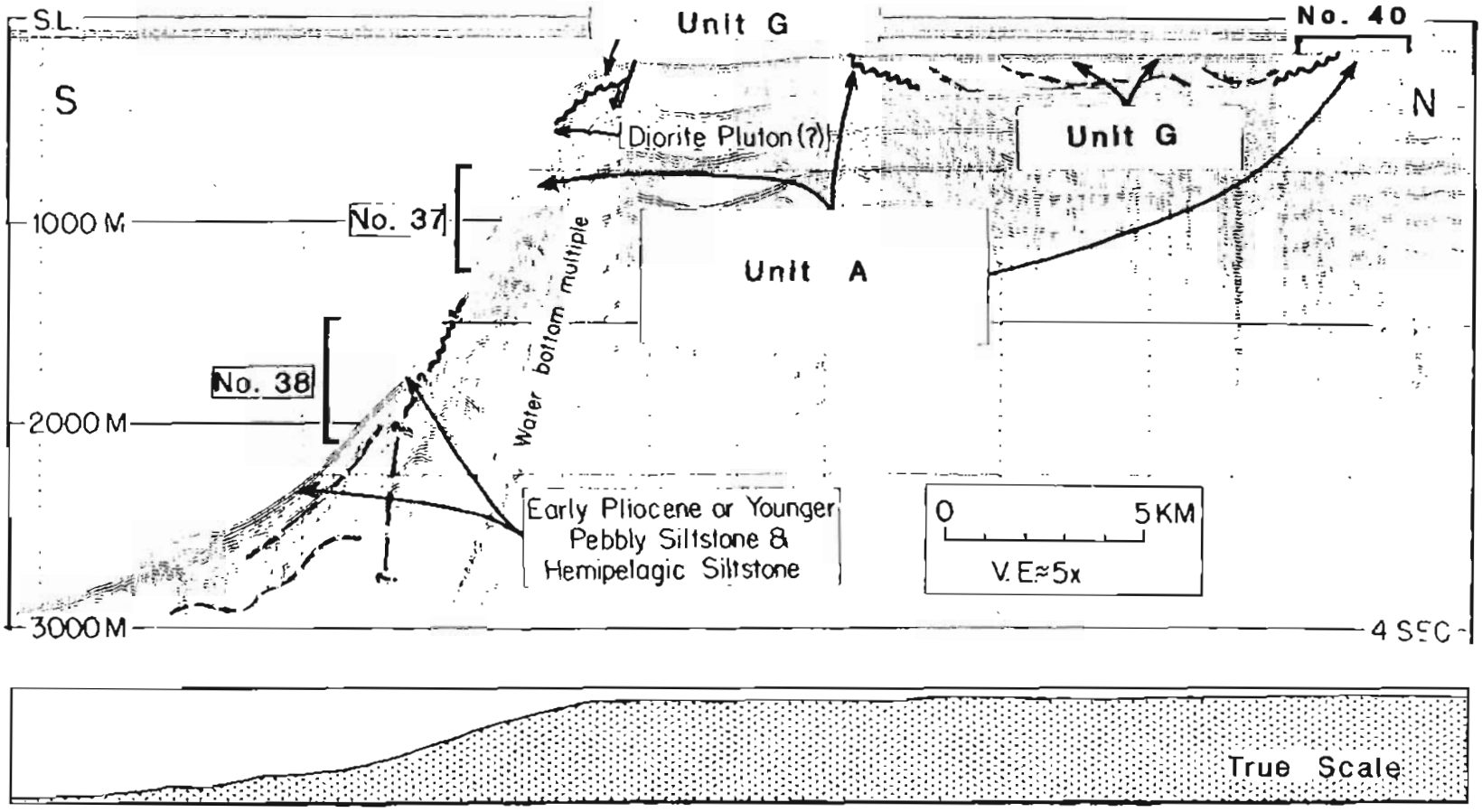


Figure 19.--Sparker seismic line and true scale bathymetry across the continental slope and Fairweather Ground near dredge localities 37, 38, and 40. The inferred diorite intrusive is based on a single angular piece of diorite recovered in dredge 37. The fragment could be an erratic.

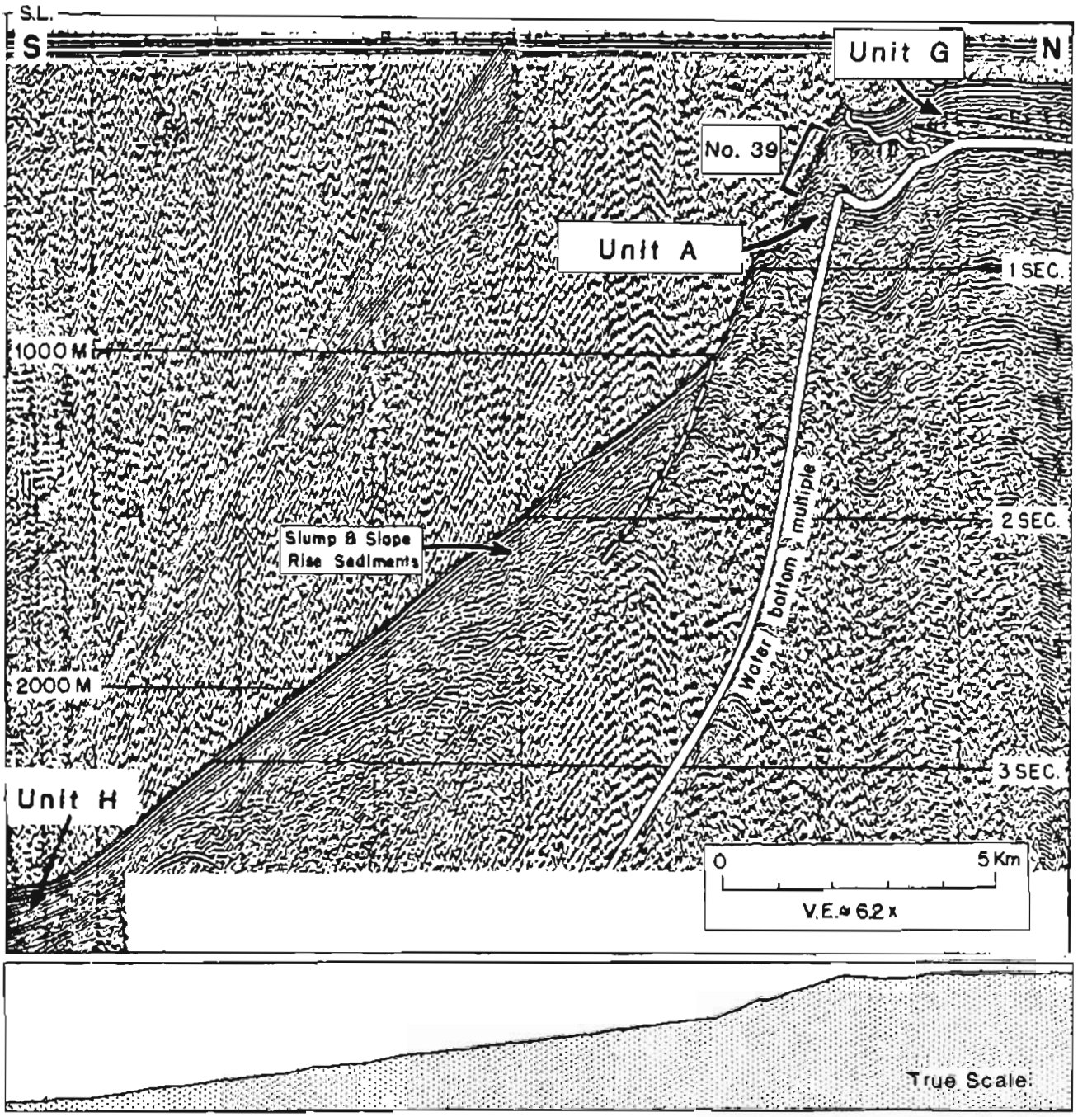


Figure 20.--Sparker seismic line and true scale bathymetry across the continental slope near dredge locality 39.

Unit E) Approximately 800 m of clastic sedimentary rocks of early Eocene (Penutian stage) to early Oligocene(?) (Refugian stage) age.

Unit F) 300+ m of clastic sedimentary rocks at least in part of late Oligocene (Zemorrian stage) age.

Unit G) The Yakataga Formation, a sequence of clastic sedimentary rocks including much glacially-derived detritus of Miocene through Pleistocene age that is as much as 2,000 m thick on the continental slope.

The units delineated on the continental slope are entirely marine. Considerable intertonguing may occur between Units B, C, and D of late Paleocene(?) through early Oligocene(?) age. They are unconformably overlain by Units E and F.

Oceanic crust near the base of the slope is overlain by hemipelagic sediments and turbidites to 6 km thick (figs. 7 and 13; Bruns, 1979; von Huene and others, 1979a, 1979b) and deep-sea deposits locally lap up onto the continental margin as a slope rise prism (fig. 19). The deep-sea sediments are mainly of Quaternary age at the surface although probable early Pliocene deposits were sampled at one locality on the slope rise prism (38). This thick ensimatic sedimentary sequence is inferred to be in part of pre-Pliocene age based on correlations made with seismic reflection data (von Huene and others, 1979a, 1979b). Unconsolidated deposits, presumably largely of Quaternary age, fill the broad Yakutat Seavalley, Alsek Canyon, and Cross Sound Canyon, and occur as relatively thin deposits elsewhere on the shelf and slope. As the deep-sea and Quaternary deposits have no direct relevance to the petroleum potential of the area, they are not discussed further in this report.

Unit A: Pre-Tertiary rocks.

Mildly metamorphosed (zeolite facies) metasandstone and argillite have been dredged from the continental slope between Alsek Canyon and Cross Sound Canyon (37 and 39) and from the Fairweather Ground topographic high on the adjacent continental shelf (40). Greenstone reported from dredge locality 40 (Plafker and others, 1978c) was determined to be greenschist in thin section and is now believed to be an erratic. These rocks are unfossiliferous but are lithologically most similar to the sedimentary part of the Late Cretaceous Yakutat Group on the adjacent mainland (Plafker and others, 1978a). These pre-Tertiary rocks are considered to be economic basement for petroleum in the Yakutat block.

A broad magnetic high roughly coincides with the Fairweather Ground outcrop area and extends northwestward to the vicinity of Alsek Canyon (Taylor and O'Neill, 1974). The anomaly, which is comparable in shape and amplitude to those related to early Tertiary granitic plutons on the adjacent mainland, suggests the presence of large intrusive bodies in the offshore pre-Tertiary basement terrane. If so, the anomalies define the minimum outcrop extent of pre-Tertiary rocks on the continental shelf.

Unit B: Eocene(?) and Paleocene(?) rocks west of Yakutat Seavalley.

Calcareous feldspatholitic sandstone and conglomerate interbedded with hard carbonaceous and organic-rich shale or siltstone have been dredged from three prominent linear ridges that lie along the lower slope west of Yakutat Seavalley (figs. 3-7). In addition, amygdaloidal basaltic flow and pyroclastic rocks and diabase dike(?) rocks were recovered with argillaceous rocks at dredge localities 4 and 6 (figs. 7 and 8). Total vertical extent of this unit is 900 m with the base not exposed.

The sedimentary rocks contain abundant carbonized plant fragments and some arenaceous foraminifers, but no age-diagnostic fossils were found. One basalt sample has a whole-rock K/Ar age of 55.2±7.1 m.y. (sample 78-22A5, table 2). Two other mafic rock samples with younger whole-rock ages of about 33 m.y. (samples 78-41K and 78-22A7, table 2) probably represent minimum ages for these rocks. If the older date approximates the true age of the rock, it would be close to the Eocene-Paleocene boundary in age. The radiometric data, together with the significantly greater thermal maturity of the shales in Unit B relative to those of definite early to middle Eocene age east of Yakutat Seavalley, are the rationale for inferring that Unit B is in part, or entirely, older than Unit C and is probably of late Paleocene to early Eocene age.

Rocks in this unit appear as acoustic basement on seismic reflection profiles so that the internal stratigraphy cannot be worked out. The age data and lithology suggest that Unit B is most probably correlative with the onshore Paleocene Orca Group, or the "unnamed siltstone" that lies below the Kulthieth Formation (Plafker, 1971). The "unnamed siltstone," however, is not known to contain either the coarse clastic rocks or basaltic rocks that have been dredged from Unit B.

Unit C: Eocene basaltic rocks.

Basaltic rocks were recovered at eight localities along the continental slope between 138°30' W. and 141°15' W. (fig. 4, table 1) and they are inferred from the seismic profiles to comprise much, if not all, of the lower part of this segment of the continental slope.

The basalt unit is at least in part of early Eocene age and could range into the middle Eocene based on microfossils in shale interbedded with the basalt or immediately overlying the unit. K/Ar whole-rock ages of four basalt

Table 2.--Potassium-argon age data for basaltic rocks

[Analysis by Geochron Laboratories Division, Krueger Enterprises, Inc. Constants used: $\lambda_\beta = 4.72 \times 10^{-10}\ yr^{-1}$, $\lambda_\epsilon = 0.585 \times 10^{-10}\ yr^{-1}$, $K^{40}/K = 1.22 \times 10^{-4}$ g/g]

Map No. (fig. 1)	Sample No. (table 1)	Analyzed material[1/]	K_2O (percent)	Ave. K_2O (percent)	Ave. $^{40}Ar_{rad}$ (ppm)	$^{40}Ar_{rad}/^{40}Ar_{total}$	Calculated age (m.y.)
2	78-41K	Slightly altered diabase cobble or outcrop	.362 .365	.363	.000871	.165 .229	33.3 ± 2.5
4	78-22A5	Fresh, glassy trachytic basalt with abundant iron ore	.0666 .0639 .0705	.0670	.000268	.083 .091	55.2 ± 7.1
4	78-22A7	Fresh, fine-grained holocrystalline basalt	.191 .196	.193	.000468	.176 .164	33.6 ± 3.9
18	79-40D	Slightly altered, porphyritic, subophitic basalt	.095 .095	.095	.000203	.104 .109	29.7 ± 3.6
20	79-33H	Slightly altered, porphyritic, intersertal basalt	.256 .253	.254	.000480	.182 .144	26.2 ± 3.0
24	79-26L	Slightly altered, amygdaloidal, porphyritic, intersertal basalt. Minor alteration	.354 .346	.350	.000982	.295 .292	38.9 ± 2.8
35	79-18D	Slightly altered hyalo-ophitic amygdaloidal basalt	.164 .162	.163	.000598	.195 .186	50.7 ± 5.2

[1/] Whole rock sample, crushed to -60/+200 mesh and treated with dilute HF and HNO_3 to remove alteration products prior to analysis.

samples from the unit yield three Oligocene (localities 18, 20, 24) and one early Eocene (locality 35) ages (table 2). The Oligocene ages are considered to be minimum ages resulting from argon loss during alteration, whereas the Eocene age of 50.7±5.2 m.y. is compatible with the paleontological data and probably approximates the actual age of the basalt sample.

Basaltic rocks in the unit represent diverse conditions of emplacement ranging from flows to breccias and aquagene tuffs. These rocks are inferred to be interbedded with minor sedimentary rocks based on the dredge results. At one locality (no. 35), the occurrence of small amounts of shale with thermally overmature kerogen suggests that shallow basaltic intrusives have been emplaced in the sequence.

It is not possible to accurately deduce the stratigraphic thickness of Unit C either from the scattered samples recovered or from the seismic reflection lines on which the basalt shows up as acoustic basement. The vertical extent through which dredge hauls of predominantly basaltic rocks have been recovered is 900 m. This thickness probably represents a minimum as the base is not known. The upper contact is likely to be gradational judging from the common occurrence of tuff and one sample of lithologically similar basalt at locality 22, well above the inferred top of this unit.

The igneous rocks comprising Unit C are entirely basaltic in composition. They exhibit a wide variety of textures ranging from glassy to diabasic. Plagioclase phenocrysts are common and serpentinized olivine phenocrysts are locally present. Augite is the predominant ferromagnesian mineral and iron oxide minerals are locally extremely abundant. Most basalts are amygdaloidal and altered to varying degrees.

Chemical analyses of major, minor, and rare earth elements are available for only one sample from locality 26, although a representative suite of

samples collected in 1979 are in the process of being analyzed. The one sample for which analyses are completed is distinctly more alkalic than primitive oceanic tholeiitic basalt and has affiniies to suites that characterize mature continental margins or intraplate ridges and seamounts (David Gottfried, oral commun., June 1980).

Basalt in Unit C has some of the highest magnetic susceptibilities found anywhere onshore or offshore in the Gulf of Alaska region (table 3). These rocks coincide remarkably closely with a pronounced linear magnetic anomaly of +250 to +600 gammas along the continental slope that has been defined by airborne and shipboard magnetic data (Nangler and Wageman, 1973; Schwab and Bruns, 1979). The anomaly is 15 to 60 km wide and extends from the Yakutat slope area in a west-northwest direction for about 500 km. The origin of this anomaly has been the subject of considerable speculation and has been variously attributed to dike intrusions by Nangler and Wageman (1973), to Mesozoic volcanic rocks extruded along the Queen Charlotte fault system by Taylor and O'Neill (1974), and to an undefined pre-Cenozoic linear magnetic source by Schwab and Bruns (1980). Coincidence of this magnetic anomaly with the highly magnetic rocks of Unit C indicates to us that the anomaly is most probably caused by the Eocene and older(?) basalt. Preliminary model studies of the anomaly suggest that it could result from a layered unit having the approximate thickness and magnetic properties of Unit C and a down-dip width beneath the continental shelf of roughly 100 km (Andrew Griscom, oral commun., July 1980).

Unit C cannot be unequivocally correlated with units either in outcrop or in wells in the Gulf of Alaska Tertiary Province. A sequence of basaltic flow rocks and breccias that are lithologically similar to some of the dredged samples occur in a small fault-bounded block along upper Hubbs Creek in the

Table 3.--Magnetic susceptibility of volcanic rocks

No. (Fig. 1)	USGS Sample Number	Weight in air	Weight in water	Volume	Density	Bridge Reading	K_T
	78 - 22A1	--	--	--	--	--	.000077
	22A2	--	--	--	--	--	.000205
4	22A4	--	--	--	--	--	.002802
	22A5	--	--	--	--	--	.005570
	22A8	--	--	--	--	--	.000076
17	78 - 45B	--	--	--	--	--	.001511
20	79 - 33G	27.9	17.2	10.7	2.61	1786	.003588
21	79 - 34E	29.7	19.0	10.7	2.78	1882	.003780
	79 - 26I	25.6	15.6	10.0	2.56	719	.001545
24	26K	29.1	18.5	10.6	2.74	1372	.002782
	26L	29.5	18.8	10.7	2.76	1690	.003395
26	77 - 9	--	--	--	--	--	.002775
	79 - 18C	26.5	15.8	10.7	2.48	494	.000992
35	18D	28.3	18.2	10.1	2.80	1132	.002409
	18E	27.8	17.2	10.6	2.62	47	.000095
	18F	27.7	17.1	10.6	2.61	1066	.002161

Samovar Hills between Cretaceous flysch on the east and middle Eocene coal-bearing beds on the west (Plafker and Miller, 1954; Plafker and Addicott, 1971). A sample collected from these volcanics in 1979 yielded an early Eocene whole-rock K/Ar age (Plafker, unpub. data, 1980). This age, together with the lithology and structural setting of the Samovar Hills volcanics, suggests that they may be correlative with the dredged basalts of Unit C.

Unit D: Eocene sedimentary and volcanic rocks.

Unit C is overlain by a diverse sequence of interbedded sedimentary and mafic pyroclastic rocks and minor basalt that is as much as 2,100 m thick east of Yakutat Seavalley but appears to thin out eastward in the vicinity of 139° W. (figs. 3 and 4).

A diverse and abundant microbiota including coccoliths, benthonic and pelagic foraminifers, siliceous microfossils, and palynomorphs in Unit D indicates an age range from early Eocene (D. lodensis zone; Penutian Stage) to probable late Eocene (Narizian stage). Discrepancies between age assignments based on the different microfossil assemblages present preclude detailed delineation of Eocene stages. The paleontological data, however, are generally compatible with a normal stratigraphic sequence. Exceptions are the occurrence of late Eocene foraminifers in samples from localities 12 and 13 in the lower part of this unit which, if correctly identified, could indicate large-scale slumping or structural complications.

Sedimentary rocks predominate in samples from Unit D and are largely organic-rich shale, calcareous and concretionary shale, and tuffaceous shale. The argillaceous rocks are interbedded with subordinate amounts of feldspatholithic sandstone that commonly has a high percentage of calcite matrix and micaceous and carbonaceous siltstone. The sequence also includes minor pebbly mudstone, palagonitic tuff and lapilli tuff, volcaniclastic

sandstone composed largely of coarse beach-worn basalt grains, and coarse-grained to pebbly volcaniclastic and bioclastic sandstone. Biogenic components of the bioclastic sandstone include a variety of organisms characteristic of shallow-water tropical carbonate reefs such as coralline algae, coral, bryozoans, echinoids, and large foraminifers such as Amphistogina sp.

Paleontologic and lithologic data on the depositional environment suggest that there has been considerable transport of shallow marine sands into deeper marine sediments. Foraminifers in the non-sandy samples are predominantly warm water species that are interpreted to indicate bathyal, largely middle to upper bathyal environments. One sample (locality 15) is thought to be lower bathyal or deeper on the basis of the pelagic foraminifers it contains. Some of the pelagic foraminifers indicate deposition in an oxygen minimum zone. In contrast, the associated bioclastic sandstones and some of the volcanogenic sandstones are interpreted as having formed in nearshore environments along a coast with fringing carbonate reefs on volcanic rocks compositionally similar to basalt in Unit C. This interpretation suggests that either Unit C was exposed to erosion along the basin margin or subaerial eruptions occurred during much of the time that Unit D was being deposited.

Unit D does not correlate with any Eocene rocks known from outcrops or wells on the adjacent mainland. It could represent a deeper marine equivalent of the Kulthieth Formation and unnamed siltstone unit in the Malaspina District (Plafker and Miller, 1957).

Unit E: Eocene and Oligocene? sedimentary rocks.

A sequence consisting of approximately 800 m of bedded sedimentary rocks underlies the upper part of the slope between about 138°45' W. and 141° W. (figs. 3 and 4). The sequence contains a rich biota of microfossils including

coccoliths, foraminifers, and palynomorphs, but most of these fossils are long-ranging forms. Those fossils that are age-diagnostic indicate that the unit is predominantly of Eocene age, probably ranging from early Eocene (Penutian stage) to late Eocene and possibly into the early Oligocene (Zemorrian stage).

Organic-rich shale, calcareous shale, tuffaceous shale, siltstone, and feldspatholithic calcite-matrix sandstone characterize Unit E. The shale is commonly laminated and contains abundant carbonized plant material, mica, pyrite micronodules, glauconite, and fish scales. The siltstone is highly micaceous.

Depositional environment was outer shelf to middle bathyal based largely on data from benthonic foraminifers. The combined lithologic and paleontologic data suggest that Unit E is a somewhat nearer-shore facies equivalent of Unit D and that in part it is younger than Unit D. Correlations with onshore units are the same as for Unit D except that if the upper age limit ranges into early Oligocene, it could be temporally equivalent to not only the Kulthieth Formation, and unnamed siltstone unit, but also the lower Poul Creek Formation (Plafker and others, 1978a).

Unit F: Oligocene sedimentary rocks.

Silty shale containing a rich diatom flora was sampled at one locality (31) on the uppermost slope near 140°15' W. (figs. 3 and 4). Thickness of this unit is estimated to be roughly 300 m based on interpretation of seismic reflection data along the dredge line (fig. 16).

Unit F differs from the underlying strata in that the shale is relatively low in organic carbon content, it contains abundant mica, it is rich in diatoms and silicoflagellates, and calcareous microfossils are absent.

The siliceous microfossils indicate a late Oligocene age for Unit F. Middle and early(?) Oligocene time may be represented by an unconformity between Units E and F although it does not show up as an angular unconformity on the seismic profiles. Eocene palynomorphs in the shale are probably reworked from beneath the postulated unconformity.

Unit F is correlative in age with the marine Poul Creek Formation which crops out on the mainland west of Icy Bay and has been penetrated by wells onshore and in OCS lease sale block 39 on the Yakataga shelf (Plafker and others, 1975, 1978a). The dredged samples differ from the Poul Creek Formation in that they do not contain the glauconite, mafic aquagene tuff or flow rocks, or the characteristic Poul Creek foraminifers. Presence of only siliceous microfossils in Unit F suggests that it may represent a deeper water facies than the Poul Creek Formation.

Unit G: Miocene and younger sedimentary rocks.

Units A through F are unconformably overlain along the continental slope by a late Cenozoic sequence of marine clastic rocks. They are thin and discontinuous along the upper slope and on the adjacent shelf from 138° W. to about 140°30' W. but they thicken rapidly westward to at least 2,000 m in the area west of Yakutat Seavalley (figs. 3 and 4). The unit is characterized by well-defined closely spaced reflectors on seismic profiles that show shoreward thickening of the sequence to form an asymmetric shelf basin whose axis lies close to the coast (Bruns, 1979; fig. 3).

Marine mudstone, siltstone, sandstone conglomerate, and conglomeratic sandy mudstone or diamictite characterize the late Cenozoic sequence in outcrop and wells (Plafker and Addicott, 1976). Poorly consolidated mudstone and clasts that are probably ice-rafted dropstones in diamictite were recovered at locality number 2 where this unit overlaps and partially buries a

ridge of Paleocene rocks (fig. 6). Strata of Unit G were not sampled elsewhere along the slope because emphasis in this study was on the pre-Yakataga stratigraphy and because the unconsolidated nature of the strata would have required sampling methods other than dredging.

Unit G is correlated with the Yakataga Formation of middle Miocene through Pleistocene age which is extensively exposed onshore and has been penetrated by wells both onshore and offshore in the Gulf of Alaska Tertiary Province (Plafker and Addicott, 1976). Paleontologic data for the samples from locality 2 indicate a Pliocene or younger age, and it is likely that the near-surface exposures on the slope are mainly in this age range.

Discussion

The dredge sample data do not permit detailed interpretations of the stratigraphy on the Yakutat slope. It must be emphasized that dredge hauls probably bias the samples in favor of moderately resistant ledge-forming slabby rock types that can be broken off by the dredge or can be sampled as talus. Very soft or very hard and massive rock units are not as likely to be recovered readily. The nature of the sampling, together with the uncertainties regarding the exact location of a given sample, preclude detailed stratigraphic reconstructions. As a consequence, the lithostratigraphic units delineated in this paper should be considered as a working model that will undoubtedly require major modification when drilling data become available for the Yakutat OCS.

The lower part of the Tertiary sequence of late Paleocene to early Oligocene age (Units B-E), with a minimum thickness of 2,800 m, shows intertonguing relationships between lithostratigraphic units. This sequence appears to be unconformably overlain by late Oligocene strata (Unit F) and the Miocene or younger Yakataga Formation (Unit G) along the slope. This suggests

significant uplift and erosion of the continental margin during early? and middle Oligocene time as well as in post-Oligocene time. The occurrence of an upper Oligocene unit, however, is based on one dredge sample and the age range of the unit is not known.

The Paleogene sequence laps up on, or abuts against, a pre-Tertiary basement in the Fairweather Ground area (Unit A) that is believed to be close to the early Tertiary continental margin. Although the nature of the basement beneath the Paleogene sequence of the Yakutat slope is not known, refraction data from the continental shelf south of Icy Bay indicate that the basin is floored by oceanic crust (Bayer and others, 1978). Thus, there is a basement transition from pre-Tertiary continental margin rocks in the Fairweather Ground area to oceanic crust in the area south of Icy Bay.

SOURCE ROCKS

Units B, C, D, and E include argillaceous rocks with organic carbon contents high enough to be considered potential source rocks for hydrocarbons. The hydrocarbon source potential of selected samples from these units was evaluated by analyses of total organic carbon cotent, kerogen type, thermal alteration index, vitrinite reflectance, and thermal analysis by Rock-Eval pyrolysis (tables 4, 5, 6). In addition, two samples were analyzed by conventional extraction and chromatography techniques. Results of analyses of the 1977 and 1978 samples, with emphasis on the Rock-Eval, extraction, and chromatography data, have been published previously (Plafker and Claypool, 1979).

Organic carbon and hydrocarbon content

Total organic carbon contents of samples listed in tables 4 and 6 range from 0.42 to 1.87 percent and average more than 1 percent carbon. Minor differences in organic carbon contents for some of the same samples listed in

Table 4.--Organic carbon and visual kerogen assessment
[Analyses by Geochem Laboratories, Inc.]

Map No.	Geochem. Sample No.	USGS Sample No.	Total organic carbon (WT %)	Visual Kerogen (R-34) % Distribution				Thermal Alteration Index (R-35)
				Amorphous	Herbaceous	Humic	Inert	
1	R219-002	79-16F	0.81	0	38	31	31	2.9
	003	16G	1.46	0	40	30	30	2.9
	004	16H	1.15	0	27	36	36	3.1
4	R201-008	78-22D2	0.84	0	71	29	0	2.4
	009	22D3	1.13	22	44	33	0	2.6
	010	22D4	*	0	67	33	0	2.5
6	006	77-20B	1.03	0	20	40	40	3.6
8	007	22B	1.45	0	83	17	0	2.3
9	R219-026	79-42D	1.24	11	56	33	0	2.3
	027	42E	1.11	0	56	33	11	2.3
10	028	43A	0.95	0	55	27	18	2.1
	029	43E	1.22	20	60	10	10	2.1
11	030	44A	*	9	45	36	9	1.6
12	018	37A	1.51	37	63	0	0	2.0
	019	37B	1.27	0	67	33	0	2.3
	020	37C	1.22	0	56	44	0	2.3
13	021	38A	1.51	31	54	15	0	2.2
	022	38C	1.54	27	55	9	9	2.2
14	023	39D	1.57	11	67	22	0	2.3
	024	39F	1.03	50	50	0	0	2.1
	025	39G	1.10	30	50	10	10	2.1
15	R201-011	78-43F	*	27	36	36	0	2.3
16	012	44D	1.64	0	100	0	0	1.9
	013	44E	1.49	0	83	17	0	1.9
	014	44F	1.41	22	67	11	0	1.9
23	R219-015	79-36A	1.34	40	60	0	0	2.2
	016	36C	1.40	30	60	10	0	2.1
	017	36D	1.86	27	55	9	9	2.1
27	R201-002	77-11B	1.12	0	86	14	0	2.1
28	001	10B	*	0	71	29	0	2.1
29	R219-011	79-24A	1.59	0	75	25	0	1.8
	012	24B	1.42	11	56	33	0	1.9
	013	24C	1.53	10	50	30	10	2.1
30	R201-003	77-17B	1.22	0	83	17	0	2.2
	004	17E	0.63	11	56	33	0	1.2
31	005	18A	0.56	0	56	44	0	1.2
32	R219-006	79-20B	0.67	0	50	40	10	2.3
33	009	21E	0.65	0	44	44	11	2.3
35	005	18A	0.54	0	22	33	44	4.0

* Insufficient sample material

Table 5.--Vitrinite reflectance summary (R-33)
[Analyses by Geochem Laboratories, Inc.]

Map No.	Geochem. Sample No.	USGS Sample No.	Number of Readings	Reflectance (%R_0) Minimum	Maximum	Average
1	R219-002	79-16F	50	1.25	1.57	1.45
	003	16G	50	1.92	2.29	2.12
	004	16H	50	1.90	2.37	2.16
4	R201-008	78-22D2	50	0.53	0.67	0.60
	009	22D3	9(Pop. 1)	.37	.59	.49
			41(Pop. 2)	.79	1.03	.90
	010	22D4	4(Pop. 1)	.45	.73	.59
			45(Pop. 2)	.86	1.09	.97
			1(Pop. 3)	1.20	1.20	1.20
6	006	77-20B	4(Pop. 1)	0.49	0.59	0.54
			50(Pop. 2)	2.90	3.64	3.32
8	007	22B	50	0.37	0.49	0.43
9	R219-026	79-42D	50	0.37	0.54	0.46
	027	42E	50	.38	.56	.47
10	028	43A	40	0.34	0.53	0.44
	029	43E	50	.34	.47	.40
11	030	44A	39	0.26	0.41	0.34
12	018	37A	50	0.31	0.46	0.37
	019	37B	50	.41	.61	.50
	020	37C	50	.41	.57	.48
13	021	38A	50	0.36	0.55	0.46
	022	38C	50	.35	.54	.44
14	023	39D	50	0.53	0.69	0.61
	024	39F	50	.33	.53	.46
	025	39G	50	.38	.58	.50
15	R201-011	78-43F	2(Pop. 1)	0.27	.31	.29
			50(Pop. 2)	.43	.63	.55
16	012	44D	46	0.23	.40	.32
	013	44E	50	.21	.42	.33
	014	44F	25	.21	.38	.29
23	R219-015	79-36A	50	0.27	0.43	0.32
	016	36C	50	.28	.41	.33
	017	36D	28	.29	.43	.36
27	R201-002	77-11B	50	0.31	0.48	0.39
28	001	10B	50	0.40	0.60	0.52
29	R219-011	79-24A	50	0.29	0.40	0.33
	012	24B	50	.27	.41	.33
	013	24C	50	.27	.42	.34
30	R201-003	77-17B	50	0.34	0.50	0.43
	004	17E	20	.18	.29	.22
31	R201-005	18A	46	.21	.36	.25
32	R219-006	79-20B	50	0.54	0.75	0.61
33	009	21E	50	0.49	0.67	0.57
35	005	18A	50	4.16	4.95	4.56

Table 6.--Organic carbon content and Rock-Eval pyrolysis data for selected dredge samples from the eastern Gulf of Alaska

[n.a. = no analysis; n.d. = no determination]

Map number (fig. 1)	Sample number	C[1] (percent)	S_1[2] (mg/g)	S_2[2] (mg/g)	S_3[2] (mg/g)	$T(S_2)$[2] (°C)	Genetic Potential S_1+S_2 (ppm)	Hydrogen Index S_2/C (mgHC/gC)	Oxygen Index S_3/C ($mgCO_2/gC$)	Transformation Ratio S_1/S_1+S_2
1	79-16F	0.86	0.09	0	0.78	0	90	0	119	1.0
1	79-16GT	1.16	0.06	.004	0.27	546	60	0.4	23	0.93
1	79-16H	1.04	0.12	0	0.54	0	120	0	52	1.0
4	78-22D1	0.75	0.104	0.375	0.69	445	479	50	92	0.22
4	78-22D2	0.84	0.099	0.415	0.72	442	514	49	87	0.19
4	78-22D3	1.13	0.145	0.816	0.14	439	961	72	12	0.15
6	77-20B	1.03	0.030	0.100	n.a.	n.d.	130	13	n.a.	0.23
8	77-22B	1.45	0.017	1.513	n.a.	426	1,530	105	n.a.	0.01
9	79-42D	1.44	0.08	0.60	0.43	437	680	42	30	0.12
9	79-42E	1.21	0.09	0.63	0.26	432	720	52	22	0.12
10	79-43A	1.37	0.04	0.41	0.98	429	450	30	71	0.09
10	79-43E	1.37	0.04	0.90	0.64	425	940	66	47	0.04
11	79-44A	0.80	0.15	0.23	0.85	424	380	26	97	0.40
12	79-37A	1.11	0.06	0.88	1.02	436	940	79	91	0.07
12	79-37B	1.10	0.03	0.27	0.91	445	300	24	83	0.11
12	79-37C	1.24	0.04	0.66	1.13	439	700	53	91	0.06
13	79-38A	1.51	0.07	0.90	1.21	429	970	60	80	0.07
13	79-38C	1.10	0.04	0.28	1.35	429	320	25	123	0.13
14	79-39D	1.67	0.05	0.59	0.38	442	640	35	22	0.07
14	79-39F	1.03	0.15	0.69	0.86	447	840	67	83	0.17
14	79-39G	0.82	0.11	0.24	0.72	452	350	29	87	0.31
16	78-44D	1.64	0.034	1.42	2.03	421	1,452	86	123	0.02
16	78-44E	1.49	0.189	1.16	2.63	425	1,350	78	176	0.14
16	78-44F	1.41	0.140	0.943	3.11	421	1,080	67	221	0.13
22	79-35D	0.68	0.06	0.22	0.39	426	280	32	57	0.23
23	79-36A	1.74	0.08	1.30	2.54	435	1,380	75	146	0.06
23	79-36C	1.87	0.11	1.98	2.61	432	2,090	106	140	0.05
23	79-36D	1.61	0.12	2.15	2.36	428	2,270	133	146	0.05
27	77-11B	1.12	0.035	1.405	n.a.	408	1,440	128	n.a.	0.02
29	79-24A	1.73	0.14	1.39	1.93	429	1,530	80	112	0.09
29	79-24B	1.78	0.14	1.38	1.73	430	1,520	78	97	0.09
29	79-24C	1.76	0.05	1.10	1.73	428	1,150	62	98	0.05
30	77-17B	1.22	0	0.810	n.a.	420	810	66	n.a.	0
30	77-17C	0.71	0.016	0.454	n.a.	420	470	66	n.a.	0.03
30	77-17E	0.63	0.048	0.232	n.a.	n.d.	280	44	n.a.	0.17
31	77-18A	0.56	0.036	0.314	n.a.	392	350	62	n.a.	0.10
32	79-20B	0.75	0.03	0.15	0.50	438	180	20	66	0.14
32	79-20E	0.41	0.09	0.04	0.44	436	130	10	106	0.70
33	79-21D	0.61	0.03	0.07	0.51	440	100	12	83	0.32
33	79-21E	0.63	0.04	0.09	0.34	441	130	15	54	0.32
33	79-21F	0.42	0.06	0.07	1.27	428	130	16	303	0.47
35	79-18A	0.75	0.05	0	0.20	0	50	0	26	1.0

[1] Total organic carbon analyses by Rinehart Laboratories, Arvada, Colorado.

[2] Thermal analyses by T. Daws and J. P. Baysinger, U.S. Geological Survey.

both tables 4 and 6 reflect analyses by different laboratories. The carbon contents of almost all samples listed are above the generally accepted minimum values of 0.5 percent organic carbon for argillaceous hydrocarbon source rocks (Tissot and Welte, 1978). The extractable hydrocarbon content (genetic potential) as derived from Rock-Eval pyrolysis ranges from 50 to 2,270 ppm (table 6). A plot of organic carbon versus extractable hydrocarbons suggests that the analyzed rocks are mostly wet gas or oil-prone (fig. 21).

Visual kerogen assessment

Organic matter in the analyzed samples is dominantly herbaceous with subordinate humic and amorphous kerogen and minor inert (coaly) components (table 4). The kerogen composition is of the type that can generate both liquid hydrocarbons and gas (Dow, 1977) and is in agreement with the data on organic carbon and extractable hydrocarbon contents.

Vitrinite reflectance and thermal alteration index

Vitrinite reflectance and thermal alteration data show large variations in maturity between units as well as within the same unit. The analyzed samples range from immature in Unit F to very mature or severely altered in Unit B. Most samples from Units D and E are submature to moderately mature with only a few that could be classified as mature (vitrinite reflectance greater than 0.6 and thermal alteration index greater than 2).

As indicated by figure 22, there are systematic variations in maturity laterally along the slope. In general, samples east of Alsek Canyon and west of Yakutat Seavalley are more mature than those in between. Samples from localities 32 and 33 east of Alsek Canyon are close to optimum maturity. A third sample from locality 35 in this area is clearly anomalous in that it has a thermal alteration index of 4.0 and vitrinite reflectance of 4.56 indicating severe alteration. As the analyzed sample was a single piece of shale

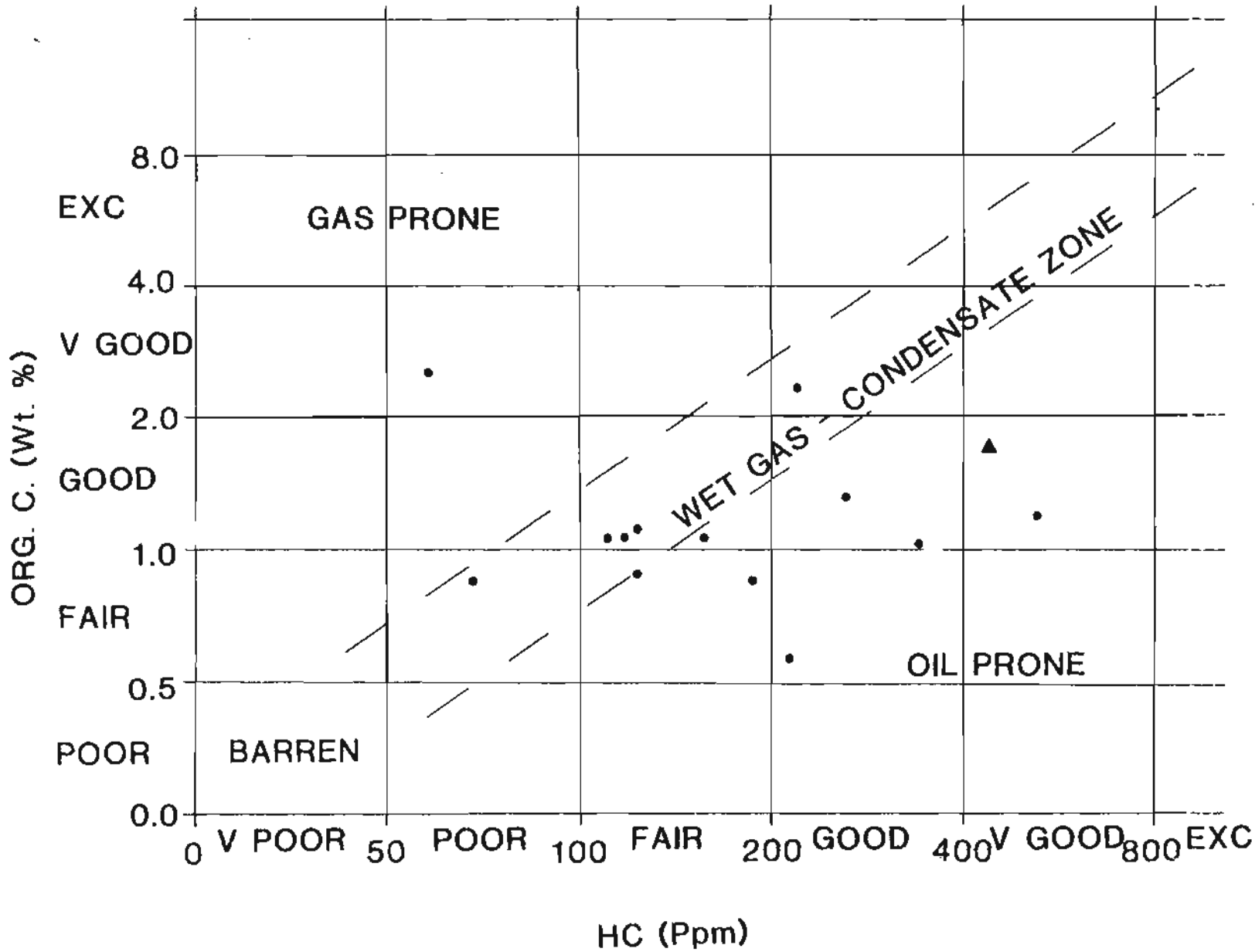


Figure 21.--Plot of total organic carbon (table 4) vs. extractable hydrocarbons (table 6) for shale samples dredged from the Yakutat continental slope. Classifications of organic richness and hydrocarbon potential are from Geochem Research, Inc., unpublished data.

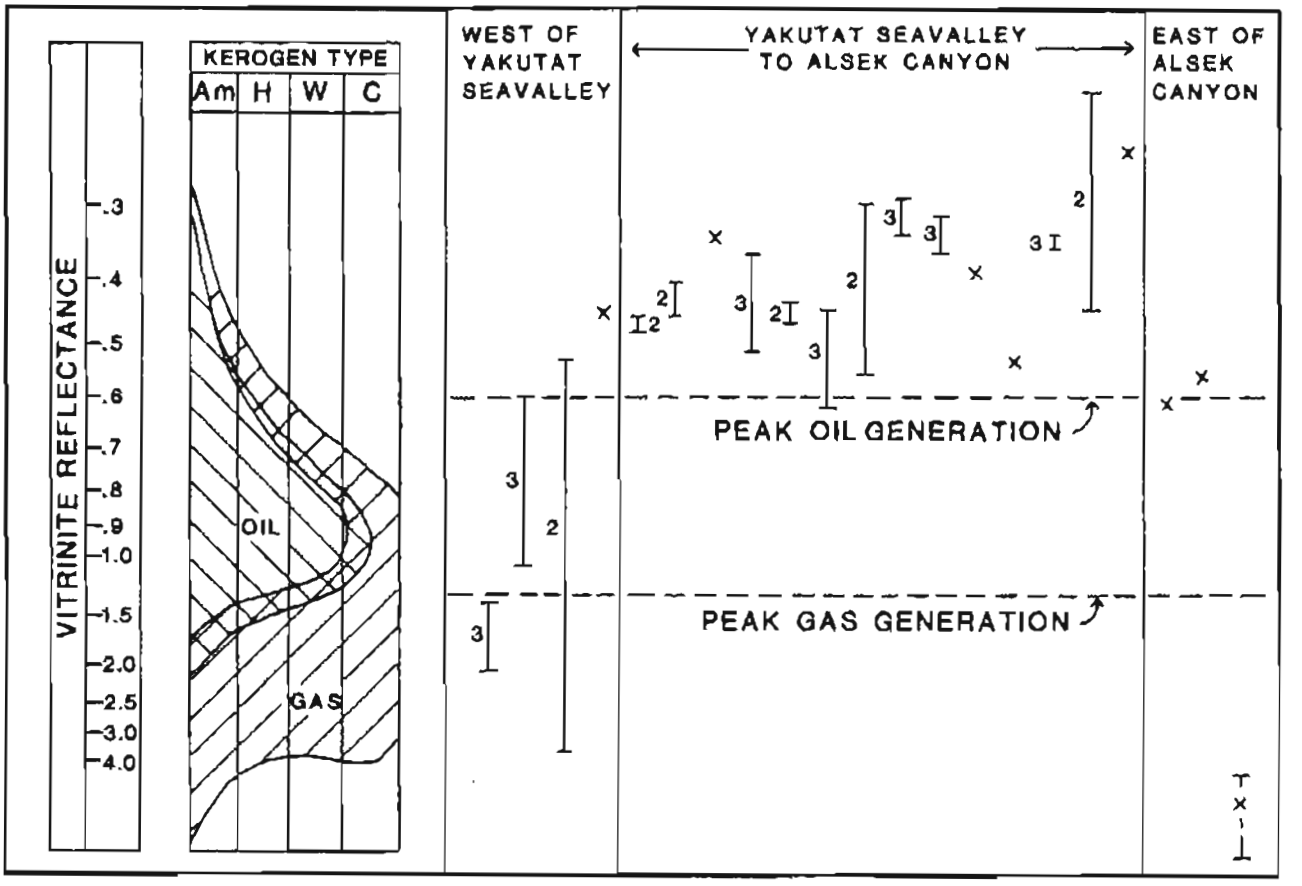


Figure 22.--Range of average vitrinite reflectance of kerogen in shale samples dredged from different segments of the Yakutat continental slope (table 5) relative to zones of hydrocarbon generation. Vertical bars show range of values for different samples in the same dredge haul and numeral beside bar indicates number of analyzed samples; an "X" indicates average values for one sample. Hydrocarbon generation zones from Dow (1977).

recovered in a dredge haul otherwise entirely of basaltic rocks, it is believed to have been "baked" by emplacement of the basalt or associated shallow intrusives.

Analyzed shales from between Alsek Canyon and Yakutat Seavalley are submature and immature with only one sample (from locality 14) that is mature.

West of Yakutat Seavalley all samples analyzed have undergone thermal histories that have resulted in maturity or overmaturity. The increase in thermal maturity from east to west across Yakutat Seavalley was noted previously from data on temperature of maximum Rock-Eval pyrolysis yield (Plafker and Claypool, 1979, fig. 4).

Extraction and chromatography

Two shales collected in 1978 at localities 4 (sample S5-78-EG-22D3) and 16 (sample S5-78-EG-44D) were analyzed for extractable hydrocarbon content by solvent extraction, elution, chromatography, and gas chromatography (Plafker and Claypool, 1979). These results are summarized below.

The sample from locality 4 is exceptionally rich in extractable hydrocarbons (700 ppm) and the saturated hydrocarbons have a mature, waxy petroleum-like distribution. The saturated hydrocarbon fraction predominates over aromatic hydrocarbons (S/A = 1.36), extractable bitumen is 71 percent hydrocarbons, and the hydrocarbon-to-organic carbon ratio is 6.2 percent. These characteristics of the extractable organic matter (assuming it is indigenous to the rock) in this sample indicate that petroleum hydrocarbons have been generated in sufficient quantities to consider the sample as a possible source rock. In addition, the relative amounts of hydrocarbons and total organic carbon indicate that the sampled rock has undergone close to the optimum thermal history for liquid hydrocarbon generation. However, the saturated hydrocarbon distribution still retains signs of slight immaturity,

such as a large predominance of pristane over $\underline{n}$-C_{17}, and a carbon preference index (CPI) value of 1.25. Rocks with similar organic matter in a downdip position which had undergone an additional 500 m or so of burial should have even more favorable source rock properties.

The sample from locality 16 is less rich in extractable organic matter, but it is still above average for immature shales. The content of extractable hydrocarbons is 101 ppm. Saturated hydrocarbons are subordinate to aromatics (S/A = 0.55) and gas chromatographic analysis indicates a mixture of saturated hydrocarbons dominated by compounds which have undergone only slight, low-temperature modification of their biochemically-derived structures. These are the sterane, di- and triterpane compounds. A lower proportion of hydrocarbons in the bitumen (0.45) and a low hydrocarbon-to-organic carbon ratio (0.61 percent) are also indicative of the low degree of thermal maturity. The saturated hydrocarbons are the type usually associated with organic matter derived from aquatic plants under marine or lacustrine conditions, with exclusion of organic matter derived from vascular plants. Environments in which this type of organic matter is deposited and preserved usually result in rocks with capacity for liquid hydrocarbon generation.

Thermal analysis

The results of thermal analysis by Rock-Eval or MP-3 pyrolysis, summarized in table 6, indicate that the dredged samples have adequate organic matter content but not of the chemical type which generates liquid hydrocarbons. These data suggest that the rocks are immature to marginally mature with respect to the intensity and duration of geothermal exposure required for generation of significant amounts of petroleum.

The original hydrocarbon-generating capacity of the rocks is indicated in a semiquantitative fashion by the total hydrocarbon yield or genetic potential

(S_1+S_2, in ppm or kilogram of hydrocarbon per metric ton of rock). The values shown for the dredged samples on table 6 range from 50 to 2,270 ppm. All but the samples from locality 23 are less than the 2,000 ppm yield considered to be a minimum for oil source rocks but in the range of yield for rocks with some potential for gas generation (Tissot and Welte, 1978).

The type of organic matter is indicated from Rock-Eval pyrolysis by the hydrogen index and the oxygen index, which are the pyrolytic hydrocarbon yield (S_2) and the pyrolytic organic CO_2 yield (S_3), respectively, each normalized by organic carbon content. Hydrogen indices for the analyzed 1977 samples, and both hydrogen and oxygen indices for the 1978 and 1979 samples are calculated and shown in table 6. The generally low hydrogen index suggests that the organic matter in the dredged samples is not the type that would generate mainly liquid hydrocarbons. These results are incompatible with the data from both visual kerogen assessment and extraction and chromatography already cited. This suggests that the hydrogen and oxygen indices may not reflect the original nature of the organic matter because of secondary alteration due to the submarine weathering that has affected the samples.

Thermal maturity is interpreted from the temperature of maximum pyrolysis yield $T(S_2)$ and the transformation ratio (S_1/S_2+S_2) given in table 6. In general, the transition from immature to mature with respect to oil generation is indicated ty $T(S_2)$ values of about 440^0 C, and transformation ratios of 0.1 (Tissot and Welte, 1978). Based on these criteria, the dredge samples east of Alsek Canyon and west of Yakutat Seavalley give consistent indications of marginal thermal maturity. This agrees closely with the independent results of visual kerogen assessment and vitrinite reflectance analysis.

Discussion

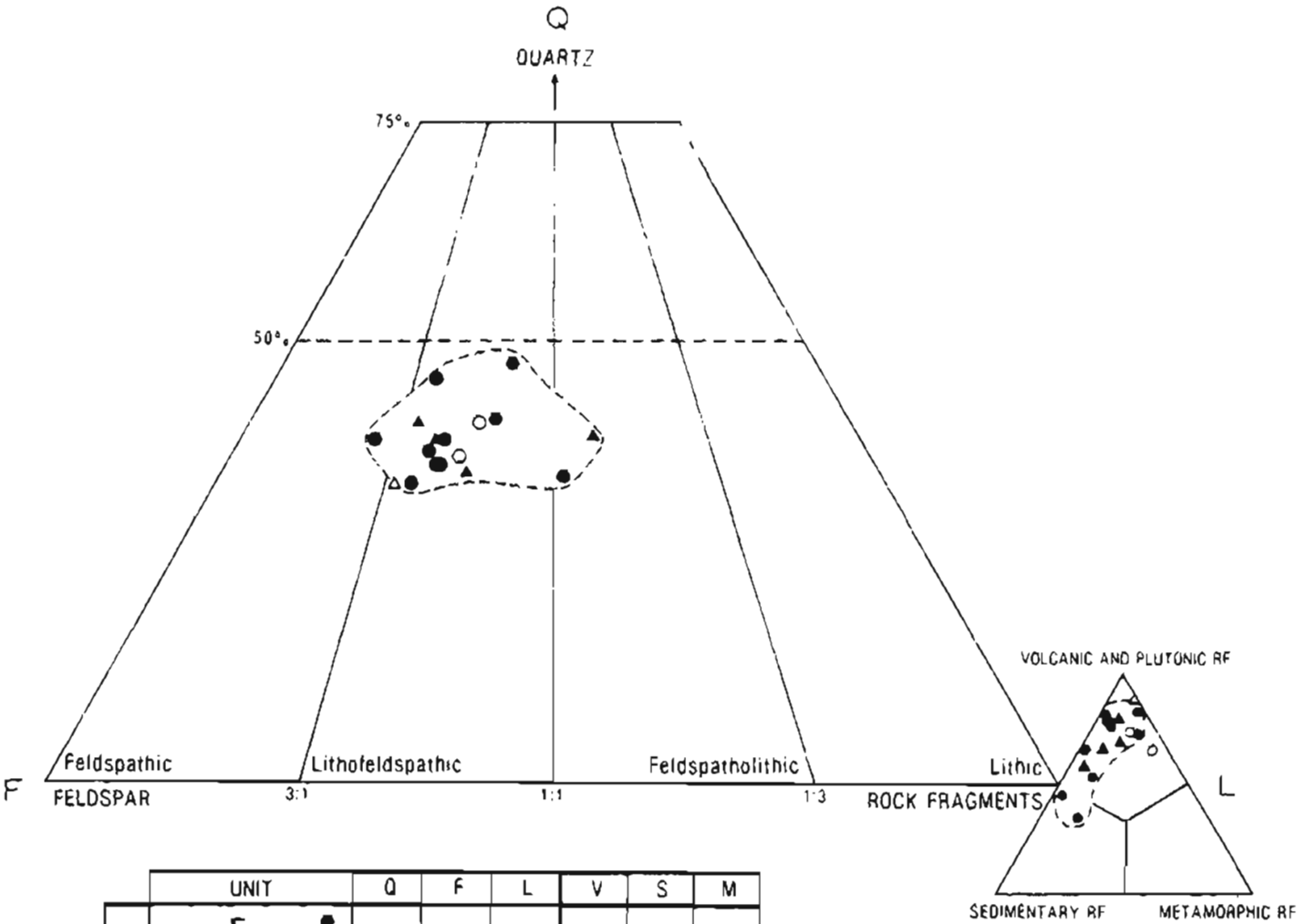
Argillaceous rocks with favorable hydrocarbon source rock characteristics are common in the early Tertiary sequence and some of these rocks have undergone a thermal history that has resulted in generation of hydrocarbons. This implies that the rocks now exposed on the lower part of the continental slope were probably buried to depths of 3,000 m or more at some time during their history in order to attain the degree of thermal maturity indicated. Subsequently, they were uplifted and stripped of at least 3 km of section to expose the mature rocks at the surface. The time of this uplift may be recorded by the Oligocene unconformity between Units E and F. Finally, the sequence had to subside to its present depths of 2-4 km below sea level along the continental slope, probably during the late Cenozoic.

SANDSTONE RESERVOIR CHARACTERISTICS

Early and middle Tertiary sandstones in the area of OCS Lease Sale 55 are the only rocks with sufficient porosity and permeability to be considered as likely potential reservoirs for hydrocarbons. As no sandstone samples were recovered from the upper Tertiary and Quaternary units, their reservoir qualities are not known, but judging from outcrop and well data, these strata are not likely to have high porosity and permeability.

Composition

Modal analyses were made of fourteen dredged samples from Units A, B, D, and E along the Yakutat slope. Most of the sandstones are lithofeldspathic (fig. 23)--that is, quartzose grains (Q) and feldspar (F) each comprise, on the average, two-fifths of total framework grains, and diverse rock fragments (L) comprise about one-fifth. Rock fragments in sandstones from the pre-Tertiary Unit A are dominantly volcanic whereas they are dominantly plutonic in the Tertiary sandstones. In general, compositions of the sandstones are



	UNIT	Q	F	L	V	S	M
OFFSHORE	F ● n=2	45	32	23	73	25	2
	B, D, E ● n=8	38	42	20	65	25	10
	A ▲ n=4	38	38	24	68	23	9
ONSHORE	Poul Creek ○ n=10 MEAN	37	41	22	67	6	27
	Tokun/Kulthieth ○ n=8 MEAN	41	34	25	74	11	15
	Yakutat △ n=35 MEAN	34	50	16	89	9	2

Q = total quartzose grains
F = total feldspar
L = total rock fragments (RF)
V = volcanic and plutonic RF
S = sedimentary RF
M = metamorphic RF

Figure 23.--Q-F-L and rock fragment ternary diagrams comparing compositions of dredged samples (solid symbols) and the mean compositions of probably coeval onshore rocks (open symbols).

comparable to age-equivalent units onshore. For reference, Q-F-L plots of mean values for onshore samples from units believed to be correlative with the offshore samples (Winkler and others, 1976; Winkler and Plafker, unpub. data) are plotted on the ternary diagram (fig. 23).

Heavy mineral suites of the offshore units are characterized by (in order of abundance) biotite, epidote, muscovite, amphibole, and garnet. Proportions of the heavy minerals vary slightly for the units, however. Typically, samples from Unit A have a significant increase in amphibole and epidote and samples from Units B, D, and E are richer in biotite, garnet, muscovite, and zircon.

Compositional contrasts between onshore and offshore units of the same age do exist. In several places, glauconitic tuffaceous sandstones of well documented Eocene age (Units D and E, figs. 3 and 4) were dredged from the continental slope. These samples consist largely of clasts of chloritized mafic volcanic rocks and are totally unlike any coeval rocks onshore, resembling instead samples from parts of the Poul Creek Formation of Oligocene and early Miocene age. Modal analyses were not made of these volcaniclastic sandstones and they are not included on the ternary diagram.

Texture and physical properties

The dredged sandstones are texturally immature and mineralogically unstable. Mechanical and chemical diagenetic effects are conspicuous in all samples. Generally poor sorting coupled with compaction and squeezing of labile rock fragments and detrital mica has yielded tight sandstones with few visible pores. In some samples, most notably in the pre-Cretaceous rocks (Unit A, figs. 3 and 4), deformation of labile grains has been so pronounced that, in effect, the grains have become matrix (pseudomatrix of Dickinson, 1970), and it is difficult to deduce their original character. This physical

reduction in porosity has been enhanced by chemical changes that have created a wide range in cements, including carbonate, chlorite, zeolite, and silica cements. In most cases, partial dissolution of framework grains has accompanied cementation.

Carbonate cement is particularly abundant in sandstones from Units B, D, and E. It may have formed quite early, inasmuch as framework deterioration in sandstones with abundant carbonate cement appears to be less advanced and little matrix or noncarbonate cement is present. Thus, these sandstones may have been relatively clean when deposited with primary matrix of just a few percent. However, compaction, alteration of framework grains, and plugging of interstices with calcite cement and matrix probably began soon after deposition.

Similar diagenetic features have been observed throughout the stratigraphic sequence onshore (Galloway, 1971; Winkler and others, 1976). Such diagenetic features generally have been ascribed to deep burial and are similar to features that Galloway (1974) observed in well samples from depths of 1,500 m or greater in the Queen Charlotte Basin.

Offshore in the eastern Gulf of Alaska, chemical diagenesis is most pronounced in pre-Tertiary and early Tertiary samples. In several pre-Tertiary samples, siliceous cement is abundant and, in fact, a few quartz-prehnite veins are present. In early Tertiary samples, a sutured fabric produced by complex interpenetration of many grain boundaries is characteristic. In part, this fabric may result from compaction, but it also is due to abundant grain overgrowths. Carbonate and zeolite cement occurs in the samples from Units B, D, and E, and one sample also has patches of prehnite. The diagenetic effects in some early Tertiary rocks offshore are analogous to effects observed in the coeval Kulthieth Formation onshore (Winkler and others, 1976). However, in

other offshore samples of Eocene age and in those of Oligocene age (Unit F), severe diagenesis is less complete, although siliceous cement and pseudomatrix are common and have reduced original porosity considerably.

Porosity, permeability, and grain density have been measured on 15 sandstone samples dredged from the eastern Gulf of Alaska (table 7). Measurements were made only on fresh-looking samples, some of which were from the interior portions of blocks with oxidized weathering rinds. Porosity and permeability values generally are low and grain densities are high, as they were for 50 samples from onshore locations (Winkler and others, 1976, Appendix 4). However, two samples of Eocene age from localities 16 and 28 have notable high porosity and modest permeability (sample nos. 78-44A, 77-10C, table 7). Inasmuch as thin sections of these two samples exhibit widespread framework alteration and pore-space reduction by compaction, formation of clay rims, and silicate overgrowths, similar to the other samples from Units B, D, and E, it seems likely that porosity is secondary. In fact, several petrographic criteria of secondary porosity described by Schmidt and MacDonald (1979) are present in the samples: (1) alternating areas of tight and open packing of grains; (2) partially dissolved and corroded grains; (3) grains fractured by collapse into adjacent pores; and (4) elongate pores of complicated shapes. Direct dissolution of detrital and secondary silicate minerals probably has created some of the secondary porosity; dissolution of early carbonate cement may also have created new pores, but few remnants of carbonate cement remain to certify that carbonate dissolution has occurred. The necessary acidic solutions may have been created as byproducts of organic reactions in adjacent mudstone, some of which has as much as 1.86 percent organic carbon and has undergone some thermal maturation (tables 4, 5, 6).

Table 7.--Sandstone reservoir characteristics

No. (Fig. 1)	USGS Sample Number	Liquid Permeability (md)	Porosity (%)	Grain Density (ρ)
5	79 - 24E	4.0	14.9	2.68
6	77 - 20C	.0006	12.0	2.68
7	78 - 21D5	.01	6.3	2.67
	21D4	.15	5.7	2.68
8	77 - 22A	.006	11.7	2.66
9	79 - 42B	3.1	21.7	2.68
10	79 - 43C	1.2	16.2	2.71
12	79 - 37F	1.3	14.4	2.69
16	78 - 44A	26.0	31.3	2.59
	44B	2.9	31.8	2.53
27	77 - 11C	.008	8.1	2.63
28	77 - 10C	35.9	23.8	2.63
29	79 - 24E	2.8	31.6	2.67
30	77 - 17A	.51	18.1	2.63
39	78 - 14B	.14	8.8	2.69

Discussion

Sandstones with a few to a few tens of millidarcies of permeability and modest to high porosities were recovered from the Paleocene? and Eocene rock units (B, D, and E) and comparable sandstones probably comprise a significant percentage of these units. Most of the sandstones recovered, however, have poor reservoir qualities due to presence of abundant unstable mineral and rock fragments, common calcite cement, and less common siliceous, zeolitic, or clay pore fillings. High initial porosities and early calcite cementation are suggested by the textures. Permeability and porosity appear to be largely secondary, and could be in part due to submarine leaching of calcite matrix in the outcrops.

The composition of the sandstones suggests a predominantly metamorphic-plutonic source terrane, whereas the pre-Tertiary sandstone has lithic and heavy mineral components suggesting contributions from a volcanic arc terrane. Compositional and textural data indicate the Tertiary sandstones were well washed when deposited and that deposition was rapid and from a nearby source area.

Suitable source terranes for the Tertiary and pre-Tertiary sandstones are not known to occur adjacent to the Yakutat block in the Saint Elias Mountains or in the Alexander Archipelago of southeastern Alaska and British Columbia. The most probable provenance for the large volume of lithofeldspathic sandstone in the Paleogene sequence of the Yakutat slope as well as the compositionally similar sandstone of the onshore Orca, Kulthieth, and Tokun Formations in the Gulf of Alaska area is the plutonic and high-grade metamorphic complex of the Coast Mountains of British Columbia and Alaska. Petrologic and radiometric studies of part of this complex by Hollister (1979) demonstrate that 10 to 20 km of overburden was stripped off these mountains

during the early Tertiary. As suggested by Hollister (1979), much of this sediment, which was initially deposited along the continental margin as slope and deep-sea fan deposits, was subsequently displaced northwestward to the Gulf of Alaska by dextral transform faulting along the margin of the North American plate.

HYDROCARBON TRAPS

There are no late Cenozoic anticlinal folds on the Yakutat OCS of the type that were drilled unsuccessfully in the adjacent Yakataga area (Aud, 1979). The most promising situations for hydrocarbon accumulations are likely to be drape folds, and structural, or combination structural-stratigraphic traps in the section of late Paleocene to early Oligocene age (Units B, C, D, E). This section has the best potential for hydrocarbon source and reservoir strata in close proximity and is apparently unconformably overlain by upper Oligocene or younger strata that could provide effective seals.

Although it is beyond the scope of this study to discuss details of possible hydrocarbon traps on the OCS adjacent to the Yakutat slope, some general observations based on the stratigraphy and regional geology can be made as a guide to exploration on the continental shelf. Preliminary structural contours showing the general form of the late Cenozoic basin have been presented previously (Plafker and others, 1978a; Bruns, 1979) and a more detailed analysis of the seismic reflection data by Bruns is in progress. At least one large structural high that is apparently an anticline within the early Tertiary section has been recognized, but neither the trend or closure along strike can be determined with the available multichannel data (Bruns, 1979, fig. 8).

Drape structures

The dredge data indicate that there may be substantial relief on the upper surface of the basalt unit (Unit C, fig. 4) along the slope. If this relief persists beneath the OCS, there is a possibility for hydrocarbon traps in drape folds over volcanic highs.

Fault blocks and faults

Relatively abrupt lithologic changes along the slope such as between pre-Tertiary and Paleogene units and between Paleogene units on opposite sides of Yakutat Seavalley (figs. 3 and 4) suggest that block faulting has affected the pre-upper Oligocene sequence. This suggests that fault blocks could be present in the area of Lease Sale 55 and that structurally high blocks and associated faults may provide traps for hydrocarbons.

Basin margin traps

Fault, stratigraphic, and combination traps may be present along the northeastern margin of the early Tertiary basin where the early Tertiary marine rocks lap up onto--or are faulted against--pre-Tertiary basement rocks. Along this trend there should be enhanced opportunity for occurrence of coarse clastic rocks, up-dip pinchouts, possible Eocene carbonate reefs, and down-to-the-basin fault seals.

Stratigraphic data from the Yakutat slope suggest that some of the early Tertiary units thin up-dip towards the pre-Tertiary basin margin and that the contact may be interpreted as a down-to-the-basin fault (fig. 4). A similar abrupt fault contact exists onshore in the Samovar Hills between Icy Bay and Yakutat Bay (fig. 3) where the most westerly exposures of pre-Tertiary rocks in the Yakutat block occur (Plafker and Miller, 1957). Here the pre-Tertiary Yakutat Group is faulted against coal-bearing terrestrial and shallow marine

strata of middle Eocene age (Addicott and Plafker, 1971) and basaltic volcanic rocks of possible early Eocene age.

These relationships suggest that the early Tertiary basin margin extends from near the west side of Fairweather Ground at the continental slope in a N. 30° W. direction through OCS Lease Sale 55 to the Samovar Hills area. This trend is markedly oblique to the present continental margin and late Cenozoic basin axis. Between the continental slope and Samovar Hills the location of the basin margin is not known although it may be detectable with deep seismic reflection or refraction data. The apparent absence of early Tertiary marine rocks in the onshore wells both east and west of Yakutat Bay (fig. 3) suggests that the shoreline at that time lay to the southwest of these wells.

Discussion

Hydrocarbon traps in the Yakutat OCS are likely to be subtle, and, if present, they will probably involve rocks below the postulated Oligocene unconformity. In this respect, the area differs markedly from the Yakataga OCS and adjacent onshore where exploratory drilling was largely confined to large, shallow anticlines of late Cenozoic age with targets in the middle and late Cenozoic section (Plafker and others, 1978a; Aud, 1979). That petroleum is present in the early Tertiary sequence is demonstrated by the unusually prolific oil seeps which issue from faulted middle Eocene strata in the Samovar Hills (Plafker and Miller, 1957). Although the Samovar Hills seeps were formerly thought to come from middle Tertiary strata overthrust by Eocene rocks (Plafker, 1971), the new offshore data indicate that the oil undoubtedly is from the late Paleocene? to Eocene sequence.

CONCLUSIONS

Our geologic data do not permit predictions regarding the petroleum potential of the Tertiary sequence that extends from the Yakutat slope beneath the adjacent continental shelf. They do indicate, however, that the best exploration targets are within the lower Tertiary sequence beneath the Oligocene unconformity where there are potential source and reservoir rocks in close proximity. The upper Oligocene and younger units are judged to be less favorable for petroleum due to low kerogen content, thermal immaturity, and poor reservoir properties in the few sandstone samples recovered from this part of the section. The critical factors for accumulation of hydrocarbons in commercial quantities will probably be the occurrence of adequate traps at drillable depths. Traps in the early Tertiary sequence, if any, are likely to be relatively subtle but at least one large apparent structural high is detectable on the available multichannel seismic data. A particularly interesting trend in which to prospect for structural or combination structural/stratigraphic traps is along the margin of the early Tertiary marine basin where it trends northeastward beneath OCS Lease Sale 55 from the west side of Fairweather Ground.

It is worth noting that the preferred early Tertiary objectives for the proposed OCS Lease Sale 55 bear little resemblance to the sections penetrated by exploratory wells in the nearby OCS Lease Sale 39 or along the coast in the Yakutat and Malaspina areas. Exploration in OCS Lease Sale 39 was focused on large, young anticlinal structures where the principal target section, of Oligocene and Miocene age, turned out to have inadequate petroleum source properties and few potential reservoirs (Aud, 1979). Onshore holes that penetrated the late Cenozoic Yakataga Formation encountered continental to

nearshore clastic rocks of poorly-defined Tertiary age overlying pre-Tertiary basement (Plafker, 1971).

Geologic differences between the areas already explored by drilling and the Yakutat slope and shelf suggest that a meaningful petroleum assessment of this area must be based on its own merits rather than by comparison with better explored, but doubtfully analogous areas elsewhere. We hope that the data on the Yakutat slope presented here will be useful in evaluation of the resource potential of the adjacent OCS Lease Sale 55 and as a guide to exploration strategy.

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