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Preliminary Results of a Geophysical Study of Portions of the Juan de Fuca Ridge and Blanco Fracture Zone

WILLIAM G. MELSON

Technical Memorandum C&GSTM 6

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U.S. DEPARTMENT OF COMMERCE
Environmental Science Services Administration
Coast and Geodetic Survey

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PRELIMINARY RESULTS OF A GEOPHYSICAL STUDY OF PORTIONS OF THE JUAN DE FUCA RIDGE AND BLANCO FRACTURE ZONE

A Study Performed Aboard the USC&GS Ship Oceanographer
October 15-26, 1968

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551.241	Sea-Floor spreading
552.3	Petrology of basalts
528.27	Gravimetry
550.382.7	Magnetic surveys of ocean basins
(266)	Eastern Pacific Ocean

PREFACE

This report was prepared on the USC&GS ship Oceanographer during and immediately after a survey of portions of the Juan de Fuca Ridge and Blanco Fracture Zone. The results are preliminary and subject to possible revision and modification. Depth soundings are not corrected for variation of sound velocity with depth, and the bathymetric, magnetic, and gravity profiles are not finalized. Shipboard identifications of some of the very fine-grained rock samples are tentative. This report is intended for restricted circulation and should not be copied or reproduced without noting the preliminary nature of this report. The rocks collected during this study are in the petrology collection of the National Museum of Natural History.

William G. Melson
Chief Scientist
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ABSTRACT

Preliminary results of a 14-day cruise by the USC&GS ship Oceanographer to the area near the junction of the Juan de Fuca Ridge and the Blanco Fracture Zone are reported. About 10 full days of bathymetry (using a narrow beam transducer), magnetics, and gravity were completed. Fifteen dredges were attempted, 13 were successful. A striking bathymetric symmetry up to 15 miles on each side of the axis was found on five crossings of the Juan de Fuca Ridge. This symmetry extends at least 17 and possibly 30 nautical miles along the Ridge axis. Relief features, ranging from 100 to 20 fathoms, were found to correlate with similar features across the axis. This bathymetric symmetry is more striking than the magnetic symmetry and is an independent line of evidence in support of sea-floor spreading. A small, median perched graben along portions of the Juan de Fuca Ridge axis is floored by very recent basaltic flows which have unusual surface structures.

Numerous textural varieties of fresh basalts were dredged from the Blanco Trough and Parks Seamount. These are probably mainly "oceanic tholeiites" (low K_2O subalkaline olivine basalts), although alkali olivine basalts may occur on Parks Seamount. Dolerites and fine-grained gabbros were dredged from the Blanco Trough and from a ridge in the eastern part of the Blanco Fracture Zone, suggesting possible exposures of parts of seismic layer 2 of the oceanic crust. No serpentinites, serpentinized peridotites, or coarse-grained gabbros, rocks common in Mid-Atlantic Ridge fracture zones, were noted in the Blanco Fracture Zone.

Magnetic evidence supporting the hypotheses that the strike of the Blanco Fracture Zone is changing and becoming parallel to the San Andreas Fault was found. The lineations of the Juan de Fuca system continue uninterrupted across the northwest extension of the Blanco Fracture Zone, showing that the zone could not have had its present strike 2 million years ago.

PRELIMINARY RESULTS OF A GEOPHYSICAL STUDY OF PORTIONS OF THE JUAN DE FUCA RIDGE AND BLANCO FRACTURE ZONE

William G. Melson

INTRODUCTION

This report summarizes the preliminary results of the first portion of a proposed systematic study of the Juan de Fuca Ridge and immediate environs (fig. 1). The methods of study included routine bathymetric, magnetic, and gravity survey lines, and 15 dredge stations. Data presented here include summaries of the major bathymetric, magnetic, gravity, and petrologic features of the surveyed region. Table 1 lists the scientists who participated in the shipboard study and in the preparation of this report.

The survey area includes the southern portion of the Juan de Fuca Ridge, and the Blanco Fracture Zone. This specific portion of the proposed survey area was chosen for initial study because: (a) there may be major petrologic differences between the Ridge and the Fracture Zone, perhaps similar to those observed in the mid-Atlantic and of importance in constructing petrologic models of the oceanic ridge system (Melson, 1968); (b) this region is of particular interest in models of sea-floor spreading based on magnetic anomaly patterns (Morgan, 1968) and yet has not been magnetically surveyed (fig. 2); and (c) metabasalt fragments, perhaps indicative of the presence of exposures of the deeper oceanic crust along fracture zone faults, have been described from piston cores from the Blanco Fracture Zone (Duncan, 1968) but, prior to this study, had not been reported in dredge samples from the Pacific ridge and fracture zone system.

Most of the survey lines are clustered along the Blanco Trough and the southernmost portion of the Juan de Fuca Ridge (fig. 3). The amount of survey miles was considerably less than anticipated, because of foul weather during the survey period. A large swell (6-12 ft) was encountered throughout the survey, and there were gale winds on october 16, 21, 23, and 24. Rough seas (5-8 ft) occurred on October 17, 19, and 22; very rough seas (8-12 ft) on October 15, 16, 18, 20, 23, and 24; and high seas (12-20 ft) on October 21.

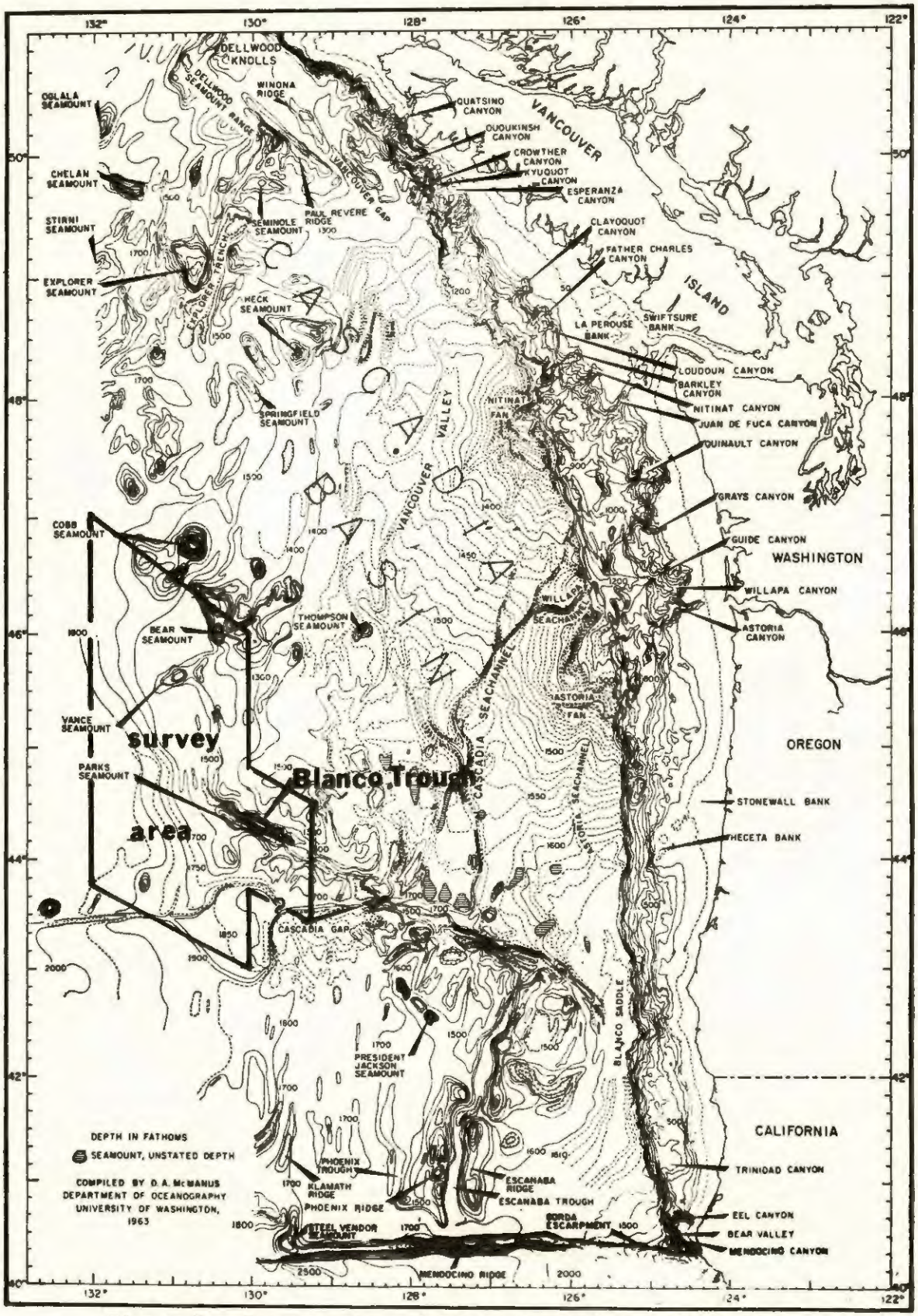

Figure 1.--Survey area and its major bathymetric features. (Bathymetry from McManus, 1964)

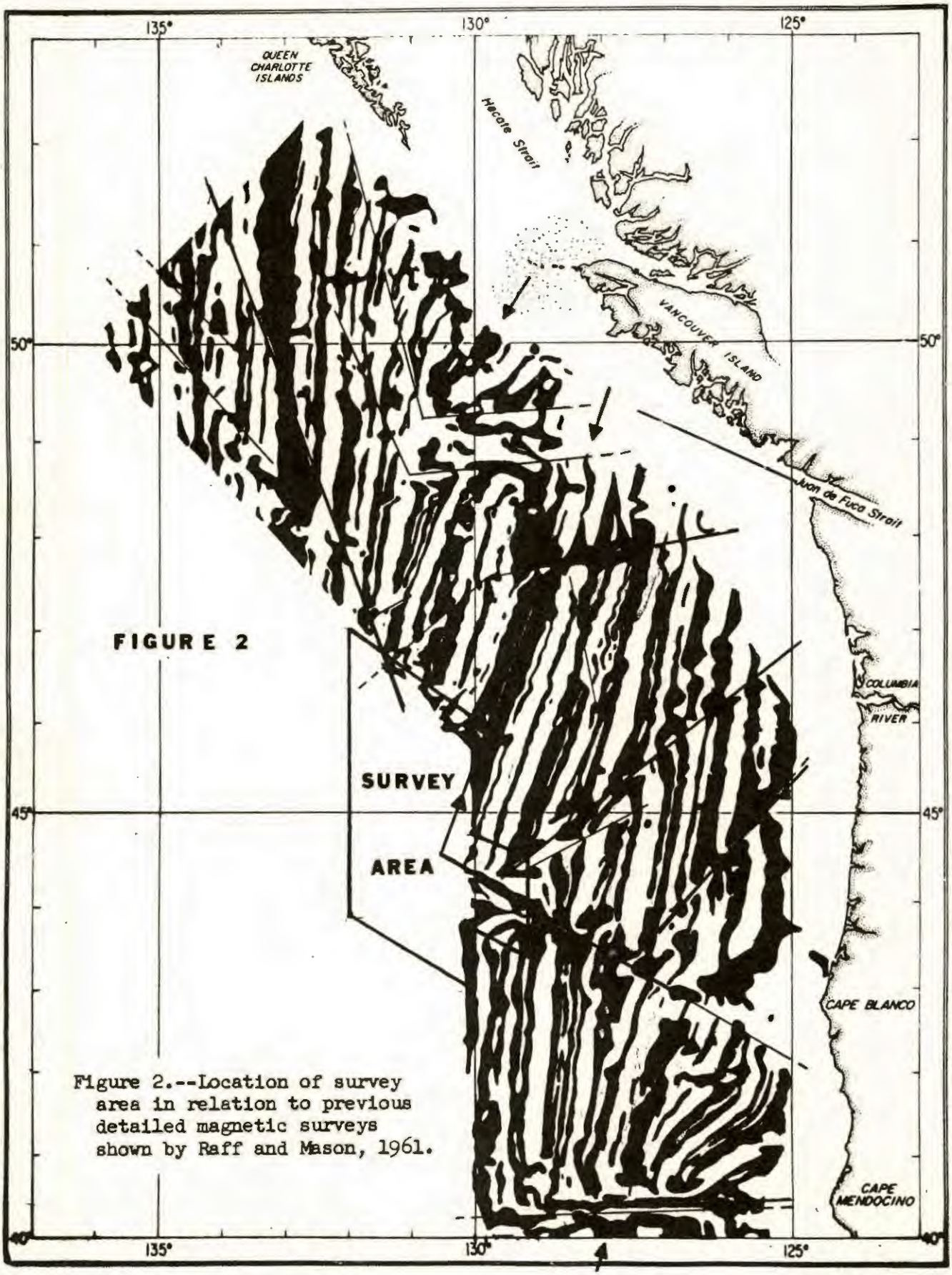

Figure 2.--Location of survey area in relation to previous detailed magnetic surveys shown by Raff and Mason, 1961.

Table 1. -- Division of scientific work during cruise

Bathymetry and sampling Control

John Duncan[2]
Thomas Simkin[1]
William Melson[1]

Magnetics and gravity

Jason Morgan[2]
Edward Higgins[2]

Petrology

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BATHYMETRY

The survey area is characterized by rugged bathymetric features that can be grouped into two distinct but related provinces: (1) the north-northeast trending Juan de Fuca Ridge, and (2) the west-northwest trending Blanco Fracture Zone. These provinces form the western and southern borders, respectively, of Cascadia Basin (fig. 1). The Blanco Fracture Zone is about 250 nautical miles (nmi) long and can be traced eastward from 131°W to a point 15 miles west of the foot of the continental slope off southern Oregon. The zone consists of a series of individual parallel and subparralel ridges and troughs with many of the ridges rising to water depths of 1300 to 1200 fathoms (fm). The troughs extend to depths of as much as 2500 fm and, with the crests of adjacent ridges, form a relief of up to 1600 fm. The crest-to-trough relief generally is on the order of 400 to 600 fm.

The Juan de Fuce Ridge merges into the western extremity of the Blanco Fracture Zone at about 44°30'N. In general, along most of its extent, the Ridge does not have a crest or a median valley as pronounced as those of

typical mid-ocean ridge systems. Instead, the relief is more subdued and less distinctive. The crest of the Juan de Fuce Ridge is generally at a depth of 1400 fm, although numerous seamounts have summits at much shallower depths.

Methods and Scope

New bathymetric data were obtained in the survey area along the tracklines as shown in figure 3. All soundings were made using a Precision Depth Recorder coupled with a stabilized narrow beam transducer. This equipment made it possible to obtain excellent PDR records which sharply outline the bottom features of the rugged area studied. Positioning for all track lines was accomplished by using Loran A fixes at 15-minute intervals. The positions of the fixes are estimated to be within 1 to 0.5 nmi of their true locations.

The bathymetric tracklines during this study were limited to specific physiographic and magnetic features of particular interest. The survey centered largely around the westernmost portion of the Blanco Fracture Zone and the adjoining portion of the Juan de Fuca Ridge. In particular, a deep trough, herein called "Blanco Trough" (fig. 1), was surveyed along north-south tracklines spaced at 5-mile intervals (see dashed inset of fig. 3). In this report, the discussion of the bathymetry is confined to the most significant features and trends noted in the preliminary examination of the PDR profiles.

Juan de Fuce Ridge

The transverse tracklines of the Juan de Fuce Ridge in the interval between 44°30'N and 45°00'N reveal remarkably symmetrical profiles which provide strong independent evidence for sea-floor spreading. A 10- to perhaps 30-mi segment of the ridge is characterized by transverse profiles similar to the profile shown in figure 4. The noteworthy features are the flat-bottomed axial rift valley, with 60 fm of relief, and the steeper slopes at 4 and 10 mi on each side of the ridge crest. Upon closer inspection of the profiles, several other symmetrical features of secondary order are also evident. The symmetry is detectable as far as 15 mi from the crest, but becomes less apparent with distance away from the crest.

Blanco Trough

An attempt was made to prepare a preliminary contoured bathymetric chart of the Blanco Trough. However, the slopes and ridge crest which border it were found to be topographically complex, and not simple northwest trending structures as had been anticipated. Scarps that trend roughly northward appear to be common, and numerous small, steep-sided features mark the east and west extremities of the trough and its bordering slopes.

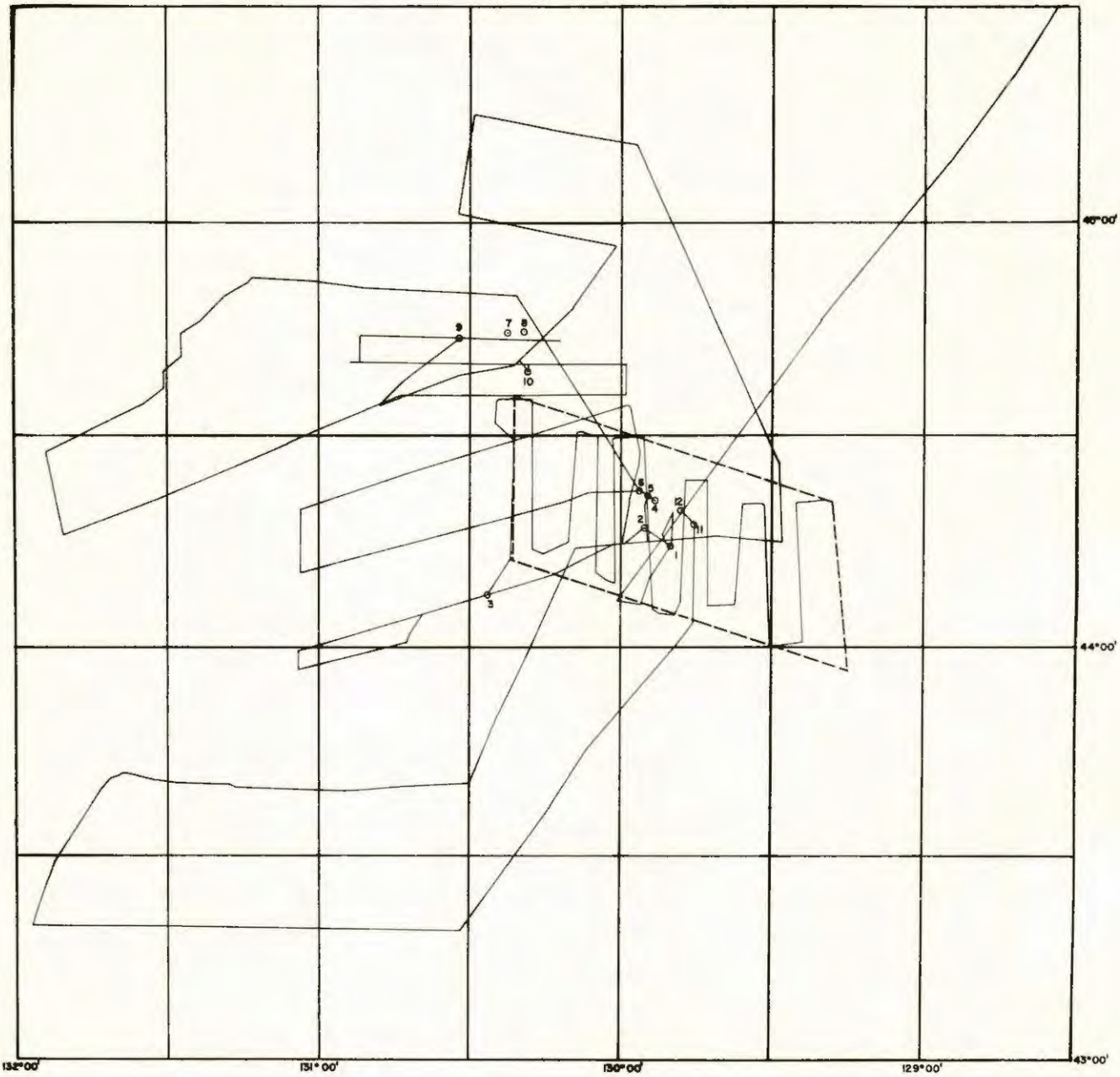
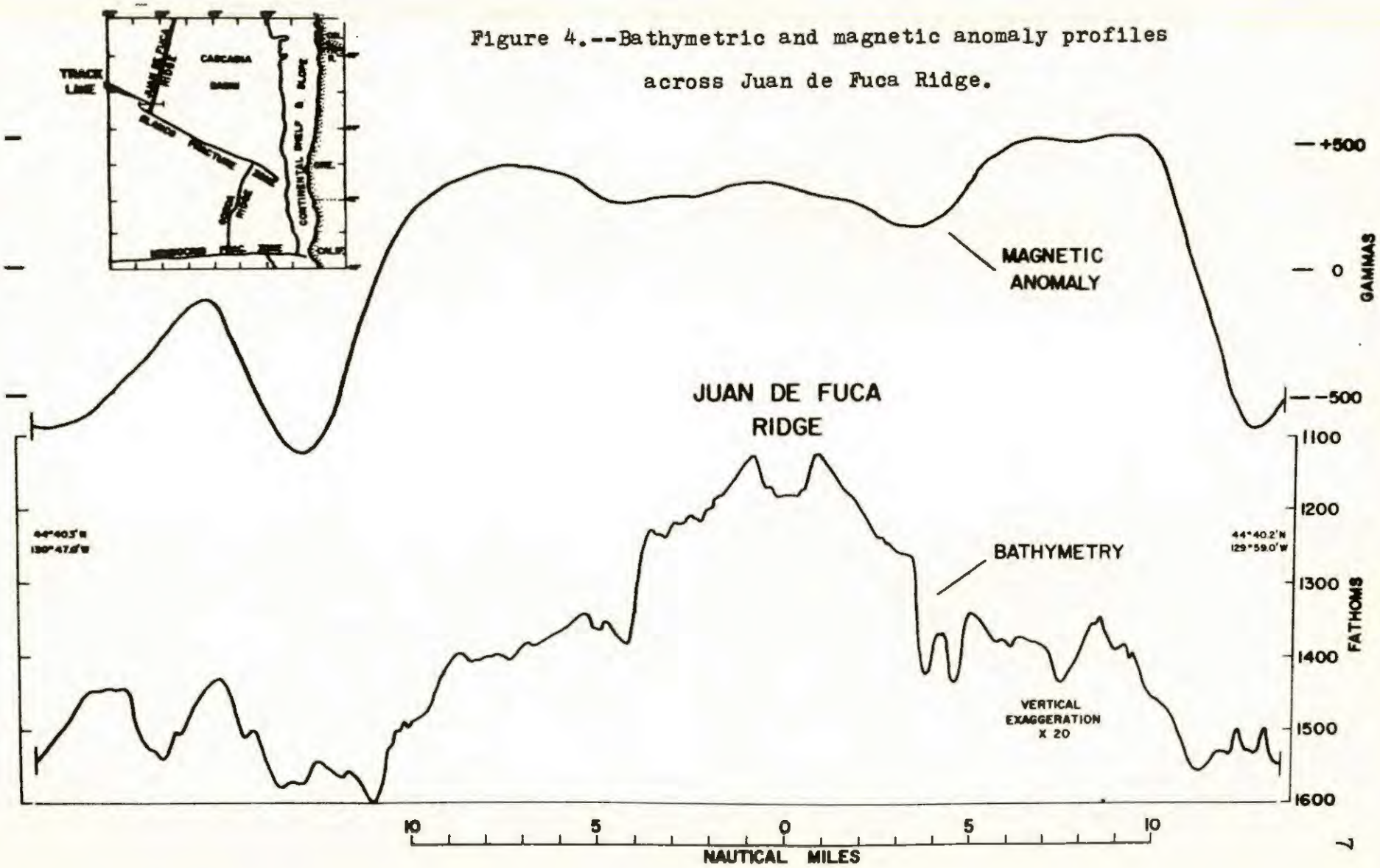


Figure 3.--Survey lines for geophysical study of Juan de Fuca Ridge--USC&GS ship Oceanographer, October 15-26, 1968. Dashed line indicates limit of special survey of Blanco Trough.

Figure 4.--Bathymetric and magnetic anomaly profiles across Juan de Fuca Ridge.



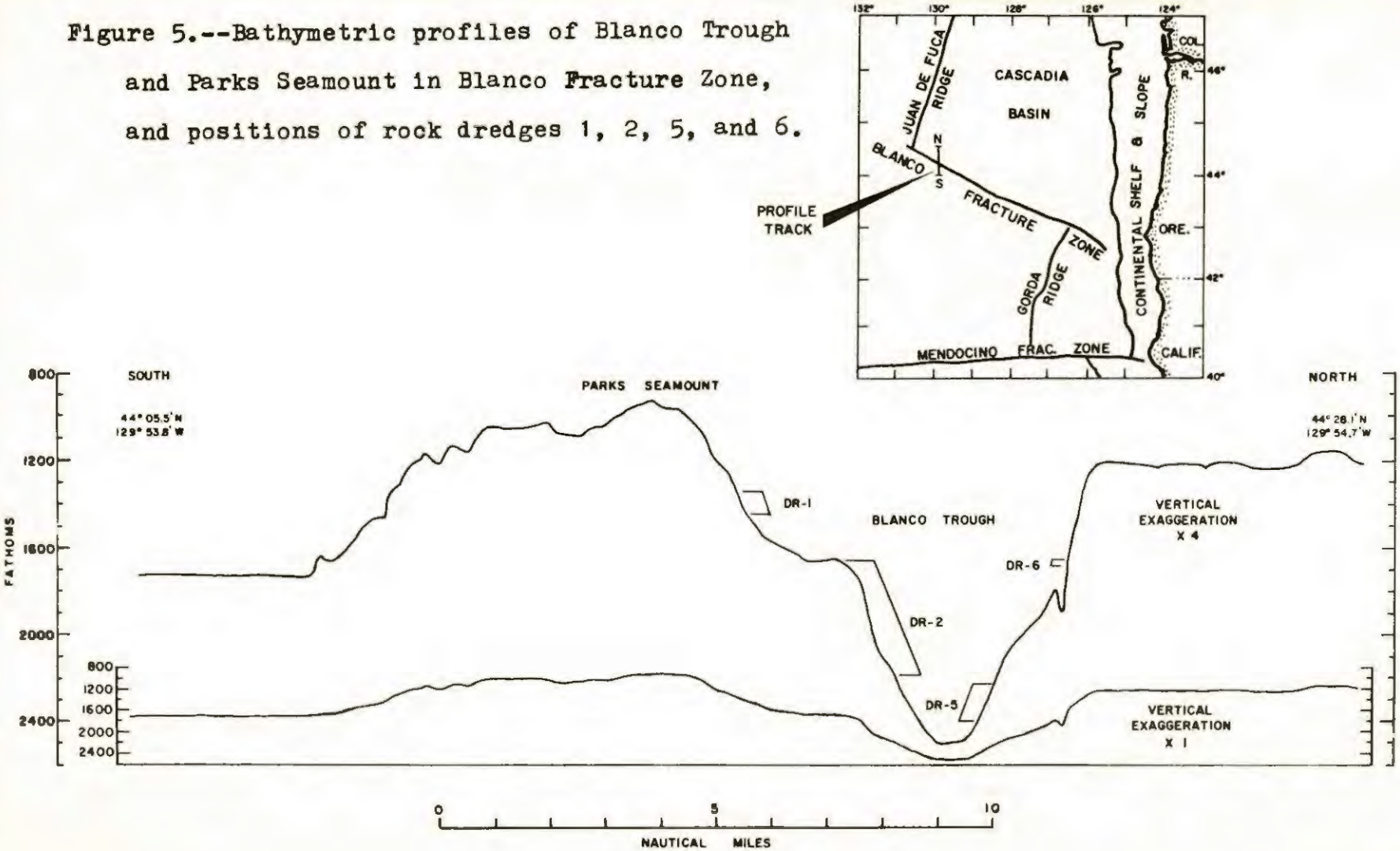
The trough reaches a maximum depth of around 2500 fm and has a sill depth of about 1600 fm. The deepest sounding obtained was 2550 fm (uncorrected). The area which lies below 2500 fm is estimated to be no more than 6 nmi long and averages about 0.3 nmi wide. The minimum slope of the trough's sides is about 20°; maximum slope angles are nearly 50°; and typical slopes are between 20° and 30° (fig. 5). The trough is asymmetrical along its axis; it rises rapidly to 1600 fm in the east, but does not reach that depth until near or perhaps beyond its junction with the Juan de Fuca Ridge.

The Blanco Trough is interpreted to be a graben, formed by approximately north-south directed tension along the western part of the Blanco Fracture Zone. This view is consistent with the gravity anomalies that were obtained across the feature.

Parks Seamount

This feature appears to be a volcanic edifice. Its shield-shaped profile has a long approximately east-west axis and a narrower north-south axis. The seamount appears to be distinctly separated from the Blanco Trough by a gentle slope or shoulder between the 1600- and 1700-fm contours. It also is petrologically and magnetically distinct from the Blanco Trough. Minimum depths of about 900 fm (uncorrected) were found on crossings of Parks Seamount. No attempt was made to determine systematically the minimum depth. It undoubtedly is somewhat less than 900 fm.

Figure 5.--Bathymetric profiles of Blanco Trough and Parks Seamount in Blanco Fracture Zone, and positions of rock dredges 1, 2, 5, and 6.



PETROLOGY

Attempts were made to characterize the rock types of the major bathymetric features. In most cases, a series of dredges were made at different depths up the same slope. Dredge sites were selected after bathymetric profiles were run, and dredge intervals on the same general slope were selected on the basis of steps or of discontinuities in slope angles. Dredge samples taken on this basis revealed considerable petrologic variations on the same slope.

There were 15 dredge stations (fig. 3) and bottom materials were obtained at all but two stations (stations 4 and 8). Table 2 summarizes the kinds of rocks found in each dredge, locality of sample, dredge depth interval, and approximate total amount of sample. Rock identifications were facilitated by on-board diamond sawing, binocular microscope inspection, and by petrographic determination of optical properties of minerals in difficult-to-identify samples. A discussion of noteworthy features of the rocks from the two main bathymetric regions follows.

Juan de Fuca Ridge

All samples are of basaltic lavas. The basalt samples in dredge 10, which were taken precisely from the flat, center portion of the median graben, are usually fresh and show marked structural differences from pillow lavas. The basalt fragments, most of which were broken from a flow surface, typically are thin (plate 1) and have a considerably thicker glass zone on one surface, presumably the outer surface, than on the other. Some show convolutions and other complex forms that were produced during the flow. Perhaps the differences between these basalts and the much more commonly dredged pillow lavas is attributable to differences between flow behavior on horizontal and sloping surfaces. In other words, pillow lavas may require down slope movement for their formations. Samples dredged farther down the slopes, and thus at greater distances from the center of the Ridge, consist of basaltic pillow lava fragments, with some manganese encrustation.

Chemical analyses of two fresh basalts from the median graben of the Juan de Fuce Ridge show that they are similar compositionally to most deep sea basalts except for slightly higher iron content (table 3). Also, one of the samples (2 in table 3) contains normative quartz, a feature rarely found among deep sea basalts.

Blanco Fracture Zone

Parks Seamount appears to be an irregularly shaped volcanic edifice, composed of pillow lavas which may range from typical "oceanic tholeiites" to alkali olivine basalts. It has a typical shield volcano profile in a north-south direction (fig. 5), but is elongated in a roughly east-west

direction. Figure 5 shows the dredge stations on the northern slope of Parks Seamount. The dredge on the middle slope (dredge 1) yielded a large collection of basalts including numerous textural varieties. Most were angular talus fragments, with thin manganese-rich encrustations. The fragments commonly show the radially developed columnar structure and outer variolitic glass rinds which characterize pillow lava fragments.

Sawed surfaces on some samples reveal numerous vesicles (plate 2), some of which are filled by soft, turquoise-colored mineral or mineral aggregates, which are as yet unidentified. Most samples contain at least a few scattered phenocrysts of olivine and plagioclase, and rarely there are aggregates of these phenocrysts; some samples contain abundant and large phenocrysts ($\frac{1}{2}$ inch in length). The phenocrysts are rarely rounded. A few large grains are rounded and may be either resorbed phenocrysts or xenocrysts.

A lower dredge (dredge 2) yielded additional fragments of pillow lavas from talus. In contrast to the upper dredge, vesicles are rare, and mineral-filled or partially filled vesicles were not noted. Similarities to the upper dredge include scattered phenocrysts of plagioclase and olivine.

Tentatively, based on as yet cursory examinations, the lower dredge appears to contain basalts with typical textures and mineralogy of the "oceanic tholeiite" family (low K_2O olivine basalts), whereas the upper dredge, based on the greater number of phenocrysts may contain alkali olivine basalts as well as "oceanic tholeiites." The greater vesicularity of the upper flows is attributable to (a) higher volatile contents than those of the flow fragments recovered in the deeper dredge, or (b) equal volatile contents of all the lavas, but the shallower depth (lower pressure) of extrusion of the upper flows, or (c) a combination of these.

Blanco Trough is characterized by fresh to weathered basalts, basaltic breccias (plate 5), outcrops of dolerites (plate 4) in its central portion, a few fragments of low-grade hydrothermally altered basalts, and by unaltered basalt on the north side near its eastern end.

Dredges 5 and 6 (fig. 5) from the northern slope of the Blanco Trough yielded basalts which macroscopically appear to be "oceanic tholeiites;" that is, they are mainly aphanitic and contain a few scattered phenocrysts of olivine and plagioclase. Saponite and a mixed-layer clay (predominately also a smectite), identified by the method of Warshaw and Roy (1961), are abundant in all of the altered rock types from this region. These clays occur as devitrification products of basaltic glass, as veins and vesicle fillings, and in pools disseminated throughout the host rock.

Fragments of greenstone were recovered in a core taken at the base of a ridge near the eastern end of the Blanco Fracture Zone (Duncan, 1968). These consisted in part of the typical greenschist facies assemblage albite-epidote-chlorite-actinolite, and included probably lower grade

Table 2.--Contents, locality, depth interval, and total weight of dredge hauls

DREDGE CONTENTS	DREDGE HAUL NUMBER												
	1	2	3	5	6	7	9	10	11	12	13	14	15
BASALT													
_____ altered (mainly due to submarine weathering).....	R	R											
_____ pillow fragments	A	A		C	C								
_____ porphyritic, with plagioclase and olivine phenocrysts	A	C			C				C				
_____ porphyritic, with abundant plagioclase phenocrysts	R	C		C	C					R			
_____ porphyritic, with abundant olivine phenocrysts	R	C	C	C	C					R			
_____ tuff				C	C								
_____ vesicular	A	R	R	R	C				R	C			
DOLERITE													
_____ fresh				R	R								
_____ hydrothermally and/or dueterically altered				C	C						C		
GABBRO, FINE-GRAINED											R		
GLASS, BASALTIC (individual fragments and/or rind on pillow fragments)													
_____ devitrified.....	C	C		C									
_____ fresh	R	C	R	R	C			A					
GREENSTONE										R	C		
_____ breccia											R		
MANGANESE CRUSTS	R	R		R			A		R	C	R		
MANGANESE NODULES												A	A
SEDIMENT													
_____ lithified				R									R
_____ unconsolidated.....				A		R	R		A	R	A		
FORAMINIFERA.....	R				A	R				R			

KEY: A = abundant; C = common; R = rare.

Table 2.--Contents, locality, depth interval, and total weight of dredge hauls--Continued

NUMBER AND DESCRIPTION OF DREDGE HAUL

1. Upper south side of the central part of the Blanco Trough (Parks Seamount), 44°15'N, 129°50'W. Dredge interval, 2482-2655 m. Dredge contents, 100 lbs.

2. Lower south side of central part of the Blanco Trough (Parks Seamount), 44°16'N, 129°55'W. Dredge intervals, 3042-3995 m. Dredge contents, 75 lbs.

3. Knoll, southwest of Parks Seamount, 44°10'N, 130°25'W. Dredge interval, 2435-2560 m. Dredge contents, 5 lbs.

5. North base of the central part of the Blanco Trough, 44°20'N, 129°55'W. Dredge interval 4090-4392 m. Dredge contents, 75 lbs.

6. Middle portion of the north side of the central part of the Blanco Trough, 44°25'N, 129°55'W. Dredge interval, 3084 m (constant). Dredge contents, 75 lbs.

7. Middle portion of the southwest side of the Juan de Fuca Ridge, 44°45'N, 130°25'W. Dredge interval, 2575-2600 m. Dredge contents, <1 lb.

9. Near the base of the southwest side of the Juan de Fuca Ridge, 44°45'N, 130°30'W. Dredge interval, 2995 m (?). Dredge contents, <1 lb.

10. Median valley of the Juan de Fuca Ridge (southern Portion), 44°40'N, 130°20'W. Dredge interval, 2195-2220 m. Dredge contents, 50 lbs.

11. Lower north side of the southeast central part of the Blanco Trough, 44°20'N, 129°45'W. Dredge interval, 3445 m (constant). Dredge Contents, 15 lbs.

12. Upper north side of the southeast central part of the Blanco Trough, 44°20'N, 129°50'W. Dredge interval, 2630-3140 m. Dredge contents, 3 lbs.

13. Lower south slope of ridge south of Blanco Fracture Zone (see figure 6). Dredge interval 2980-3230 m. Dredge contents, 35 lbs.

14. Upper south slope of ridge south of the Blanco Fracture Zone (see figure 6). Dredge interval 2616-2836 m. Dredge contents, 5 lbs.

15. Upper north slope of ridge south of the Blanco Fracture Zone (see figure 6). Dredge interval, 2302-2438 m. Dredge contents, <21 lbs.

Table 3.--Chemical analyses of fresh basalts from central basalt-floored graben near southern end of Juan de Fuca Ridge (44°40'N., 130°20'W, 2193-2220M). Gene Jarosewich, analyst.

	1	2	3	4	5
SiO_2	49.95	50.42	49.21	0.74	49.34
Al_2O_3	14.80	13.90	15.81	1.50	17.04
Fe_2O_3	1.74	2.01	2.21	0.74	1.99
FeO	9.15	10.54	7.19	1.25	6.82
MgO	7.75	6.92	8.53	1.98	7.19
CaO	12.04	11.34	11.14	0.78	11.72
Na_2O	2.48	2.51	2.71	0.19	2.73
K_2O	0.10	0.13	0.26	0.17	0.16
H_2O+	0.11	0.16	------	----	0.69
H_2O-	0.07	0.07	------	----	0.58
TiO_2	1.48	1.81	1.39	0.28	1.49
P_2O_5	0.12	0.16	0.15	0.04	0.16
MnO	0.19	0.21	0.16	0.03	0.17
	99.98	100.18			
Q	---	.53	--	--	--
OR	.59	.77	1.54	--	.95
AB	20.99	21.24	22.93	--	23.10
AN	28.96	26.28	30.21	--	33.77
DI	24.51	23.84	19.43	--	18.88
HY	15.25	20.57	11.21	--	12.16
OL	3.89	--	7.25	--	3.87
MT	2.52	2.91	3.20	--	2.89
IL	2.81	3.44	2.64	--	2.83
AP	0.28	0.37	0.35	--	0.37

1. USNM 111276 (original no. 10-251).
2. USNM 111275 (original no. 10-252).
3. Average of 33 fresh basalts dredged from the Mid-Atlantic Ridge, at depths greater than 1000 meters.
4. Standard deviation of average in Column 3.
5. Average 'oceanic tholeiite' (Engel, Engel, Havens, 1965).

assemblages as well as only slightly hydrothermally altered basalts. The fragments do not show a pervasive foliation, although slickensided, chlorite-coated surfaces are common. Analogies were drawn between these samples and some of the greenstones previously described from the Mid-Atlantic Ridge (Melson, 1966). During the cruise an attempt was made to locate the source of greenstone fragments which were judged to be locally derived. The stations and bathymetric profile of the dredge locality are shown in figure 6. Dredge 13 from the lower slopes of the ridge yielded a large and varied collection of rocks, including slightly hydrothermally altered dolerites and fine-grained gabbros, as well as greenstones composed of considerable chlorite, possibly saponite, and other minerals. No schistose fragments were collected. Epidote-bearing greenstone varieties are rare, and the greenstones, which appear in part to be meta-pillow lavas, are probably of sub-greenschist facies. Alteration of the dolerites may reflect deuteric alteration or post-cooling hydrothermal metamorphism.

These samples appear to confirm a local source for the greenstone fragments and, combined with dredges taken from the upper slopes, suggest that the ridge (fig. 6) is a fault-bound block. These faults evidently have exposed some rocks which originally crystallized hypabyssally, some of which possibly were metamorphosed at some distance within the oceanic crust. In a hydrothermal fissure system, depth of metamorphism may be quite shallow, perhaps less than a kilometer. Deeper depths of metamorphism cannot, however, be ruled out. Dredges from the upper slopes did not encounter outcrop nor significant talus accumulations. The samples yielded only a few small rock fragments but numerous fragments of manganese oxide crusts and nodules, suggesting a relatively stable, undisturbed regime along the upper portion of the ridge. This stable feature of the upper slope, combined with outcrops of rock near the base of the ridge, is consistent with the view that the ridge is an uplifted, faultbounded block (horst).

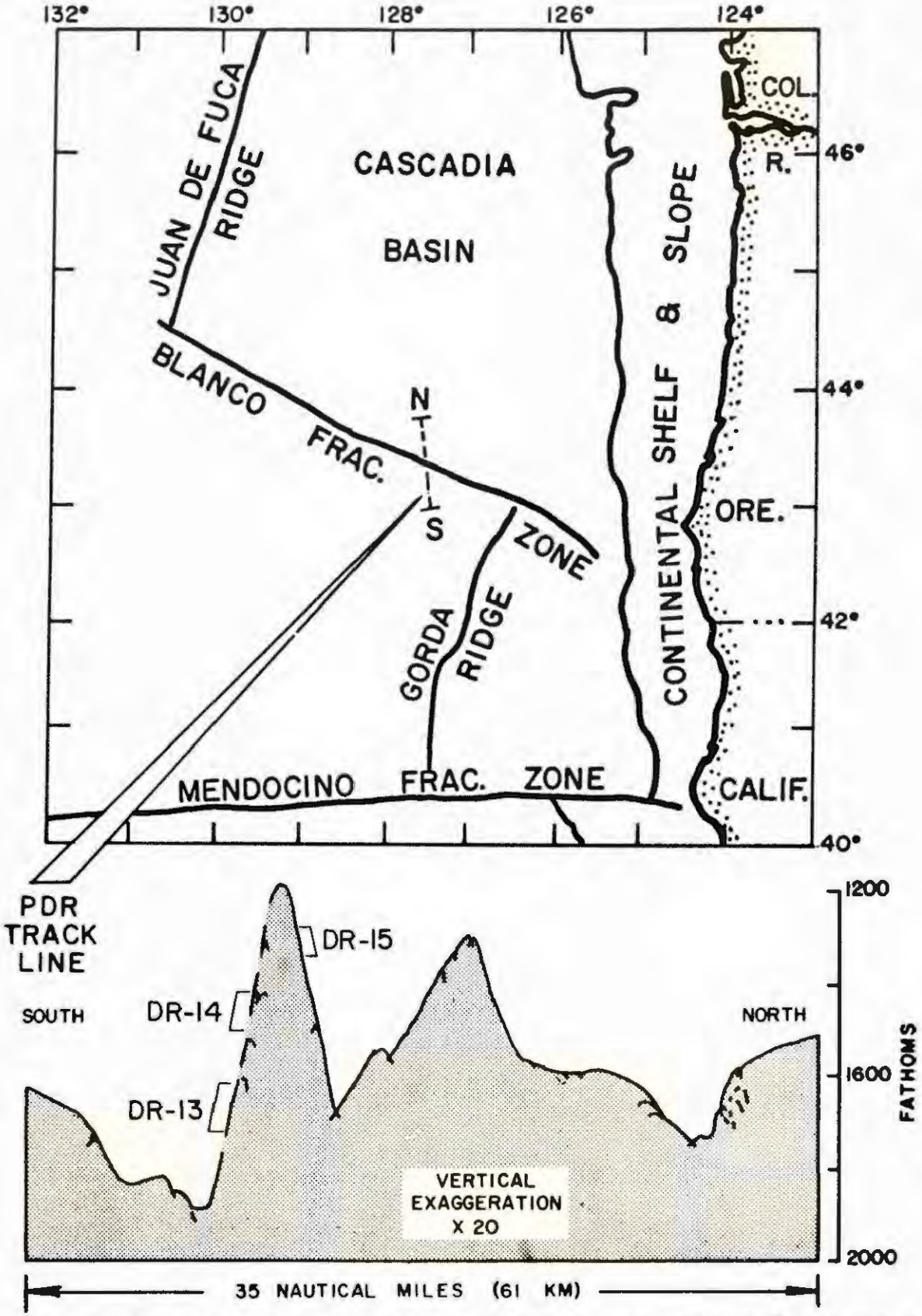


Figure 6.--Profile of dredging locality in Blanco Fracture Zone and positions of dredges 13, 14, and 15.

MAGNETICS

The purpose of the magnetic survey was to extend the boundaries of detailed magnetic coverage (Raff and Mason, 1961) into the area surrounding the junction of the Juan de Fuca Ridge axis and the Blanco Fracture Zone. Bad weather reduced the number of survey miles obtained and often determined the direction in which the lines could be run. The northern portion of the proposed survey was not completed. The fault A-A shown in the summary diagram (fig. 9) was not investigated. It remains to be seen if this fault continues southeastward to the Juan de Fuca axis (perhaps this will be a new transform fault in the region), or if it is an old fault which does not offset the younger magnetic pattern.

The magnetic data were obtained each minute from a proton precession magnetometer towed 700 ft behind the ship. A regional magnetic field -- using the spherical harmonic coefficients of Hendricks and Cain (1966) -- was computed for October 1968. These values were subtracted from the measured total intensity values to obtain the magnetic anomaly. The anomalies here do not have the same datum as the Pioneer Survey (Hendricks and Cain, 1966); anomalies from tracks east of 130°W will be compared to Raff and Mason's (1961) map to determine a constant to be added to the anomalies calculated here in order to make the two maps blend into one another. No corrections were made for ship's heading, magnetic storms, or diurnal variations.

A preliminary magnetic anomaly map of the area near the junction of the Juan de Fuca Ridge axis and the Blanco Fracture Zone is shown as figure 7. About 25 percent more lines are yet to be added to the base from which this contour map was made, but these are short segments and should change only minor details. As mentioned above, a constant value will be added to these points to better merge with Raff and Mason's map. The area north of about 44°25'N has the linear strike of the Juan de Fuca Ridge and was confidently contoured. The area south of this parallel is obviously more open to reinterpretation.

Four features of this map are noteworthy. In the northern portion of the map, the central anomaly, the Jaramillo event, the Olduvai event, and the Gauss normal interval are clearly present. The features are identified in figure 7 by the numbers 0, 1, 2, and 3, which roughly correspond to the age of these features in millions of years. Second, the southern portion of the map has an irregular pattern. Third, there is a very intense positive anomaly (+1500 gamma) at the junction of the ridge axis and the trough. This large anomaly probably has tectonic significance, but surprisingly has no outstanding topographic expression. It is desirable to study this junction more thoroughly on a future cruise. Fourth, a region of positive magnetic anomaly follows the south wall of the Blanco Trough. This feature is apparent on the map shown here and in the north-south profile across the trough shown in figure 10. This feature will be discussed elsewhere.

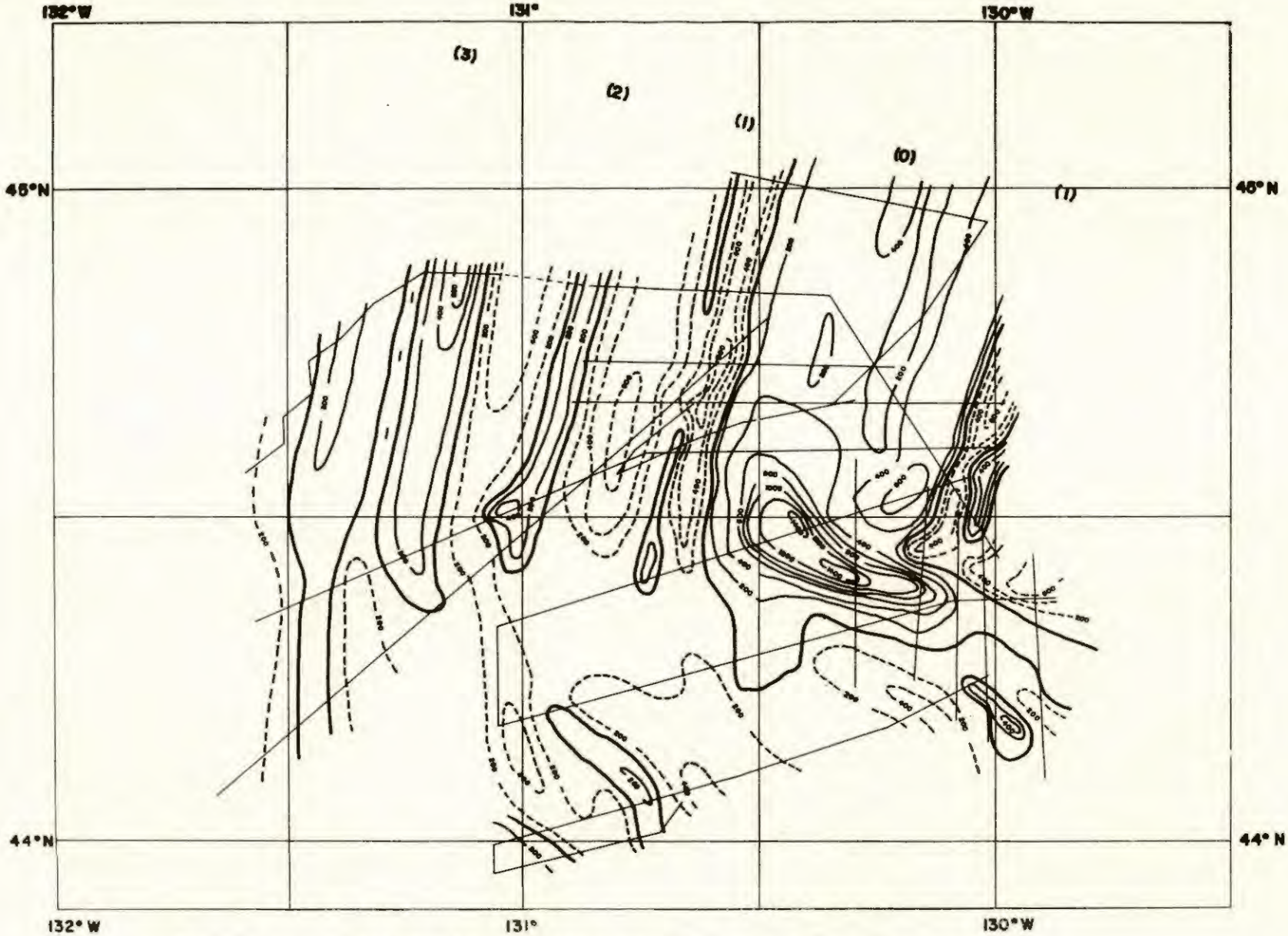


Figure 7.--Preliminary magnetic anomaly map of region near Juan de Fuca Ridge - Blanco Trough Junction.

The lack of a linear pattern south of 44°25'N and the existence of the Juan de Fuca pattern north of this parallel is very significant. These data lead one to conclude that the Blanco Fracture Zone has changed its strike to become more closely aligned with the San Andreas fault system. If the Blanco were a typical fracture zone, it would have an inactive extension trending toward the northwest for as far as would correspond to the age of the Juan de Fuca Ridge system times its spreading rate. This extension would offset the magnetic lineations. North of this line there would be the pattern of the Juan de Fuca and south of the line there would be the pattern of the Gorda. Instead, the Olduvai and Gaussian anomalies of the Juan de Fuca system continue across the hypothetical extension. This continuity may be explained if we assume that the Blanco is changing its strike in an attempt to become parallel to the San Andreas (Morgan, 1968). The irregular magnetic pattern in the south of this figure then results from the older fracture zones that were formerly active in this region. This is analagous to the irregular magnetic pattern north of the easternmost Blanco Fracture Zone. This irregular pattern may be further confused by possible east-west trending features that have been sampled by predominately east-west traverses.

South of the irregular pattern, there should be the undisturbed pattern associated with the Gorda Ridge segment. Two lines just south of the area of the contour map (see track lines in fig. 2) were run. The magnetic anomalies of these two lines are compared to magnetic anomalies measured just north of the Mendocino Fracture Zone (Raff and Mason, 1961) in figure 8. Clearly, the Gorda pattern is continuous up to at least latitude 43°40'N. The data here are not sufficient to display the sequence of events involved in this change of strike of the Blanco. A series of east-west lines between 43°40'N and 44°40'N extending from 130°W to, say, 135°W should provide the necessary data. Figure 9 summarizes the finding of this survey and shows how the study relates to the previous magnetic work.

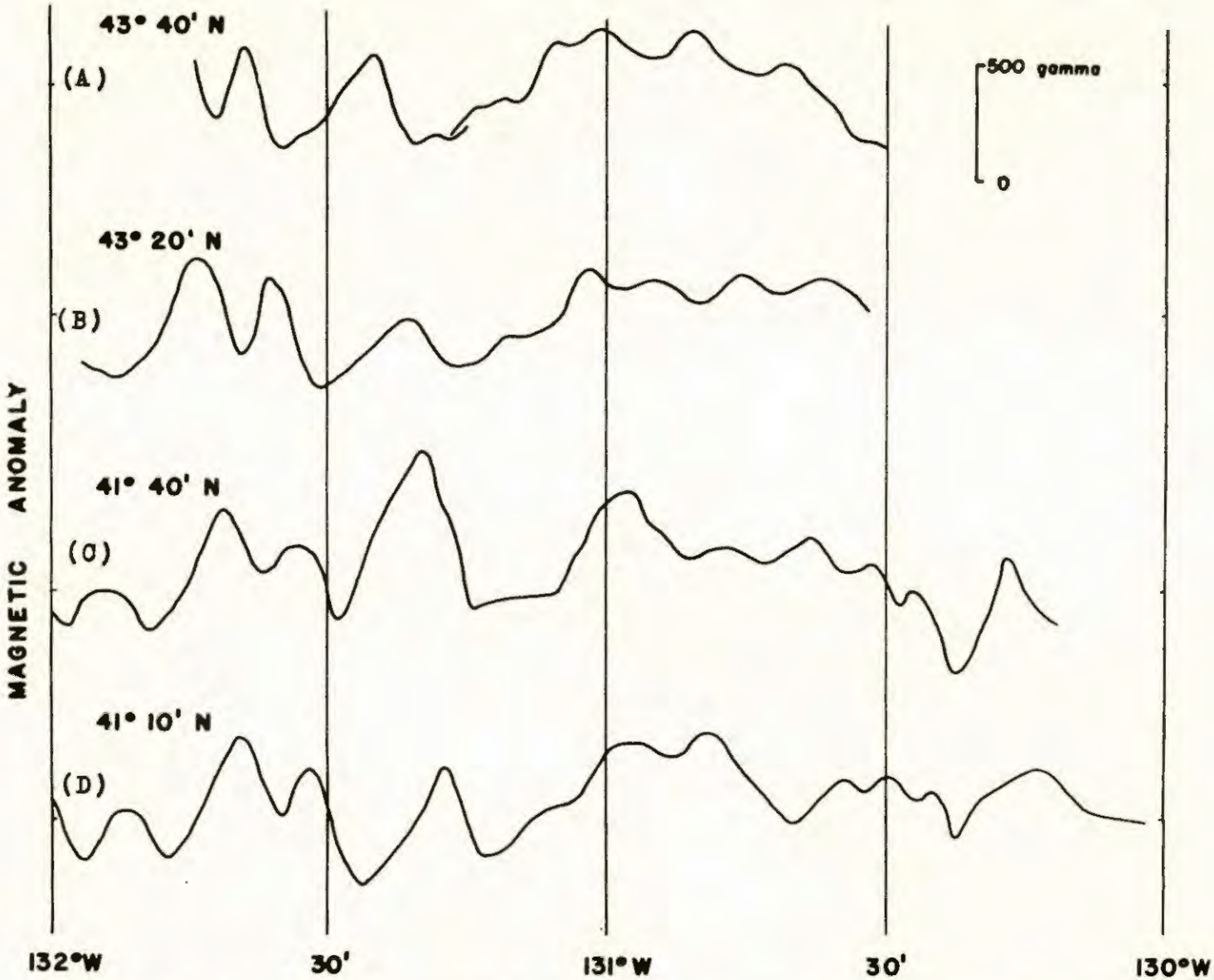


Figure 8.--Southernmost magnetic profiles of survey (A,B) and profiles near Mendocino Fracture Zone (C,D).

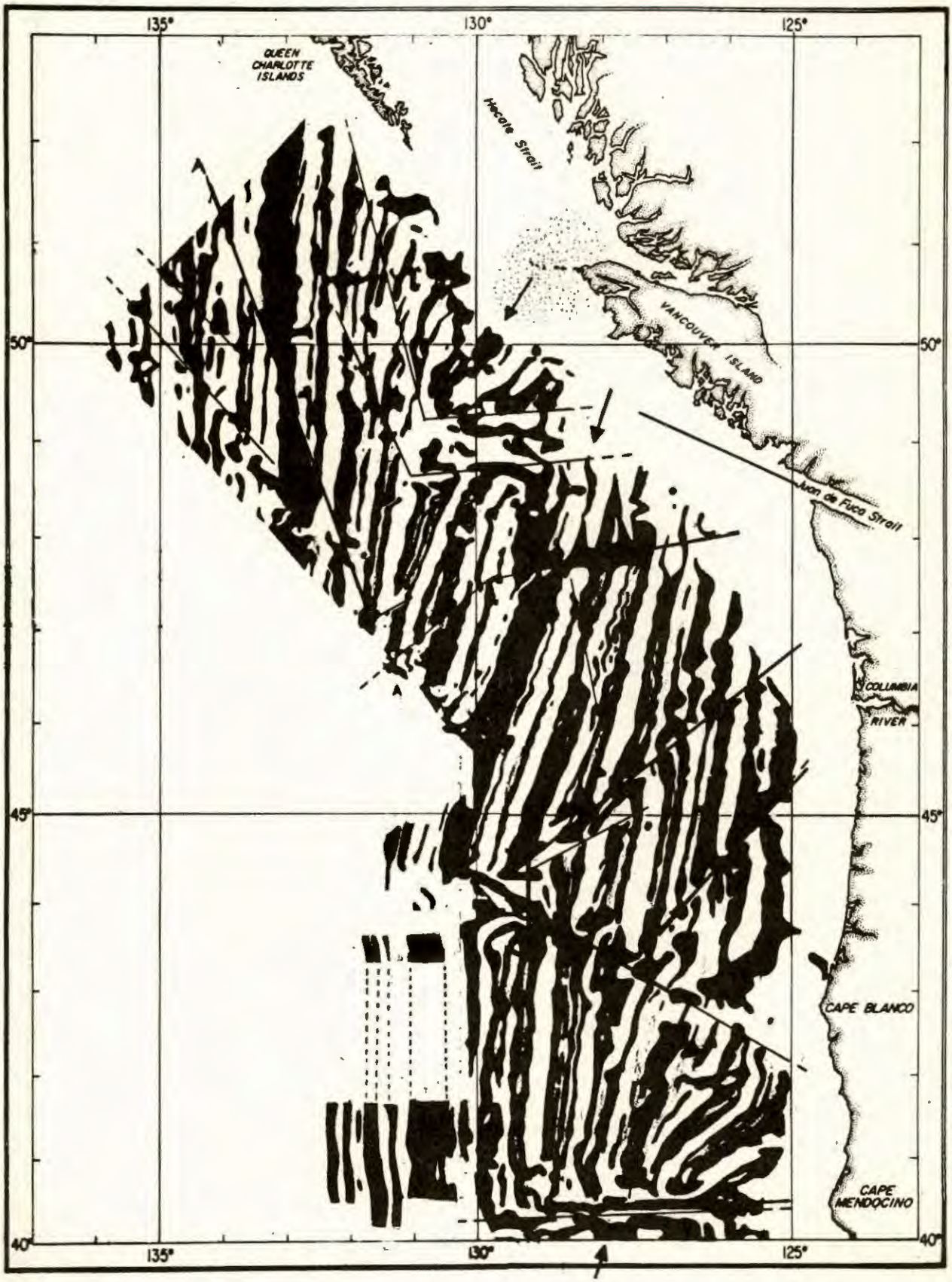


Figure 9.--Summary magnetic anomaly map showing how the area surveyed relates to previous surveys.

GRAVITY

A gravity survey of the study area was performed using the Oceanographer's Askania Gss 2 Model C Seagravimeter mounted on an Anschutz gyro-stabilized platform. Gravity measurements were obtained on all track lines within the survey pattern whenever sea surface conditions were below sea state 5. Because of the short traverse legs, with frequent course and speed changes, some portions of the data must be discarded due to inability of the gravimeter to adjust rapidly to large accelerations. All gravimeter data were logged digitally using the Oceanographer's computer facilities. Together with navigation and bathymetric data, the gravimeter values are compiled into free-air and Bouger anomaly maps of the area.

Due to the failure of facilities on board for the reduction of the gravity data, only one profile was reduced and analysed. Figure 10 shows this profile: a north-south traverse across the Blanco Trough. A broad -75 mgal free-air anomaly occurs above the trough as was qualitatively but not quantitatively expected from the bathymetry of the trough. The simple Bouger anomaly profile shows a sharp +100 mgal relative anomaly associated with the deepest portion of the trough. Since the simple Bouger anomaly was used, as opposed to the complete Bouger anomaly (terrain corrected), the actual magnitude of this high will not be as great as the simple profile indicates. The high, which nevertheless does exist, may be indicative of a narrow upwelling of the mantle along the axis of the trough, as one might expect to occur along a zone of rifting and shearing.

The trough is 2500 fm deep in a region of generally 1500 fm depth. This 1000-fm relief, coupled with a basalt-water density contrast of 1.7 gm/cm^3, should produce a negative free-air anomaly over the trough of -130 mgal if there are no density inhomogeneities in the crust or mantle and the crust-mantle boundary (Moho) is flat. The fact that we observe only a -50 mgal free-air anomaly shows that some compensation has occurred. If this compensation occurs only in crustal thinning, we may assume that the Moho rises about 3 km beneath the trough. It is too early to do more than estimate the relative magnitude of crustal thinning. Analysis of the full series of survey lines and computation of the terrain-corrected Bouger anomalies for the entire region will be necessary before a more definite statement is possible.

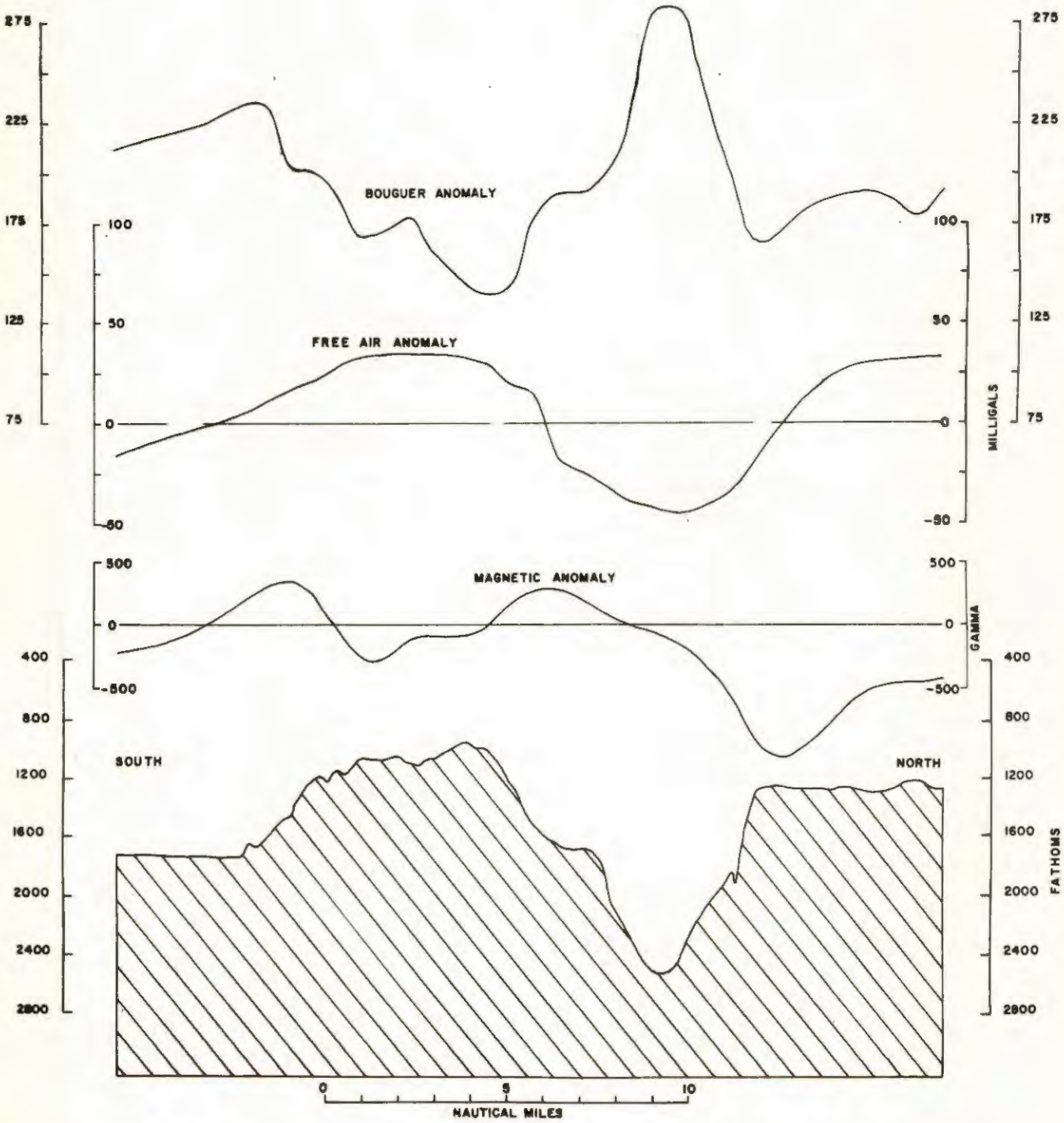


Figure 10.--Gravity and magnetic anomaly profiles across Blanco Trough at profile track shown on figure 5.

DREDGING

The dredging operation was accomplished by attaching the main dredge and its heavy anchor chain (fig. 11) to 45,000 ft of stepped (3/4- to 3/8-inch) cable on the 150-hp winch of the aft main deck. The dredge was lowered quickly to within a few hundred meters of the bottom and a series of lowerings and ship maneuvers followed. Wind and sea generally prevented drifting up slope so the ship moved in an up-slope direction until bottom contact was indicated. Although the length of cable paid out in dredging operations often ranges from one and one-half to 2 meters for every meter of water depth, the heavy anchor chain ahead of the dredge helped hold it on the bottom and cable-to-depth ratio was less than 1.15-to-1 throughout 12 succesful dredges. Time required to obtain each dredge sample ranged from 108 to 205 min and the average time was $2\frac{1}{2}$ hr per dredge station. Roughly half of the time on any station was used to lower and raise the dredge and the remaining time was divided between maneuvering (from first winch stop to first bite) and actual dredging. The dredge was on the bottom an average of nearly one-half hour per station. During the last 5 stations it was possible to reduce maneuvering time to nearly one-half hour. Control of the dredging operation--in addition to the usual indicators of ship position, bottom depth, cable out, and cable tension--was increased by two other instrument techniques: 1) A pressure recorder was attached to the cable near the dredge (fig. 11) to allow reconstruction of dredge depths after completion of each station, and 2) A tension recorder was used to graphically record the load cell tensiometer reading of cable tension and rate of tension change.

Pressure Recorder

This device consists of a cylindrical chart drum that is rotated on its axis by a clock mechanism as a Boudron pressure tube deflects a stylus around the drum to produce a direct plot of pressure vs time. A 12 hr clock and 80,000-psi pressure gage were used. These components performed satisfactorily for the maximum dredge depth of 4400m. A 6-hour clock would have been a better choice, but it was possible to easily identify one-minute events on the trace of the 12-hr clock. A calibration table for the instrument was used to convert pressure readings (in psi) to water depths (in meters), using values of mean density of a seawater column for the northeast Pacific from Table 17 of H.O. Pub. 607 (U.S. Naval Oceanographic Office). A graph was constructed to relate gage deflection to water depth. Accuracy of instrument calibration was checked in two ways. First, the pressure recorder was attached to the cable of a STD (salinity-temperature-depth) cast to 2000 m and the pressure record indicated a maximum depth of 2010 m. Second, another test opportunity occurred as the flat floor of the Juan de Fuca Ridge median valley was being dredged (dredge 10) when the dredge lay quietly on the bottom for some time before starting to bite. The PDR consistently recorded a depth of 2180m to the valley floor. The reduced sounding (applying sound velocity corrections from a STD cast in nearby water) was 2223 m and a depth of 2220 m was indicated by the pressure record. The pressure recorder proved of great

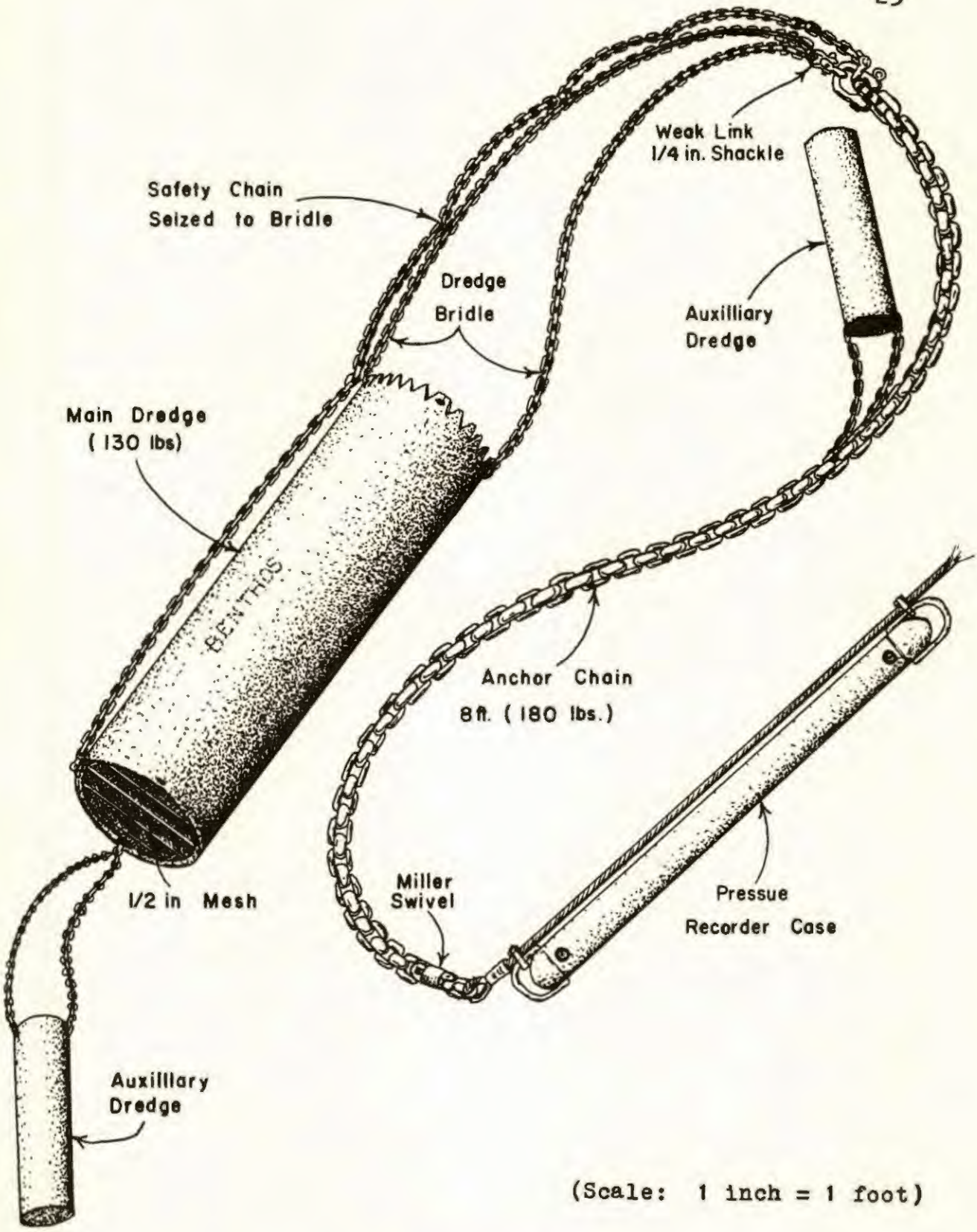


Figure 11.--Dredge array used for Juan de Fuca Ridge Project during October 1968 survey by USC&GS ship Oceanographer.

value because impact of the recorder housing caused vibration of the stylus. This produced a broad "depth band" on the record, but the stylus immediately returned to a thin trace when undistrubed. The trace therefore indicated intensity of impacts at the same time that it recorded depth and time of impact. By studying the pressure record of the first dredges, it was possible to spot wasted time and to complete later dredges in less time.

Tension Recorder

This instrument produced a permanent graphic record of both cable tension and rate of tension change as detected by the tensiometer. The record could be monitored, compared with previous traces to determine varying dredging conditions, and later correlated with other data from the same dredge haul. Characteristic features of the tension trace record show what the dredge is doing and this is a great help in interpreting dredge behavior.

AGES OF ROCKS AND BATHYMETRIC FEATURES

Estimates of the ages of rocks and bathymetric features in this region may be obtained from identification of magnetic anomalies, and correlating these with bathymetry and dredge stations. The validity of this method is dependent on the validity of the Vine-Matthews interpretation of the origin of oceanic ridge system magnetic anomalies, an interpretation we believe to be correct.

Figure 7 shows the magnetic anomalies in the region of principal interest, and the approximate ages of anomalies in millions of years. The central high portion of the Juan de Fuca Ridge (fig. 4) is less than 1 million years old up to 25 nmi from the axis. Assuming steady-state sea-floor spreading, the central "perched" graben began formation no longer than 50,000 years ago, and the basalts which compose the upper part of its floor may be less than a few thousand years old. This view is in accord with the fresh state of the basalts dredged at station 10 (fig. 3). Unfortunately, dredges at stations 7 and 9, in areas of presumably older basalts, yielded only manganese crusts and pelagic mud.

The central portion of the Blanco Trough and part of its southern slope has a positive anomaly of the Juan de Fuca Ridge. This suggests that the basalts which compose most of the crust in this region are quite young, probably less than a million years old.

On the other hand, the north side of the trough is characterized by a negative anomaly which correlates with a magnetic anomaly age roughly between 1.5 and 2.5 million years. The dredge samples do not appear to give unequivocal evidence of an older age for the rocks of the north slope compared to the rocks of the south slope. However, the occurrence of deep-seated rocks (low grade metabasalts, dredge 11) only on the north slope, where presumably rift faulting without recent concomitant extensive lava flows may be in process, is in accord with an older age of the north slope.

Parks Seamount has a slightly negative anomaly over it on one crossing (fig. 10), suggesting it may be composed largely of basalts older than 0.7 million years.

The strong positive anomaly (over 1400 gammas) at the junction of the Juan de Fuca Ridge and Blanco Fracture Zone is a striking feature of the region. It coincides with rugged terrain dominated by northward trending ridges which appear to be transected by the westward extension of Blanco Trough. This anomaly may be a result of extensive recent basaltic extrusion and intrusion combined with rapid graben formation from (a) the normal east-west crustal extension along the Juan de Fuca Ridge and (b) the north-south directed extension associated with the postulated rotation of the Blanco fault zone. (Morgan, 1968)

ACKNOWLEDGMENTS

The success of this project was possible because of the cooperation and skill of the officers and crew of the USC&GS ship Oceanographer and the excellent research capabilities of the ship. Special thanks are due Commanding Officer, Capt. John O. Phillips; Executive Officer, Cdr. Merlyn E. Natto; and Operations Officer, Lt. Cdr. Dee E. Kimbell. Of 15 deep-sea dredge stations, 13 were successful. This unusually high percentage of successful dredges is attributable largely to the skill of the Oceanographic Officer, Lt. Michael H. Fleming, and the crew operating the deep-sea winch. The project also involved: setting up a petrographic laboratory and diamond saw in the oceanographic laboratory; special assistance in using a pressure recorder on the dredge wire; special assistance in electronic monitoring at two hydrophone stations; modifications of computer facilities to meet magnetic and gravity reduction requirements; preparation of preliminary boat sheets at a scale unanticipated in the project instructions; numerous photographic tasks to make scale changes on bathymetric charts during the cruise; special positioning requirements during selection of dredge sites and during detailed surveying of the Blanco Trough; and special assistance in preparation of this report -- provided largely by Daniel Twohig and George Thomas. Paul Grim, ESSA Oceanographer, Pacific Marine Center, Seattle, Washington, initiated and prepared the proposal for certain technical aspects of the field survey. All help and assistance in these operations is gratefully acknowledged.

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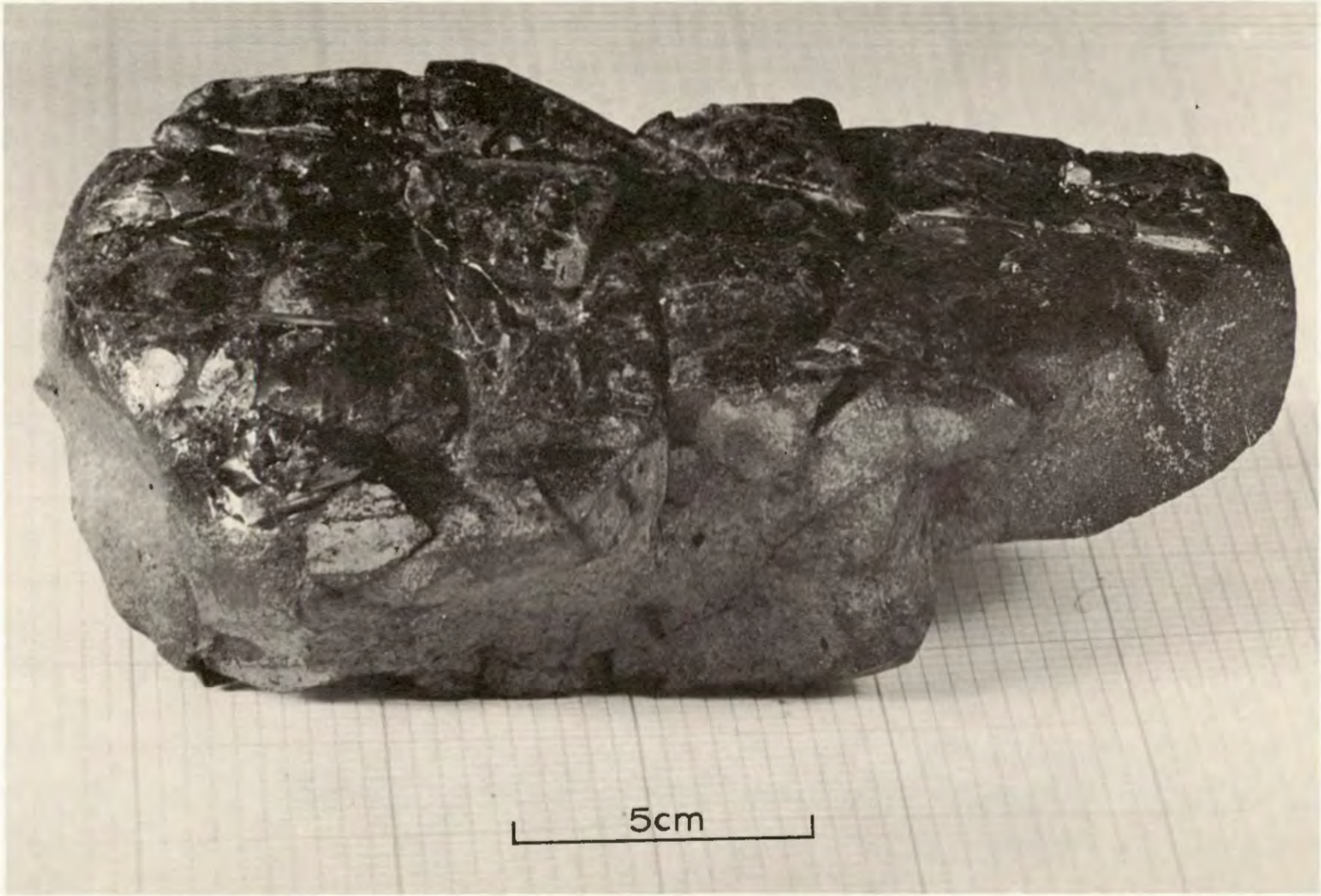

PLATE 1. Basalt with glassy rind. Dredge 10 from central portion of median perched graben, southern part of Juan de Fuca Ridge. U.S. National Museum catalog number 111240.

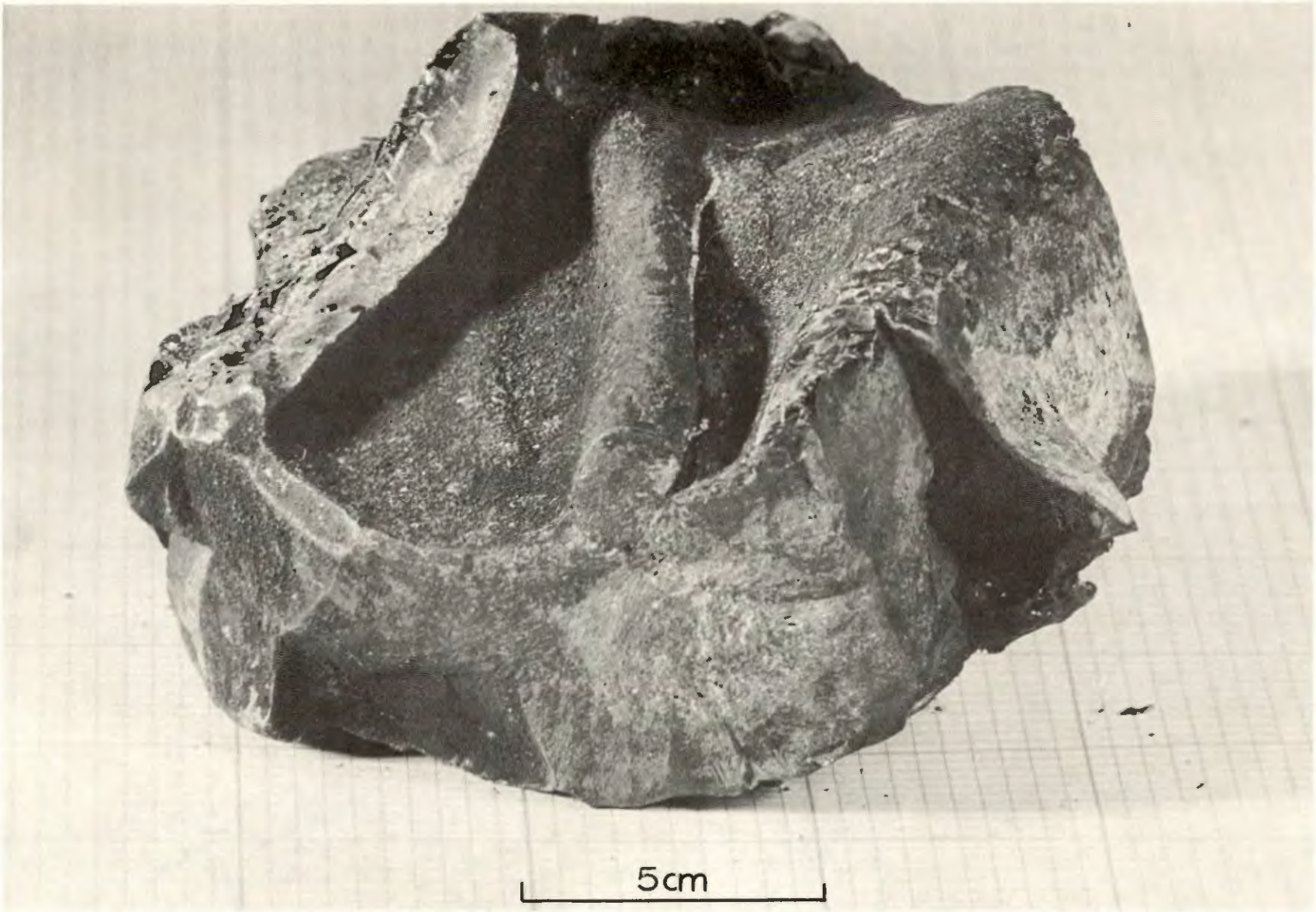

PLATE 2. Basalt exhibiting convolutions. Dredge 10 from central portion of median perched graben, southern part of Juan de Fuca Ridge. U.S. National Museum catalog number 111240.7.

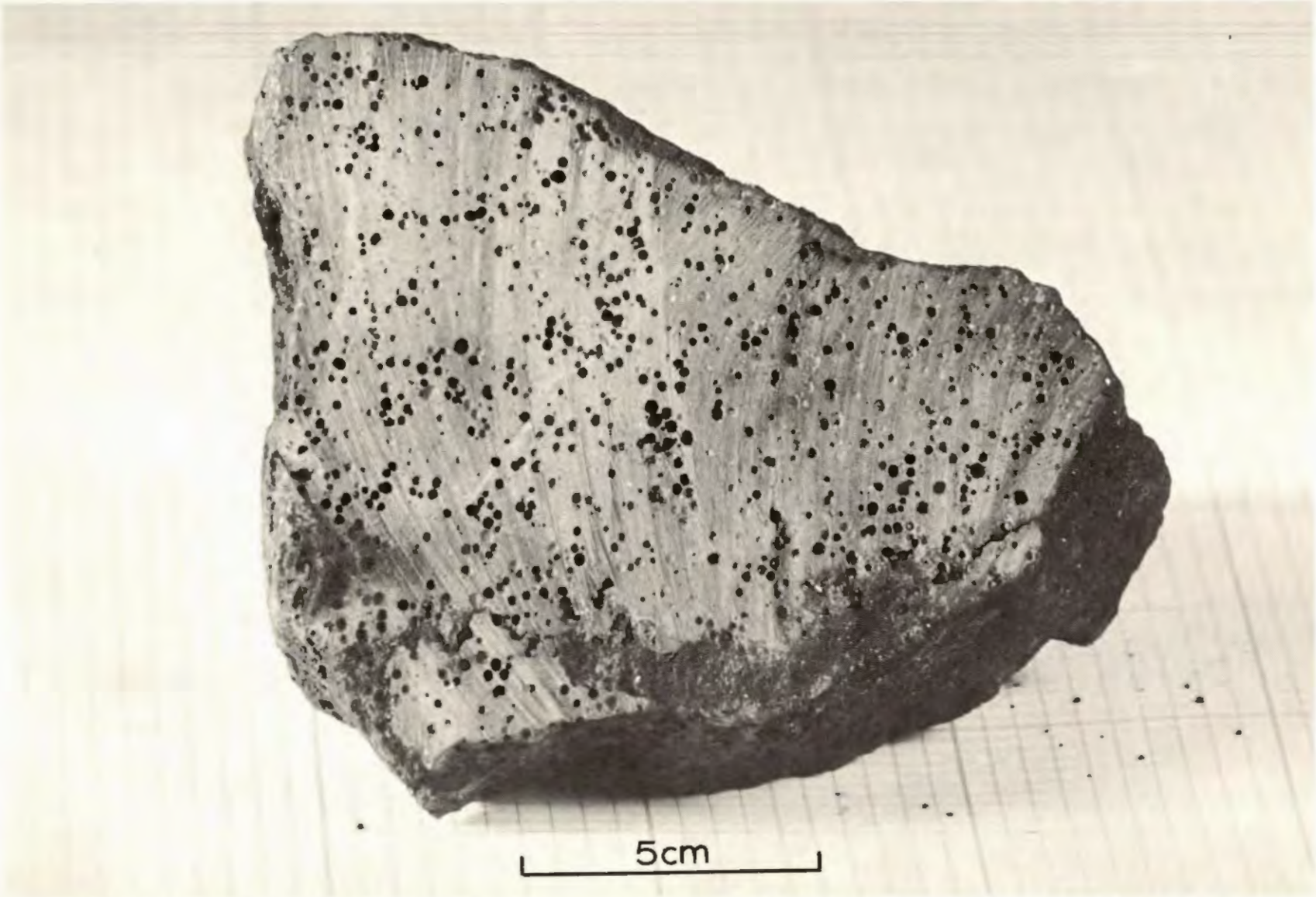

PLATE 3. Vesicular basalt. Dredge 1 from upper south side of the central part of Blanco Trough (Parks Seamount). U.S. National Museum catalog number 111229.9.

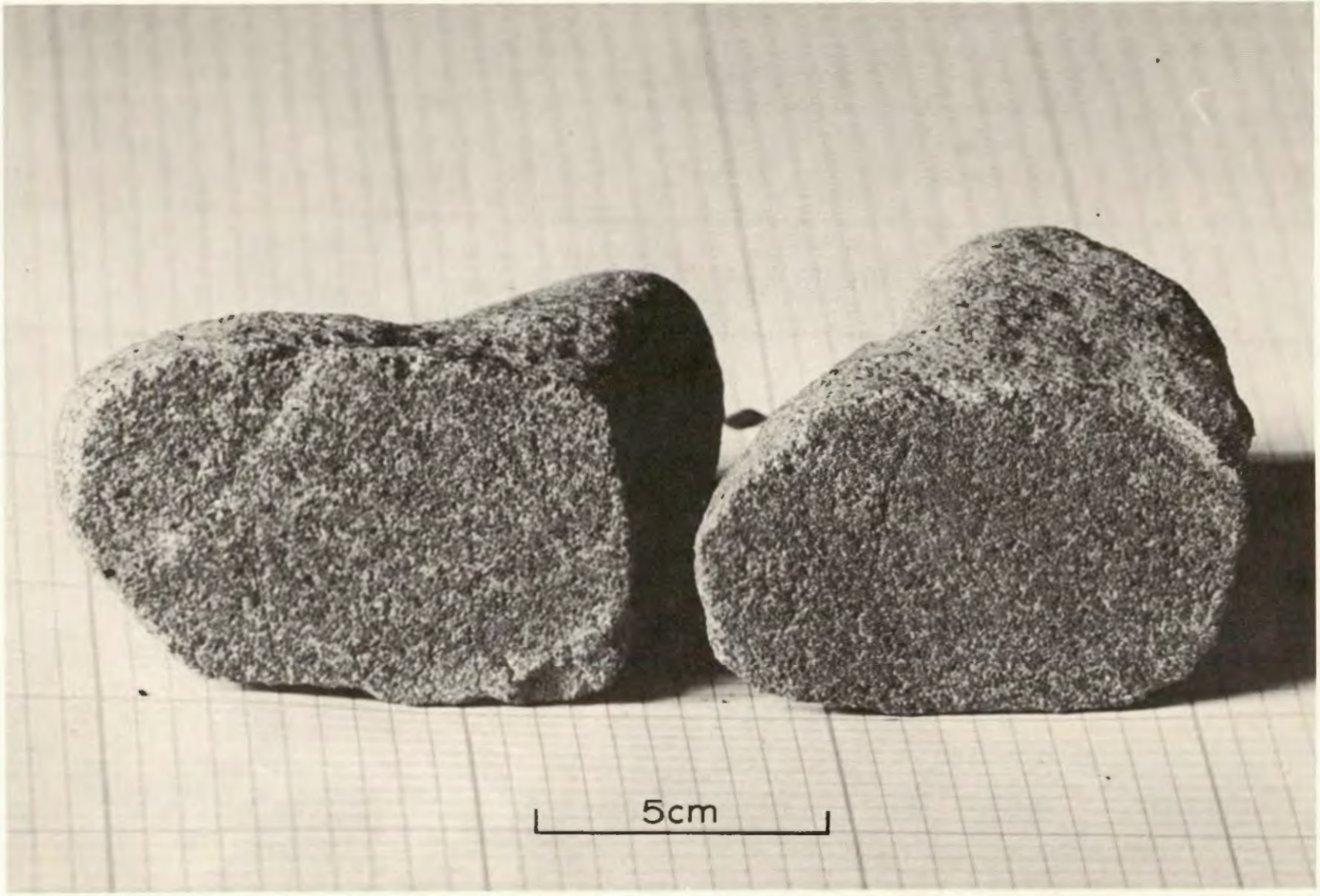

PLATE 4. Dolerite. Dredge 6 from middle portion of the north side of the central part of Blanco Trough. U.S. National Museum catalog number 111238.150.

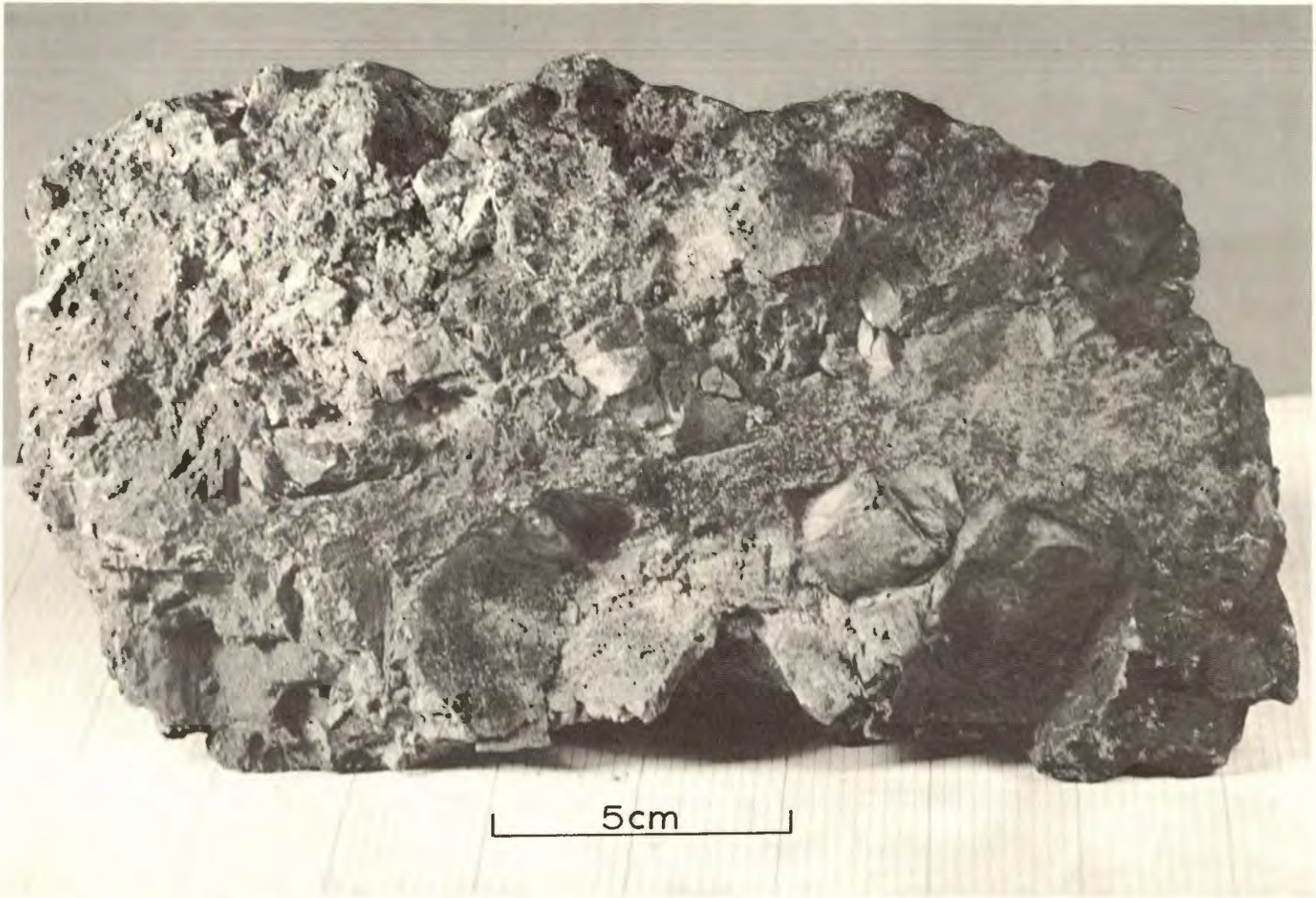

PLATE 5. Basalt tuff. Dredge 6 from middle portion of the north side of the central part of Blanco Trough. U.S. National Museum catalog number 111237.76.