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# *Topography and Lithology of the Mendocino Ridge*<sup>1</sup>

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## ABSTRACT

Twenty-two slope-corrected bathymetric profiles of the Mendocino Ridge between  $125^{\circ}\text{W}$  and  $129^{\circ}\text{W}$  are presented, and the method of their development is discussed. The crest of this Ridge lies at an average depth of 2000 m, falling off to 3200 m on the north and to 4400 m on the south. A short, steep scarp, fresh dredge-haul material lacking manganiferous crusts, and earthquake epicenters suggest recent faulting on the north. Basalt cobbles and pebbles were the principal constituent of six dredge hauls taken on the Ridge; their petrology is described in the APPENDIX (p. 247). Very well-rounded pebbles indicate that the crest was once at or above sea level.

*Introduction.* The Mendocino Escarpment, a major feature of the earth's surface, has been extensively studied in a reconnaissance manner (Murray 1939, Shepard and Emery 1941, Menard and Dietz 1952, Menard 1955, Harrison et al. 1957). The present study is focused on the conspicuous Mendocino Ridge between  $125^{\circ}\text{W}$  and  $129^{\circ}\text{W}$ , located west of the continental slope and the Gorda Escarpment (Fig. 1).

The 22 bathymetric profiles presented in this study were obtained on Scripps Institution cruises; six were obtained in 1957 using an EDO UQN/1B Echo Sounder and 16 in 1959 using Precision Depth Recorders. The base map was constructed from data of these and other Scripps Institution cruises, with minor additions from compilation sheets of the U. S. Navy Hydrographic Office.

*Bathymetry; Method of Profile Construction.* Because the sides of the Mendocino Ridge are very steep, the soundings have required slope corrections. Such corrections are necessary because the beam from the conical sound cone records the nearest perpendicular surface as the bottom, even though this surface may not be directly under the ship (Fig. 2: point 7). Consecutively

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recorded soundings often come from a single point or highlight. Thus the recorded trace is a hyperbola (Hoffman 1957, Krause 1962), and the sea floor lies deeper than the recorded hyperbola except at the peak of the Ridge (Fig. 2. point 20).

The six profiles from the 1957 cruise were corrected for slope by use of both geometric construction and calculation in order to compare the two methods. Depths were corrected for variations in electrical frequency, converted to meters, and then corrected for sound velocity using data from CARNEGIE Sts. 128 and 129 (Sverdrup et al. 1944). Depths were read at one-minute intervals of ship's time (about  $\frac{1}{3}$  km horizontal distance) and plotted to an unexaggerated scale (Fig. 2). For the geometrical construction, arcs were swung, using the corrected depth as radius and the ship's position as the center. The sea floor was assumed to be tangent to the arc, except where the bottom is very steep; in these few cases, the bottom (if observed) was assumed to exist at the point where the radius subtends a vertical angle of  $30^\circ$ , which is the maximum angle of the sound cone.

Slope corrections were also computed. The slope of the bottom was calculated as that recorded between one-minute soundings. Where appropriate, the slopes on either side of a sounding were averaged to represent the slope at that sounding. This recorded slope ( $\tan \varphi$ ) is related to the true slope ( $\tan \theta$ ) by:  $\sin \theta = \tan \varphi$ . The sounding run was assumed to have been made perpendicular to the slope (Krause 1962). The true depth of the reflection point and the displacement of the reflection point from the recording position of the ship were calculated through simple trigonometric relations according to the above equation (Table I: line 1). A comparison of the geometric and calculated slope-corrected profiles is shown in Fig. 2 (profile 11).

The geometrically constructed profile approximates most closely the true profile because of the interpretation that went into the construction. The calculated profile is almost the same. A few calculated points had to be discarded after plotting (arrows on Fig. 2); these were obviously in error upon inspection of the profile.

The 16 FANFARE profiles were recorded on Precision Depth Recorders and therefore needed no corrections. Because the corrected profiles produced by calculation on the 1957 profiles so nearly matched the ones obtained by the laborious geometric construction method, the FANFARE data, consisting of the recorded depth, time of sounding, and ship's speed, were programed for a CDC 1604 Computer (Smith 1963). The program changed fathoms to meters, added sound-velocity corrections according to Matthew's tables, and corrected for slope. A sounding on a relatively constant slope was corrected with the equations given on line 1 of Table I, using a three-point average as the recorded slope. Sometimes, when the slope was not uniform in the interval but did not change abruptly enough to be classed as a "nickpoint" (see below), the depth being corrected fell far off the line that joined the soundings on

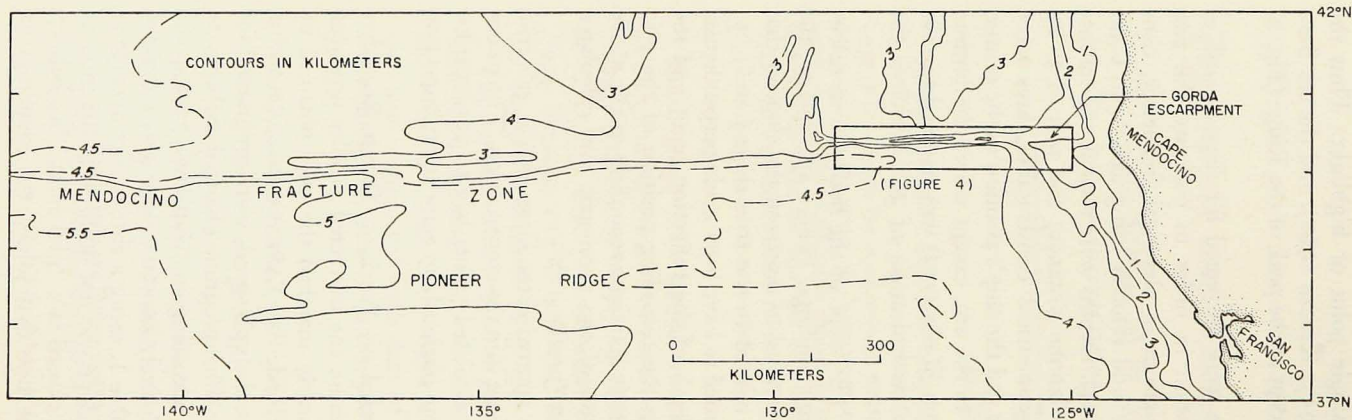


Figure 1. Index chart showing the location of the area studied in relation to the regional bathymetry.

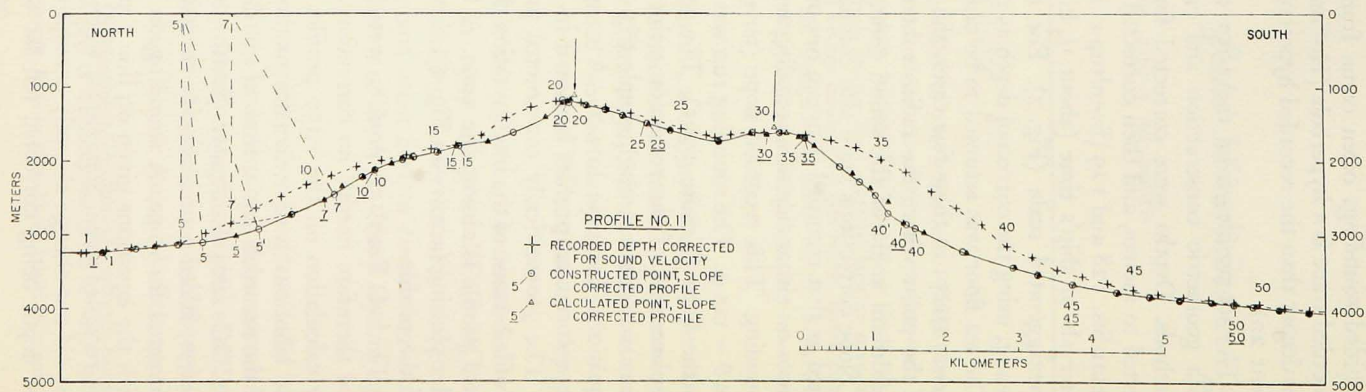


Figure 2. Comparison of slope-corrected profiles produced by geometrical construction and calculation. Every fifth point is identified. Primed numbers of geometrically constructed points indicate that the sound cone is tangent to the bottom at more than one spot. Arrows refer to erroneously calculated points (see text).

TABLE I. SLOPE CORRECTION EQUATIONS.

 $\varphi, \mu$  = Recorded Slopes;  $D$  = Recorded Depth.

Type of Point	Horizontal Displacement (HD)	True Depth (TD)
NORMAL SLOPE		
1.	$HD = D \cdot \tan \varphi$	$TD = D \cdot \sqrt{1 - \tan^2 \varphi}$
NICKPOINTS		
2. Slopes in same direction	$HD = D \cdot \frac{\sqrt{1 - \sqrt{1 - \tan^2 \varphi} \cdot \sqrt{1 - \tan^2 \mu} + \tan \varphi \cdot \tan \mu}}{\sqrt{1 + \sqrt{1 - \tan^2 \varphi} \cdot \sqrt{1 - \tan^2 \mu} + \tan \varphi \cdot \tan \mu}}$	$TD = D \cdot \frac{\sqrt{1 + \sqrt{1 - \tan^2 \varphi} \cdot \sqrt{1 - \tan^2 \mu} - \tan \varphi \cdot \tan \mu}}{\sqrt{1 + \sqrt{1 - \tan^2 \varphi} \cdot \sqrt{1 - \tan^2 \mu} + \tan \varphi \cdot \tan \mu}}$
3. One slope equals zero	$HD = D \cdot \frac{1 - \sqrt{1 - \tan^2 \varphi}}{\tan \varphi}$	$TD = D$
4. Slopes in opposite directions	$HD = D \cdot \frac{\sqrt{1 - \sqrt{1 - \tan^2 \varphi} \cdot \sqrt{1 - \tan^2 \mu} - \tan \varphi \cdot \tan \mu}}{\sqrt{1 + \sqrt{1 - \tan^2 \varphi} \cdot \sqrt{1 - \tan^2 \mu} - \tan \varphi \cdot \tan \mu}}$	$TD = D \cdot \frac{\sqrt{1 + \sqrt{1 - \tan^2 \varphi} \cdot \sqrt{1 - \tan^2 \mu} + \tan \varphi \cdot \tan \mu}}{\sqrt{1 + \sqrt{1 - \tan^2 \varphi} \cdot \sqrt{1 - \tan^2 \mu} - \tan \varphi \cdot \tan \mu}}$

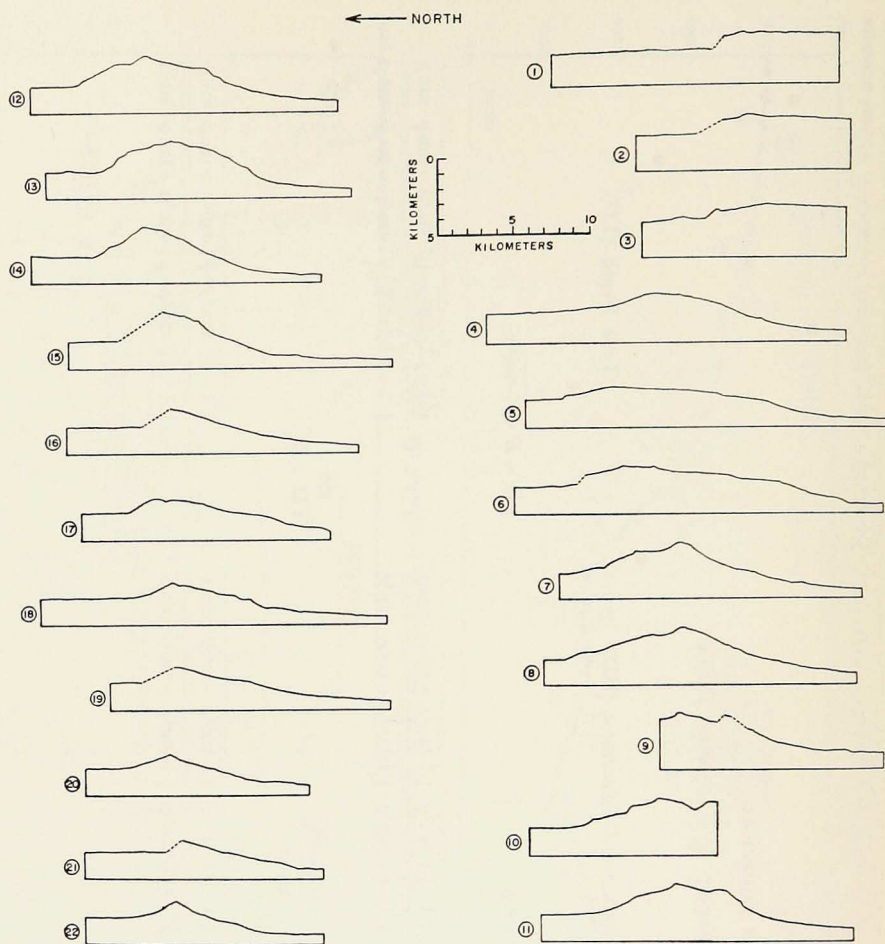


Figure 3. Slope-corrected bathymetric profiles of the Mendocino Ridge. Base of all profiles is at 5000-m depth. See Fig. 4 for locations.

either side, and an erroneous point resulted; these points could be detected by examination.

The equations used for correcting soundings taken at sudden changes of slope, or at nickpoints as modified after Krause (1962), are given in lines 2, 3, and 4 of Table I. These equations are invalid for recorded slopes greater than  $45^\circ$  found on some profiles to the north of the Escarpment, because  $\sqrt{1-\tan^2\phi}$  is negative; in such cases, an assumed slope of  $30^\circ$  was drawn from the last valid point recorded on the top of the slope to the extension of the lower slope (shown by dashed lines in Fig. 3); this gave a minimum value for the slope.

*Bathymetry; Description of the Profiles.* Fig. 3 shows the 22 slope-corrected profiles at natural scale. The locations of the profiles and dredge hauls are given in Fig. 4. Except for the first three profiles that cross the western end of the Gorda Escarpment, the profiles in Fig. 3 show a regional change in depth across the Escarpment, the sea floor on the south being 1200 m deeper than that on the north. On profiles 4, 5, and 6, the Ridge is 15 km wide, with a relief of 200–2500 m from the peak to the south side. Slopes range from  $5^{\circ}$  to  $10^{\circ}$  on the south and from  $10^{\circ}$  to  $20^{\circ}$  on the north. On profiles 5 and 6, a short, steep scarp is present on the north side. Profiles 7 through 13 narrow to a width of about 10 km, and the relief increases to about 3000 m. The Ridge here is roughly symmetrical, with both the north and south sides falling off in a series of steps; average slope angles range between  $15^{\circ}$  and  $20^{\circ}$  on the north and are about  $20^{\circ}$  on the south, but some slopes are as much as  $30^{\circ}$ . On nearly all of these profiles (7–13), a bench on the north steepens abruptly to the peak and is bounded on the outer margin by a scarp. Profiles 8 and 11 lack the distinctive scarp, but an abrupt change in slope is still apparent. A remarkably persistent region of uniform slope,  $9^{\circ}$ – $17^{\circ}$ , extends for about 2 km south from the peak. Profiles 14 and 15 maintain the width and relief of the profiles to the east but develop the steep slope of at least  $30^{\circ}$  seen on the profiles to the west. In the remaining profiles, the relief decreases to 2000 m, the width narrows to less than 10 km, and the south slope becomes smoother with average slopes of  $15^{\circ}$ .

*Dredge hauls.* The six dredge hauls from the Mendocino Ridge (Table II; Plates I, II) contain basalt, which is commonly covered with manganese oxide crust; detailed descriptions are given in the APPENDIX. The basalt is typically microcrystalline and composed of labradorite, pigeonite, and a high content of disseminated accessory ore, probably maghemite (R. Mason, personal communication). Most dredge hauls contain basaltic glass in various stages of devitrification. The only other materials found are manganiferous oxides (CASCADIA-8, all of FAN-BD-20, FAN-BD-25, FAN-BD-33), clayey calcareous ooze (FAN-BD-36), serpentine (FAN-BD-36), and siliceous sponges coated with manganiferous oxides (FAN-BD-33).

With the possible exception of FAN-BD-36, all material dredged was lying loose on the bottom as scree, breccia, or chemical precipitates. The basalt occurs as pebbles and cobbles, either loose or covered with manganese or as a conglomerate set in a clayey matrix. In dredges CASCADIA-8 and -9 (Plate I A, B), the rocks are angular or subangular. On the other hand, dredges FAN-BD-25, -33, -36 contain rocks that range from rounded to very well rounded. Nevertheless, the uniform lithology of thousands of pebbles demonstrates that they were eroded from the Ridge rather than rafted into place.

The clayey calcareous ooze of dredge FAN-BD-36 (Plate II D) contains siliceous microfossils that resemble modern assemblages. At present the rock

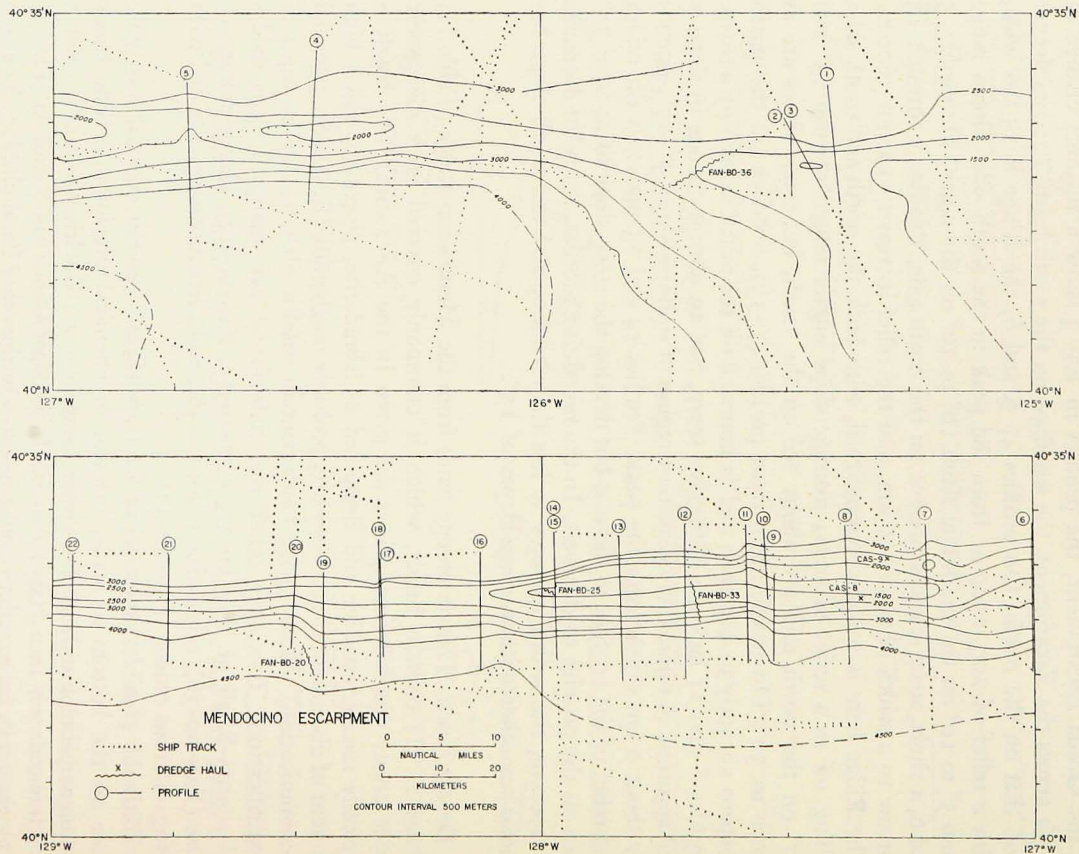


Figure 4. Bathymetric chart of Mendocino Ridge showing location of profiles and dredge hauls.



TABLE II. DREDGE HAULS ON THE MENDOCINO RIDGE.

CRUISE	DREDGE HAUL	POSITION		DEPTH m	DESCRIPTION
		N	W		
FANFARE (BAIRD)	FAN-BD-20	40° 18'	128° 29'	4200-4500	Manganese nodules
		40° 15'	128° 28'		
FANFARE (BAIRD)	FAN-BD-25	40° 23'	128° 00'	1250-1400	Well-rounded, basalt pebbles coated and cemented with manganiferous oxides
		40° 22'	127° 58'		
FANFARE (BAIRD)	FAN-BD-33	40° 24'	127° 42'	3300-1250	Manganiferous nodules; subangular to rounded basaltic pebbles coated with manganiferous oxides
		40° 20'	127° 41'		
FANFARE (BAIRD)	FAN-BD-36	40° 22'	125° 38'	1820-2390	Boulders and cobbles of basalt conglomerate; calcareous ooze
		40° 19'	125° 44'		
CASCADIA	CAS-8	40° 22'	127° 21'	1700	Angular basalt pebble conglomerate encrusted with manganiferous oxides
CASCADIA	CAS-9	40° 26'	127° 18'	2400	Angular basalt pebbles with edges slightly rounded; without manganiferous oxide coating

may be forming at the dredge site. Slickensides occur on the serpentine and appear to be direct evidence of faulting. The manganiferous oxides occur naturally as a chemical precipitate in the depths where found in this study.

*Discussion.* The dredge haul contents and locations support the interpretation of the profiles, that the scarp on the outer edge of the bench on the north side is a fault that has been active more recently than any on the south side of the Ridge. This scarp could result from either normal faulting or from minor vertical adjustments associated with the much larger horizontal movements along the Mendocino fracture zone, as deduced by Vacquier et al. (1961) on the basis of offset magnetic anomalies.

Manganiferous oxides, occurring in the form of nodules in the deeper hauls and as coatings in the shallower hauls, are found on all the samples from the south side of the Ridge but are lacking on the one sample (CASCADIA-8) obtained below the shelf break on the north side. The absence of manganese implies that the CASCADIA-9 sample had been exposed on the sea floor for a relatively short time. The rate of growth of manganese nodules on the deep ocean floor is given by Goldberg (1961) as 1 mm/5 × 10<sup>3</sup> years, but there is no evidence that the mechanism or rate of accretion is the same for shallow-water coatings and deep-water nodules.

Earthquake epicenters located along the Ridge provide further evidence of recent faulting (Fig. 5). Although it is tempting to conclude that the north

side is active on the basis of this distribution, it has been pointed out (R. Nason, personal communication) that epicenters cannot be located accurately enough in this area to distinguish between those occurring on the north and those occurring on the south. Furthermore, taking the average of the epicenter positions, while removing individual errors, cannot take into account the possibility of systematic errors due to unknown variations in seismic velocities on either side of the Ridge. The epicenter data are therefore suggestive rather than supporting evidence of recent faulting on the north side.

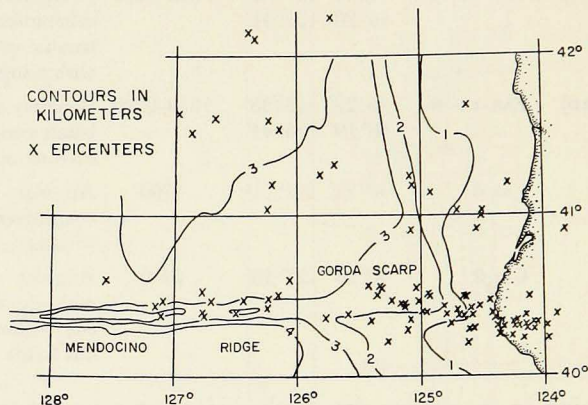


Figure 5. Earthquake epicenters on the Mendocino Ridge and Gorda Escarpment, modified from Cameron (1961). Some of the epicenters on the Gorda Escarpment may be associated with the San Andreas Fault.

The dredge haul material indicates that the crest of the Ridge was once at sea level. The formation of the highly rounded pebbles of FAN-BD-25 would have required a high energy environment, such as a surf zone, for their formation. The cobbles or pebbles of CASCADIA 8 and 9, taken lower on the Escarpment, are angular and have only slightly rounded edges, which might be attributed to abrasion from rolling down a cliff. FAN-BD-33 sampled nearly the entire south side of the Escarpment; this material consisted of manganese nodules, angular cobbles, and subangular to rounded cobbles and pebbles that might have come from the lower, intermediate, and upper parts of the Ridge, respectively. FAN-BD-33, taken over the crest of the Gorda Escarpment, provides the most varied assemblage; some of the material shows indications of rounding. The minimum relative change in sea level required to produce the rounded material at each dredge haul location is: FAN-BD-25, 1250 m; FAN-BD-33, 1250 m; and FAN-BD-36, 1740 m.

The bench on the north side of the peak may be an erosional terrace. There is no supporting evidence, however, because all dredge hauls containing rounded material were taken on the south side of the Ridge, with the possible exception of FAN-BD-25, which sampled the crest near profiles 14 and 15 where

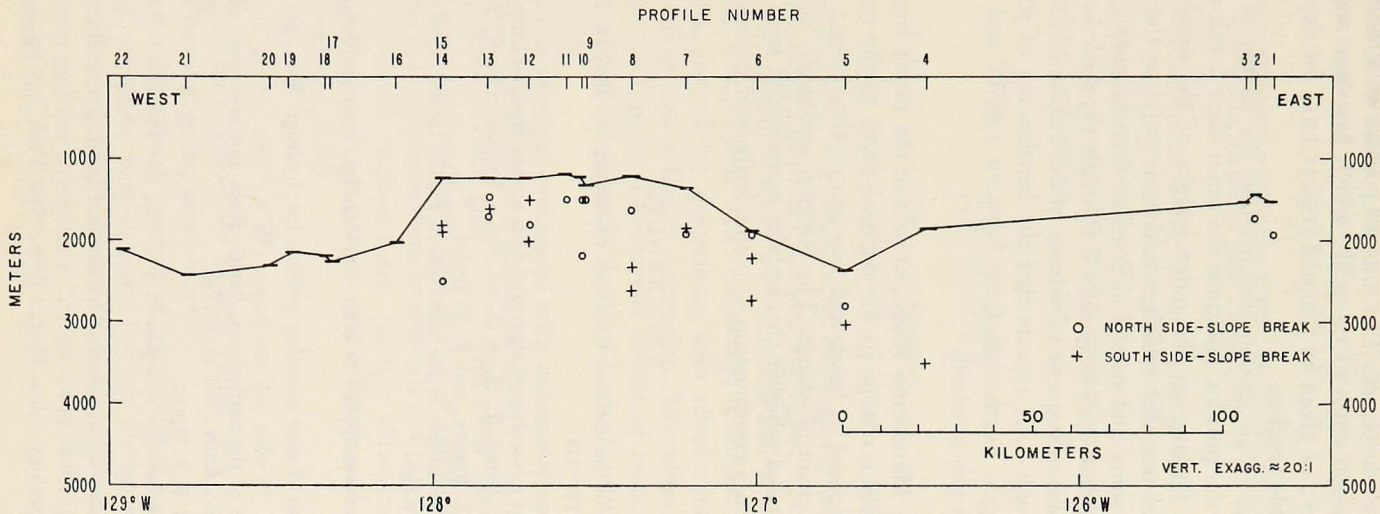


Figure 6. East-west profile of Mendocino Ridge showing depth of the crest and shelf breaks on the north and south sides.

the bench is not well developed. The rounded pebbles were most likely dredged from the smooth slope south of the peak, which has slope angles within the range of  $12^{\circ}$  to  $20^{\circ}$ , as given by Shepard (1963: 171) for depositional slopes on gravel and cobble beaches.

Fig. 6 demonstrates an attempt to correlate the depths of the breaks in slope observed on the profiles. (Because the outer shelf break may have been produced by later faulting on the outer margin of the north-facing bench, the point measured was that which would correspond to the break in slope between the back shore and coastal cliffs of modern beaches). Except for the general level of 1500 m seen in profiles 8 through 13, the correlation is poor. Unless one postulates subsequent subsidence of the section of the Ridge crossed by profiles 4 through 7, it appears that the benches are of structural rather than erosional origin. Further dredging between  $126^{\circ}$ W and  $127^{\circ}$ W might provide answers to this question.

*Summary.* The Mendocino Ridge, as part of the much larger Mendocino fracture zone, marks a change in the regional depth to the north and south. The Ridge is composed of basalt and was at one time at sea level, probably existing then as a chain of islands. The Ridge is seismically active at present, but it cannot be stated whether this activity is associated with minor vertical adjustments or with a continuation of major horizontal movements along the fracture zone.

#### REFERENCES

CAMERON, J. B.

1961. Earthquakes in the northern California coastal region. Part II. Bull. seismol. Soc. Amer., 51: 337-354.

GOLDBERG, E. D.

1961. Chemical and mineralogical aspects of deep-sea sediments in *Physics and Chemistry of the Earth*. Ahrens, L. H., et al., ed. Vol. 4. Pergamon Press, New York. 317 pp.

HARRISON, J. C., G. L. BROWN, and F. N. SPIESS

1957. Gravity measurements in the northeastern Pacific Ocean. Trans. Amer. geophys. Un., 38: 835-840.

HOFFMAN, J.

1957. Hyperbolic curves applied to echo sounding. Int. hydrogr. Rev., 34 (2): 45-55.

KRAUSE, D. C.

1962. Interpretation of echo sounding profiles. Int. hydrogr. Rev., 39: 65-123.

MENARD, H. W.

1955. Deformation of the northeastern Pacific Basin and west coast of North America. Bull. geol. Soc. Amer., 66: 1149-1198.

MENARD, H. W., and R. S. DIETZ

1952. Mendocino submarine escarpment. J. Geol., 60: 266-278.

MURRAY, H. W.

1939. Submarine scarp off Mendocino, California. Field Engrs. Bull., 13: 27-33.

SHEPARD, F. P.

1963. Submarine geology. ed. 2. Harper Bros., New York. 557 pp.

SHEPARD, F. P., and K. O. EMERY

1941. Submarine topography off the California coast. Spec. Pap. geol. Soc. Amer., 31; 171 pp.

SMITH, S. M.

1963. A computer program for producing sound velocity and slope corrected bathymetric profiles. Scripps Inst. Oceanogr. Ref. Rep. 63-15; 14 pp.

SVERDRUP, H. U., ET AL.

1944. Observations and results in physical oceanography, Cruise VII of the Carnegie (1928-29). Oceanogr. IA. Publ. Carneg. Instrn. Wash., 545.

VACQUIER, V., A. RAFF, and R. WARREN

1961. Horizontal displacements in the floor of the northeast Pacific Ocean. Bull. geol. Soc. Amer., 72: 1251-1258.

## APPENDIX

### DREDGE HAULS

CASCADIA 8; 40° 22' N, 127° 21' W; 1700 m; S. side of Mendocino Ridge.

Notes: 15 kg of black, very fine-grained basalt gravel and cobbles encrusted in part with manganiferous oxides. Largest aggregate, 15 cm across.

A representative cobble of basalt was examined and is rimmed with a layer of volcanic glass 1 mm thick. Microscopically, it consists of about 89% of an almost opaque devitrifying groundmass with acicular microlites of feldspar having both random and radiation orientation. Microlites are usually frayed at the ends and intergrown. Phenocrysts consist of calcic labradorite 0.05-0.25 mm across (5%) and pigeonite (1%). About 5% of the rock consists of small angular voids.

A representative aggregate encrusted with manganiferous oxide consists of angular pebbles and sand set in a matrix of clay (15%). Rock types consist of (i) isotropic, brown volcanic glass (15%) with a few microlites and a yellow alteration product; (ii) devitrifying glass (15%) as cobble above; (iii) mottled devitrifying glass (15%) intermediate between (i) and (ii); (iv) microlitic basalt (15%) with labradorite 0.02-0.1 mm (40%), clinopyroxene (45%), ore 0.05-0.1 mm (10%), set in a matrix of mafic minerals, and fine-grained yellow material (5%) replacing voids.

CASCADIA 9; 40° 26' N, 127° 18' W; 2400 m; N. side of Mendocino Ridge.

Notes: 4 kg of dark, steel-grey basaltic gravel. No manganiferous oxide stain present. Gravel angular, edges blunted.

The microcrystalline basalt consists of labradorite 0.1-1.4 mm, two generations (35%), pigeonite 0.05-0.2 mm (35%), fibrous mineral of perhaps chloritized hornblende (20%), and ores 0.01-0.2 (10%). Feldspar laths are oriented randomly and the pyroxene is present as random grains and radiating fibrous aggregates.

FAN-BD-20; 40° 18'N, 128° 29'W to 40° 15'N, 128° 28'W; 4200–4500 m; S. side of Mendocino Ridge.

Notes: 20 kg of manganese nodules of assorted sizes, the largest 12 × 12 × 20 cm. These spherical to flat-shaped nodules have a botryoidal surface. Microscopically, under reflected light, the manganiferous oxide is steel grey and shows layers 0.5 cm thick with a concentric layered structure. The oxide encloses clay and angular mineral grains, mostly 0.05–0.2 mm across (5–10%), of clinopyroxene, quartz, feldspar, serpentine (?), fine-grained aggregates, and yellow alteration products. The grains are probably mostly windblown silt.

FAN-BD-25; 40° 23'N, 128° 00'W to 40° 22'N, 127° 58'W; 1250–1400 m; crest of Mendocino Ridge.

Notes: About 180 kg of well-rounded, dark-grey basalt pebbles and cobbles coated and cemented with manganiferous oxides. The phenocrysts proportion is 10–20% and consists of about equal portions of labradorite and pigeonite (0.1–1 mm). In addition, the rock consists of groundmass labradorite 0.05–0.2 mm (20–30%), ophitic groundmass leuco-clinopyroxene (55–60%) probably pigeonite, ores (10%), and a yellowish secondary mineral (1–10%) that fills voids. The devitrified groundmass abounds with radiating aggregates of pyroxene and feldspar.

A manganiferous-oxide-coated pebble conglomerate of pebbles in a clay matrix and consisting of devitrifying basaltic glass (with a few phenocrysts of labradorite and pigeonite) in various stages of development and alteration.

FAN-BD-33; 40° 20'N, 127° 41'W to 40° 24'N, 127° 42'W; 1250–3300 m; S. side of Mendocino Ridge.

Notes: 50 kg of grey-brown cobbles and pebbles and siliceous sponges coated with manganiferous oxide, and manganese nodules. Pebbles are subangular to rounded and have very smooth surfaces. The holocrystalline basalt consists of labradorite 0.05–0.4 mm long (35%), pigeonite 0.05–0.15 mm long (25–45%), ore (5–10%), alteration products including chlorite (10–25%) and vesicles (0–5%).

A specimen of manganiferous-oxide-encrusted pebble conglomerate consists of pebbles set in a matrix of clay, manganiferous oxide, and grains of volcanic glass and minerals. The subangular pebbles consist of the above-described basalt and devitrifying basaltic glass.

FAN-BD-36; 40° 22'N, 125° 38'W and 40° 19'N, 125° 44'W; 1820–2390 m; over crest of Gorda Escarpment.

Notes: 300 kg of cobbles and boulders of basalt, altered basalt, conglomerate, calcareous ooze, and serpentine.

Where fresh, the dark-grey basalt consists of 40% phenocrysts of equal amounts of labradorite and pigeonite, 0.1–1.2 mm. The groundmass consists

of ore (10% of specimen) and somewhat more clinopyroxene than plagioclase. About 5% of chlorite was present in the specimen examined. Where altered, the basalt consists of oligoclase and chlorite (replacing labradorite) and relatively unaltered pigeonite. Chlorite (5%) often occurs in large blebs, especially where it replaces plagioclase. Thin veins, 0.05–0.2 mm across, pass through the specimen examined and consist of chlorite (with perhaps some serpentine), calcite, and albite.

A boulder of clayey calcareous ooze consisted of 5–10% mineral grains, 0.05–0.1 mm, of which 20% was either glauconite or chlorite. Taro Kanaya (now at Tohoku Univ., Japan) inspected the abundant diatoms and found a predominantly modern assemblage.

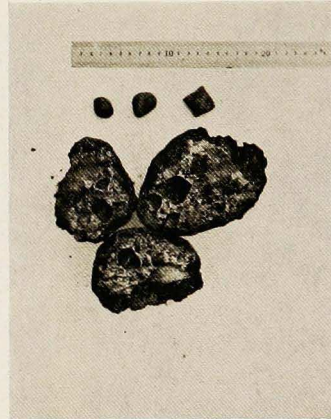
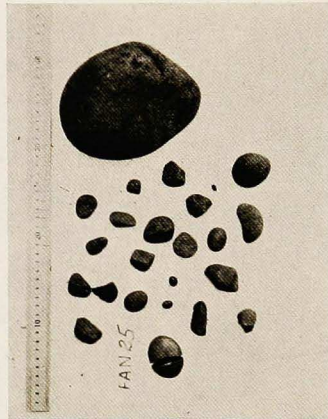
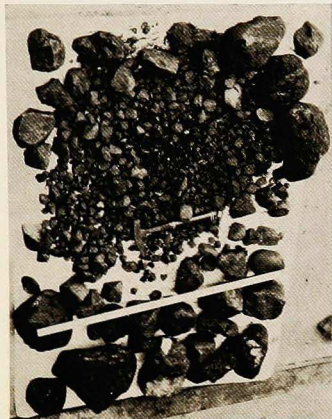
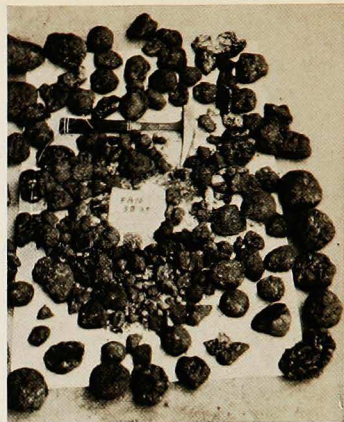
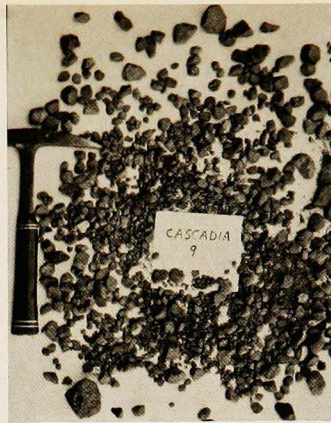
A boulder of serpentine carried a polished, slickensided surface.



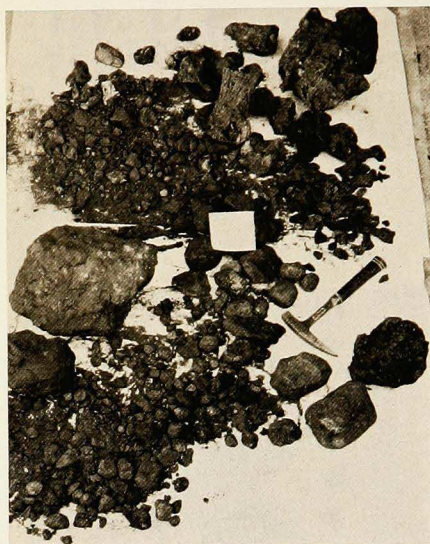


Plate I. Dredge hauls.

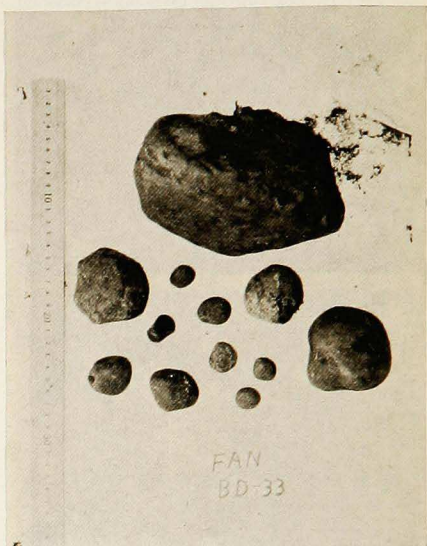
- A, CASCADIA 8: basalt with some manganiferous oxide crust.
- B, CASCADIA 9: basalt.
- C, FAN-BD-20: manganese nodules.



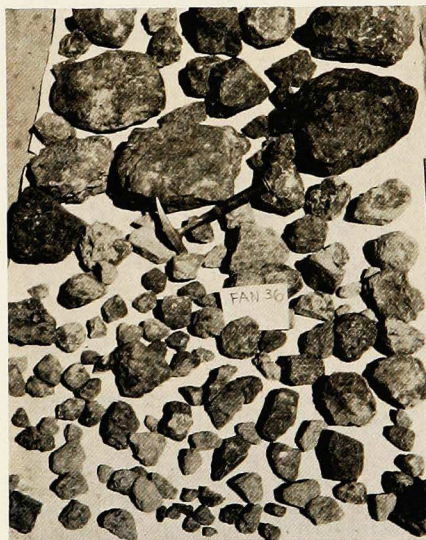
- D, FAN-BD-25: basalt with some manganiferous crusts.
- E, FAN-BD-25: well-rounded pebbles and cobbles of basalt.
- F, FAN-BD-25: pebble conglomerate of basalt in clay matrix encrusted with manganiferous oxide; note rounded pebbles.



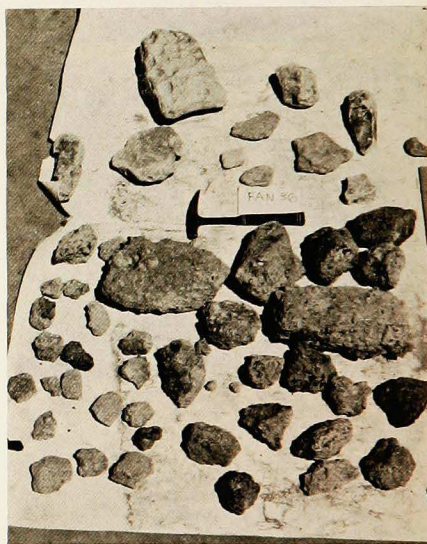
A



B



C



D

Plate II. Dredge hauls. A, FAN-BD-33: basalt, manganiferous crust, and manganese-stained glass sponges. B, FAN-BD-33: rounded pebbles and cobbles of basalt. C, FAN-BD-36: basalt and other hard rocks. D, FAN-BD-36: conglomerate and calcareous ooze.