UNIVERSITY OF WASHINGTON

DEPARTMENT OF OCEANOGRAPHY

Technical Reports

Nos. 200, 201, 202, 203, 204, and 205

A COMPILATION OF ARTICLES REPORTING RESEARCH

SPONSORED JOINTLY BY

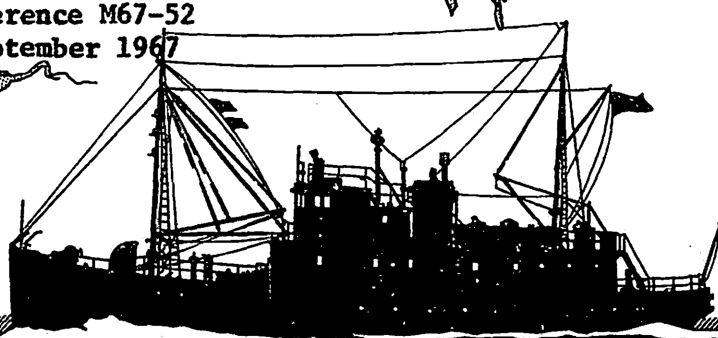
THE U.S. ATOMIC ENERGY COMMISSION

and

THE OFFICE OF NAVAL RESEARCH

U.S. Atomic Energy Commission
Contract AT(45-1)-1725
and
Office of Naval Research
Contracts Nonr -477(37)
and Nonr-477(10)
Project NR 083 012

Reference M67-52
September 1967



SEATTLE, WASHINGTON 98105

UNIVERSITY OF WASHINGTON
DEPARTMENT OF OCEANOGRAPHY
Seattle, Washington 98105

Technical Reports

Nos. 200, 201, 202,
203, 204, and 205

A COMPILATION OF ARTICLES REPORTING RESEARCH SPONSORED JOINTLY BY THE U.S. ATOMIC ENERGY COMMISSION and THE OFFICE OF NAVAL RESEARCH

U.S. Atomic Energy Commission
Contract AT(45-1)-1725
and
Office of Naval Research
Contracts Nonr-477(37)
and Nonr-477(10)

RICHARD H. FLEMING
Chairman

CLIFFORD A. BARNES
Principal Investigator

ARTICLES REPORTING RESEARCH SPONSORED JOINTLY BY THE
U.S. ATOMIC ENERGY COMMISSION AND THE OFFICE OF NAVAL RESEARCH

Technical Report No. 200

NOTES ON PATAGIUM IN THE RADIOLARIAN GENERA HYMENIASTRUM AND DICTYASTRUM, by Hsin-Yi Ling. Micropaleontology, *12*(4): 489–492. 1966.

Technical Report No. 201

PHYSIOGRAPHY OF COBB AND GORDA RISES, NORTHEAST PACIFIC OCEAN, by Dean A. McManus. Geological Society of America Bulletin, *78*:527–546. 1967.

Technical Report No. 202

ORGANIC CARBON IN SURFACE SEDIMENT FROM THE NORTHEAST PACIFIC OCEAN, by M. Grant Gross. International Journal of Oceanology and Limnology, *1*(1): 46–54. 1967.

Technical Report No. 203

CURRENTS AT THE COLUMBIA RIVER MOUTH, by Alyn C. Duxbury. Photogrammetric Engineering, *33*(3):305–310. 1967.

Technical Report No. 204

SEDIMENT MOVEMENT ON THE CONTINENTAL SHELF NEAR WASHINGTON AND OREGON, by M. Grant Gross and Jack L. Nelson. Science, *154*(3750):879–885. 1966.

Technical Report No. 205

TIDAL PERIOD OSCILLATIONS OF AN ISOHALINE SURFACE OFF THE MOUTH OF THE COLUMBIA RIVER, by Alyn C. Duxbury and Noel B. McGary. International Journal of Oceanology and Limnology, *1*(2):71–84. 1967.

UNIVERSITY OF WASHINGTON
DEPARTMENT OF OCEANOGRAPHY
TECHNICAL REPORT NO. 201

DEAN A. McMANUS *Dept. Oceanography, University of Washington, Seattle, Washington*

Physiography of Cobb and Gorda Rises, Northeast Pacific Ocean

Abstract: Two oceanic rises, present near the coast of the northwestern United States, are bordered on the east by the continental rise, on the west by abyssal hills and plains, and on the north and south by fracture zones. A third fracture zone separates and smaller zones transect the rises. Physiographic provinces on the rises include a crest province with a median valley, a flank province, and a transition province. The crest of Gorda Rise has greater relief and a better-developed median valley and associated positive magnetic anomaly than the Cobb Rise. Both may be Miocene or older. Their physiographic provinces, particularly those of Gorda Rise, are more similar to those of the Mid-Atlantic Ridge than to those of the East Pacific Rise.

In previous studies, Cobb and Gorda rises have been interpreted as northern extensions of the East Pacific Rise in the southeast Pacific. Alternative interpretations are that the northern rises may be a rejuvenated segment of an older arcuate rise off the west coast of the United States, or that they may form an auxiliary ridge associated with the Mendocino Fracture Zone and are possibly unrelated to the East Pacific Rise.

CONTENTS

INTRODUCTION

Most studies of the oceanic rise system in the eastern Pacific have dealt with the East Pacific Rise in the southeast Pacific. The continental rise off the coast of the northwestern United States, however, is bordered on the seaward side by an area of hills, ridges, seamounts, troughs, and generally rough topography. This area was designated by Menard and Dietz (1951) as the Ridge and Trough province and later as a northern extension of the East Pacific Rise by Menard (1960; 1964), who gave a recent summary of work in the area.

Menard (1962) identified the Blanco Fracture Zone which crosses the oceanic rise, and a more detailed study (McManus, 1965c) has suggested that the oceanic rise is segmented

Geological Society of America Bulletin, v. 78, p. 527–546, 7 figs., April 1967

into two rises, the Cobb Rise and Gorda Rise (Fig. 1), by the fracture zone. A similar conclusion was reached by Wilson (1965).

The relationship between the East Pacific Rise of the southeast Pacific and the oceanic rises off Washington and Oregon is problematical. According to one interpretation (Menard, 1960), the northern rises are the extension of the East Pacific Rise, which is considered to merge with the North American continent in the Gulf of California and extend under the southwestern part of the United States. It then reappears through transcurrent faulting as a topographic feature of the sea floor off the Oregon coast. A recent interpretation by Talwani and others (1965) is similar, but does not call on offset by transcurrent faulting to emplace the rises. The present pattern, instead, reflects original sites of development. Another recent interpretation (Wilson, 1965) considers the northern rises to be a continuation of the East Pacific Rise, but the emplacement is by means of transform faulting along the San Andreas fault. In this interpretation the East Pacific Rise does not continue under the continent of the western United States. It is apparent, therefore, that the rises off the northwestern United States are, as yet, inadequately related to the remainder of the oceanic rise system of the world ocean.

Topographic and sedimentologic studies in the region of Gorda and Cobb rises (*referred to by* Wilson, 1965, as Juan de Fuca Ridge) have been made by the Department of Oceanography, University of Washington, since 1956. Some results of the sedimentologic studies (Enbysk, 1960, Ph.D. dissert., Univ. Washington, Seattle, Washington; Enbysk and Budinger, 1960; Enbysk and Cooper, 1965; McManus, 1965a; Nayudu, 1959, Ph.D. dissert., Univ. Washington, Seattle; 1964; Nayudu and Enbysk, 1964), and a compilated topographic chart covering part of the area (Fig. 2) (McManus, 1964) have been published.

Bathymetric studies of Cobb and Gorda rises on the sea floor off the northwestern United States have resulted in the recognition of several physiographic provinces. A preliminary description was given by McManus (1965b), and they are of particular interest because they have not been reported from the East Pacific Rise in the southeast Pacific (Menard, 1964, p. 121); yet, they are similar to those reported from the Mid-Atlantic Ridge (Heezen and others, 1959).

ACKNOWLEDGMENTS

This research was supported by Office of Naval Research Contract 477(37), Project NR 083 012, and U.S. Atomic Energy Commission Contract AT(45-1)-1725.

GORDA RISE

Boundaries

The margins of both Gorda Rise and Cobb Rise are indistinct tectonically, and are, therefore better described topographically. The southern margin of the topographic rise on Gorda is a sharp boundary, as oceanic rise topography is present on the sea floor north of the Mendocino Fracture Zone (Menard, 1960), but is absent on the sea floor immediately south of it. The eastern margin of the rise topography is also distinct, for it is bordered on the east by the continental rise (Fig. 1); the northern limit is the Blanco Fracture Zone. The western boundary, however, is ill-defined at the present time. To the west there is an extensive area of abyssal hills, and just to the north of the hills, Tufts Abyssal Plain. The border between the rise topography and the hills indicated in Figure 1 may be moved west of 130° W. when detailed studies are made of the area.

Gorda Rise, as presently defined by topography, represents a somewhat equidimensional area of about 58,000 km^2. It is about 220 km wide in the south and 330 km wide in the north. At the northeastern corner the rise is separated from the continental slope by only 30 km of the continental rise passing through Blanco Gap. Even at the western margins of the rise, the continental slope is only about 370 km distant.

Crest Province

Two categories of physiographic provinces are recognized on Gorda and Cobb rises, as on the Mid-Atlantic Ridge (Heezen and others, 1959): a crest province and flank province (Fig. 3). The crest province on Gorda Rise is about 150 km wide and continues eastward to within 100 km of the Oregon coast. The most prominent feature of the province is the median Escanaba Trough (Fig. 2) of 500 fathoms relief, trending as an almost linear feature slightly east of north. The trough is 280 km long, about 30 km wide, and appears to be open at both ends. The southern end is open to the continental rise, and sediment of continental rise

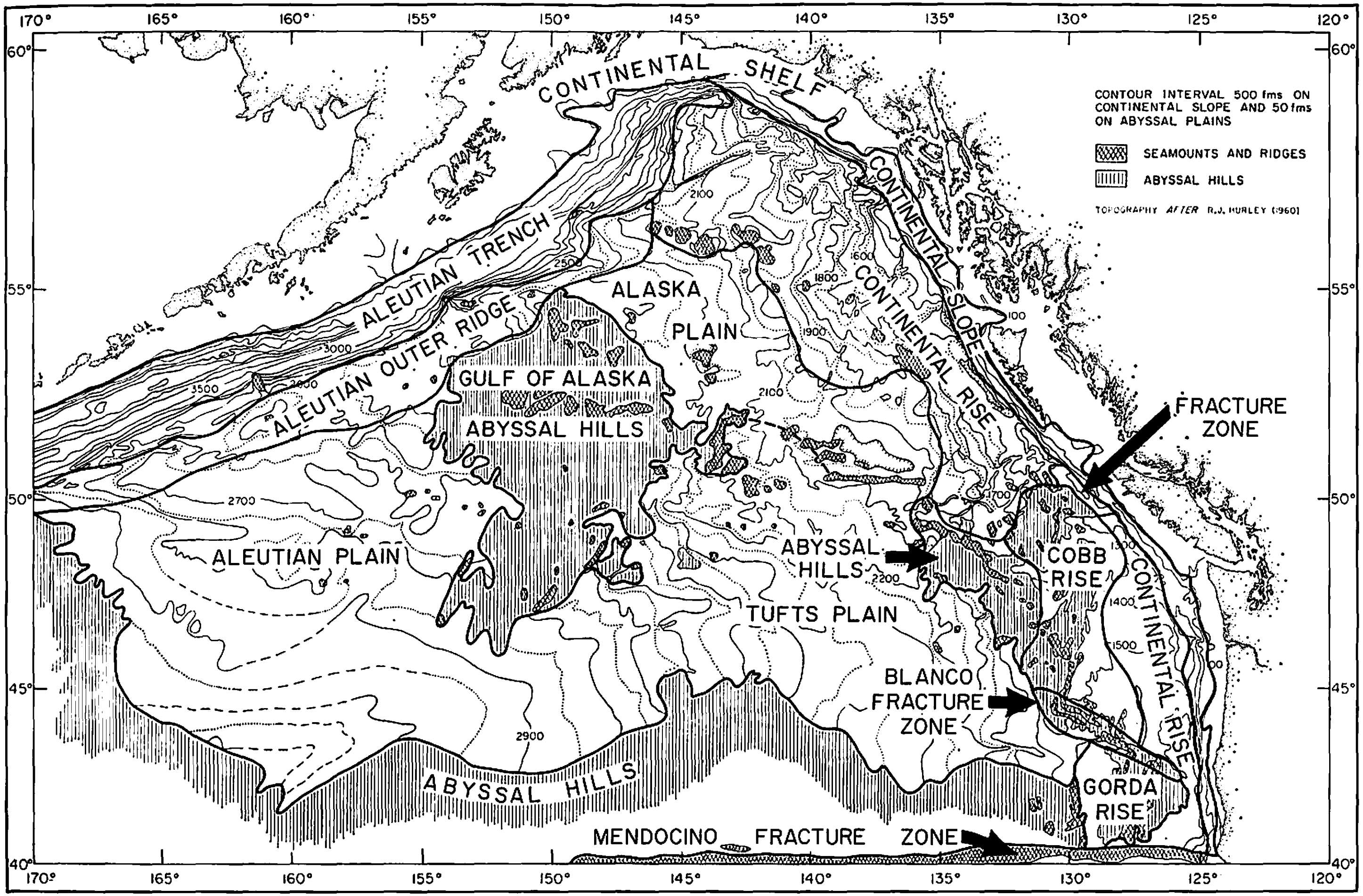


Figure 1. Physiographic provinces in northeast Pacific Ocean. An alternate western limit of Cobb Rise can be drawn along western margin of abyssal hills extending northwestward from identified part of Cobb Rise.

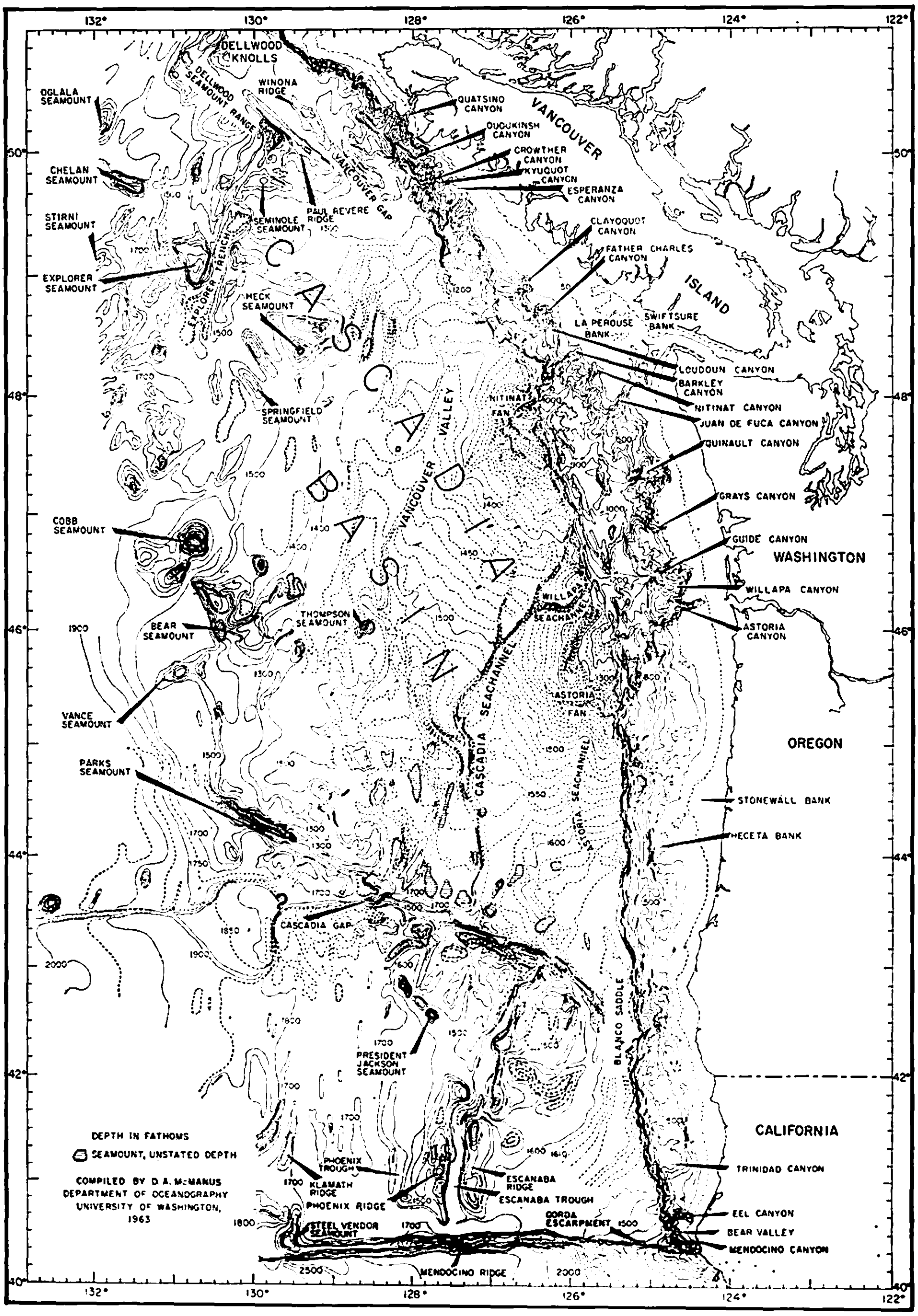


Figure 2. Bottom topography of Gorda Rise and part of Cobb Rise (McManus, 1965c), northeast Pacific Ocean. Cascadia Basin represents continental rise and eastern flank of Cobb. Contour interval is 100 fathoms with 10-fathom form lines added on continental rise and 50-fathom lines on Tufts Plain.

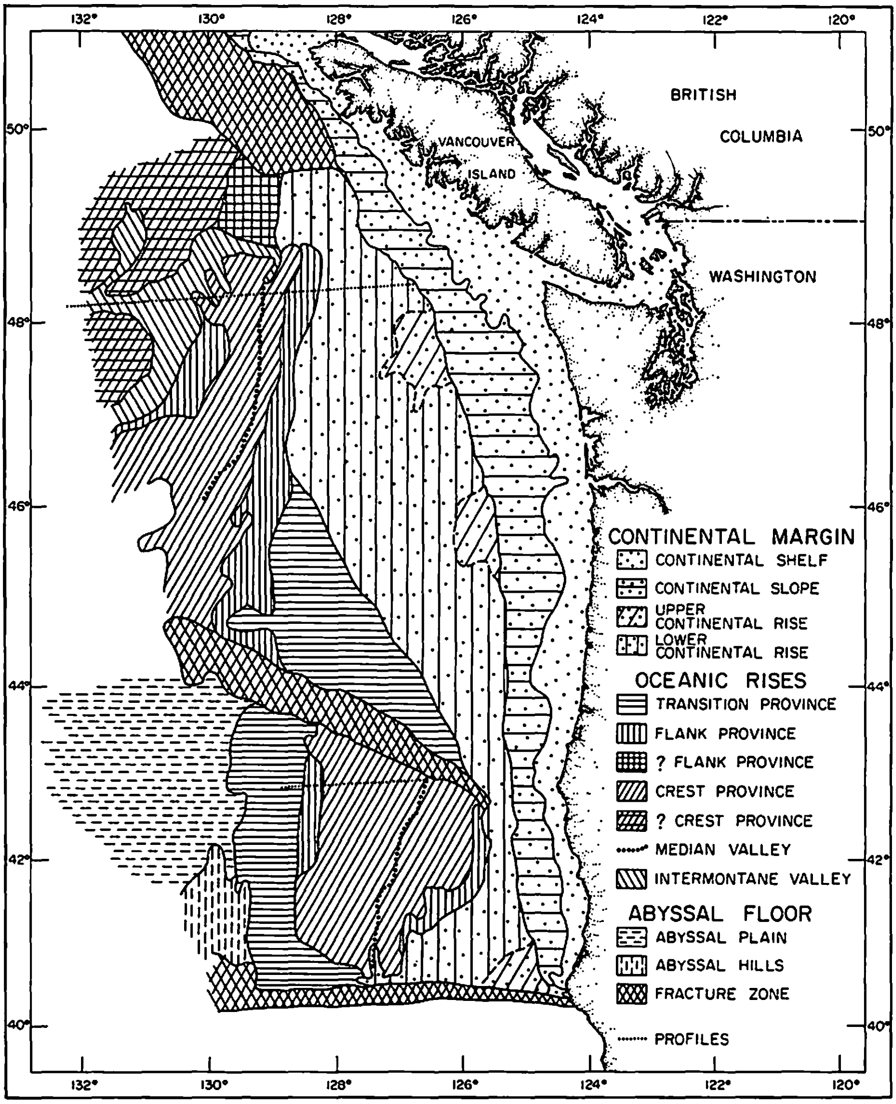


Figure 3. Physiographic provinces on Gorda and Cobb rises, northeast Pacific Ocean. Northern part of Cobb and southwestern part of Gorda Rise are poorly surveyed. Median valley is poorly developed on Cobb Rise but may extend southward to Blanco Fracture Zone.

type is present in the southern part of the trough. The northern end appears to open into a deeper, northwest-trending trough, part of the Blanco Fracture Zone. A narrow sill at 1700 fathoms may separate Escanaba Trough at 1800 fathoms from the fracture zone trough at 1900. About midway along Escanaba Trough, a right-lateral offset of the trough-axis is shown (Fig. 2). At this point the trend changes from north to more northeasterly. The ridges bordering the trough are similarly offset and diverted in trend.

Escanaba and Phoenix ridges, bordering Escanaba Trough, each about 40 km wide, have an average relief between 300 and 400 fathoms. Although the average depth of the ridges is about 1200 fathoms, a few peaks on the ridges rise to depths of less than 1000.

A profile of the bottom topography across the northern part of the rise (Fig. 4) was traced

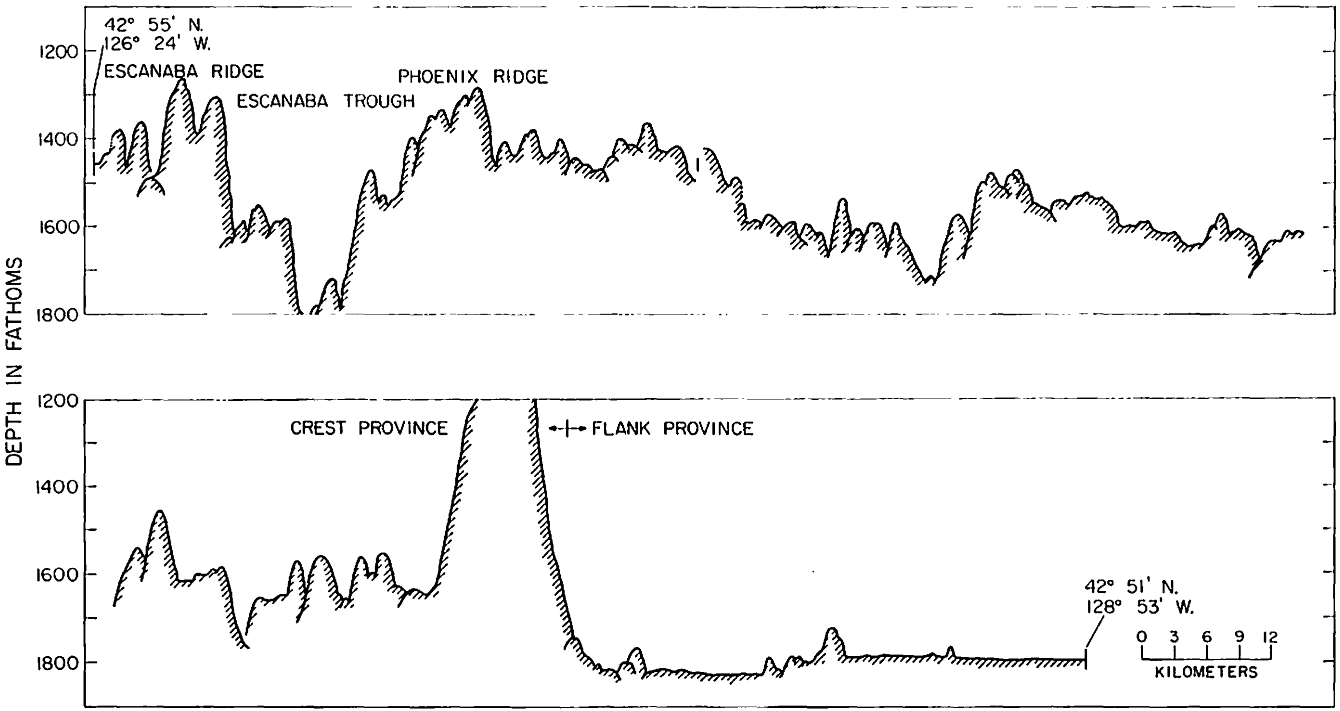


Figure 4. Profile across crest of Gorda Rise, northeast Pacific Ocean. Escanaba Trough is median valley on the rise. Seamount marks boundary between crest and flank provinces. Note difference in topographic expression of the two provinces. Location of the profile is shown in Figure 3. Verticle exaggeration = 23

from a nonprecision echo-sounding record and should be evaluated accordingly. West of Phoenix Ridge the crest province is shown to consist of broad positive and negative relief features having a mean depth of 1600 fathoms. To the west are the smoother topography and smaller hills of the flank province.

The crest province of Gorda Rise appears to consist of the following longitudinal segments from axis outwards: (1) a median trough, (2) a ridge which has the greatest relief in the province, and (3) a broader area of large hills about a relatively constant regional depth.

Flank and Transition Provinces

Flank and transition provinces are present on Gorda Rise (Fig. 3), the distinction being the presence of small hills of a few tens of fathoms relief in the flank province; otherwise, the surface in both provinces is smooth. The transition province represents a region having surface features not directly related to, but seeming to have been rendered anomalous by the presence of the rise.

The flank province is about 40 km wide and delimited from the crest province by the smaller size of the hills and the smoother floor. Locally, however, as in the southwestern part of the rise, the crest and flank are indistinguishable because of flat areas between large hills. The typical hills on the flank are 10–50 fathoms in relief and less than 1 km wide. Instead of occurring as a single hill, they are usually found in clusters less than 5 km wide. The echo-sounding records from the northwestern corner of the rise suggest that some hills on the flank have been partly buried by the sediment, forming the smooth, flat floor between clusters of hills. This sediment is part of the fanlike feature noted by Hurley (1960, p. 37) where Cascadia Seachannel is emitted from Cascadia Gap. A more complete burial of the flank apparently has occurred on the eastern side of the rise due to the prograding of the continental rise.

The transition province is well developed along the western side of the rise over an area 330 km long and 90 km wide. Although in the northern part the province is affected by the fanlike deposit at the mouth of Cascadia Gap, throughout the central part it is a smooth flat feature having a bottom gradient often less than 1:1000, at a depth slightly less than 1800 fathoms. South of 41° N. data are minimal, but the area appears to be part of the transition province. The western margin of the province is a pronounced scarp, and although it is commonly only a few tens of fathoms high, in one place it has 105 fathoms' relief; at the base is Tufts Abyssal Plain. In the southwest the transition province is bordered by abyssal hills of several hundred fathoms relief; it is considered transitional because the smooth abyssal plain-type topography is not rise topography. The province, however, is apparently separated from Tufts Plain by a scarp paralleling the axis of the rise.

COBB RISE

Boundaries

The southern and eastern topographic boundaries of Cobb Rise are relatively distinct. On the south is Blanco Fracture Zone and on the east, at least as far north as 50° N., is the continental rise (Fig. 1). The western boundary of Cobb topography can be drawn along either of two lines at the present time. In one interpretation the boundary is coincident with the boundary selected by Hurley (1960, Pl. 1), separating rough and smooth topography; in the other, the boundary lies within the rough topography. On the north, Cobb Rise is bordered by the continental rise in the form of Queen Charlotte Fan. The exact nature of this contact is open to interpretation. Some authors have suggested that another east-west fracture zone might be present (Hurley, 1960, p. 64; Menard, 1960). The proposed fracture zone topography may possibly be covered in large part by the continental rise sediments although no direct evidence is available. On the northeast is a fracture zone paralleling the continental slope and occupying the position of the continental rise.

The boundaries of Cobb Rise described here differ from those of the Juan de Fuca Ridge (Wilson, 1965). The Juan de Fuca limits proposed, however, were based principally on the pattern of the magnetic anomalies charted by Raff and Mason (1961). Consequently, some differences in demarcation can be expected.

If the western boundary of Cobb Rise shown in Figure 1 is accepted, then the rise represents a region of over 116,000 km^2. Near the Blanco Fracture Zone the rise is 190 km wide and near its northern terminus 195 km wide. The northeastern corner of the rise is less than 75 km from the continental slope, from which it is separated by a fracture zone. The crest of Cobb Rise is at about 1400 fathoms depth (Fig. 5), although numerous seamounts have summits at much shallower depths. (Cobb Seamount, for example, comes within 18 fathoms of the surface.) Cobb Rise is bordered on the east by the two large deep-sea fans forming the continental rise. The depth of this contact increases from 1400 fathoms in the north to more than 1600 fathoms in the south where a transition province separates Cobb Rise from the fan. On the southwest, Cobb Rise is bordered by Tufts Plain at a depth of about 2150 fathoms. Only the eastern part of the rise has received sufficient study to permit sketching of physiographic provinces. Future studies may show the northwest-trending ridge that branches from Cobb Rise to be a part of the rise, but for the present it is considered a separate volcanic ridge.

Crest Province

As on Gorda Rise, both crest and flank provinces are identified, but the crest province on Cobb Rise is probably not one continuous, uninterrupted unit (Fig. 3). If the area indicated as (?) crest province is later verified as crest, the rise must become increasingly complex toward the north. Considering, therefore, only the easternmost part of the crest, the part

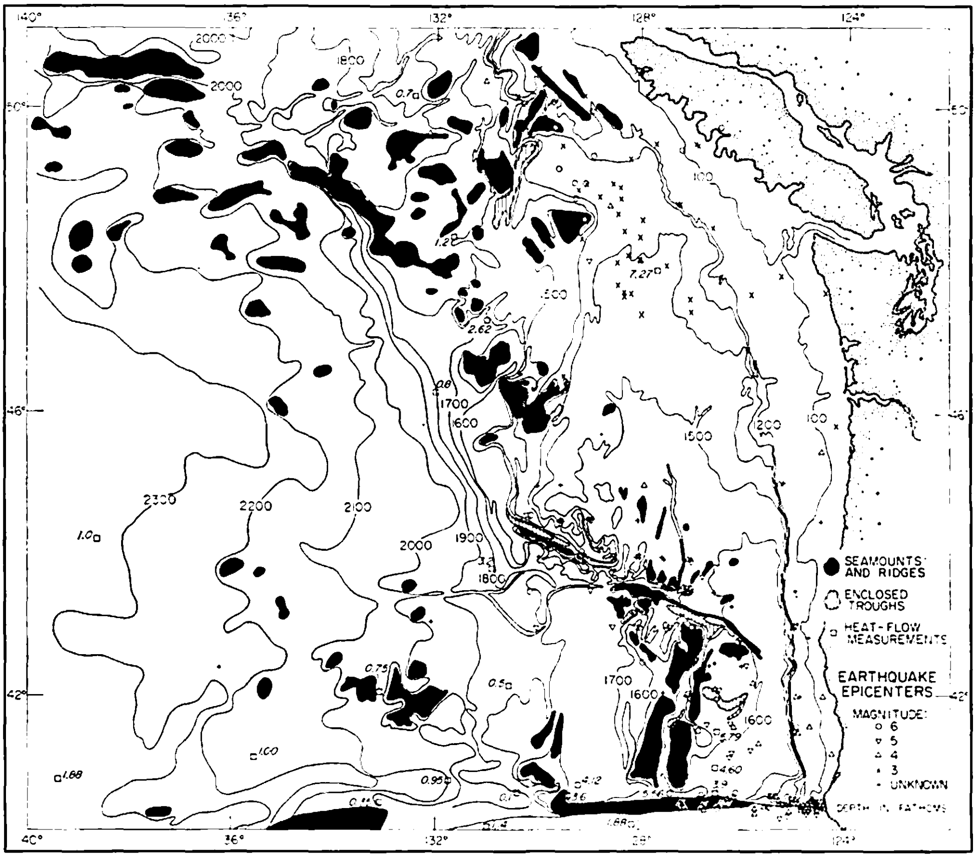


Figure 5. Generalized bottom topography of continental rise, oceanic rises, and deep-sea floor in part of northeast Pacific showing earthquake epicenters and ocean floor heat-flow measurements. Contour interval is 100 fathoms. Only the 100-fathom isobath is drawn for continental shelf and slope. Heat-flow measurements have been compiled from sources noted in text. Epicenters on land are omitted. Topography generalized from Hurley (1960), McManus (1964), and charts of the U.S. Coast and Geodetic Survey

referred to as Juan de Fuca Ridge by Wilson (1965), the crest is about 450 km long and as narrow as 50 km in the central part.

The crest province does not consist of pronounced ridges and a median valley as on Gorda Rise; instead, the relief is more subdued and less distinctive. Crossings of the crest from east to west in the vicinity of Heck Seamount record an area 15–30 km wide of 175–250-fathom hills rising from a level of close to 1400 fathoms (Fig. 6). The hills are usually 7–10 km wide, and even with a relief of only 50–60 fathoms are, much larger than hills in the flank province. Three crossings of the crest between 48°10′ N. and 48°40′ N. show the area of large hills to be delimited on the west by a scarp 300, 375, and 200 fathoms in relief. At the base of the scarp is a trough, 4–5 km wide, its western side formed by Heck Seamount and associated seamounts. The trough is shown in Figures 2 and 3 as a southern continuation of an intermontane valley north of Heck Seamount. The trough is deeper toward the north (1580 fathoms) and has a flat floor like that of the narrow depression north of the Heck Seamount group and the plain to the west. Toward the south the bottom of the trough rises to about 1450 fathoms on the profile in Figure 6; the bottom becomes more irregular, and the western side less distinct. The flat floor and steep wall characteristics of this trough are a mirror image of the southern end of Escanaba Trough on Gorda Rise.

A crossing of the crest at 47°30′ N. reveals hills of less than 100 fathoms relief and the intervening flat-floored depressions that originally suggested the name Ridge and Trough Province. One narrow depression whose floor drops to 1530 fathoms is represented by a closed 1500-fathom contour on Figure 3 just west of the shallowest part of the crest, southeast of Springfield Seamount.

Approximately 50 km farther south two more crossings of the crest were made, the first at about a 45-degree angle with the crest axis, the second at about a 30-degree angle. In the first crossing, the crest province begins on the eastern side with a narrow region of hills having a relief of less than 70 fathoms, a depth of about 1400 fathoms, and a width of less than 10 km. At the western margin of these hills the bottom drops as a 160-fathom scarp to a depth of 1490 fathoms and a flat-floored trough 4 km wide. The west wall of the trough is about 50 fathoms high, and leads up to a relatively flat plateau about 10 km wide with a few 20-fathom hills at each margin.

The second crossing shows the 110-fathom scarp forming the eastern side of the trough, its bottom at 1470 fathoms. The western side, however, appears as small irregularities rising gently to a margin at 1450 fathoms depth with hills continuing to the west.

A crossing northeast of Brown Bear Seamount recorded the two large depressions and adjacent ridges or seamounts (Fig. 2). An additional crossing at about 45°20′ N. revealed a small depression similar to the one previously described. The crest province, therefore, appears to be a region of hills standing in relief of less than 100 fathoms, excepting those near the seamount areas that are as much as 250 fathoms. The ridge line of the rise is at slightly less than 1400 fathoms; just west of this summit a trough is found, typically 4 km wide and at least 100 fathoms deep.

Flank and Transition Provinces

Two provinces, similar to those of Gorda Rise, are identified on the flanks of Cobb Rise: a flank and a transition province. Both are best known to the east of the Cobb crest where, near the northern limit of the distribution, the flank province is about 40 km wide (Fig. 3); its floor is smooth, although in some areas irregularities with a relief of about 10 fathoms occur. One or two clusters of hills about 5 km wide with a relief of 50–70 fathoms are found on each crossing. The floor of the province here is at 1380 fathoms. The western margin is usually marked by the presence of a large hill (200–300 fathoms relief), but in places a depression separates the flank from the large hills of the crest (Fig. 6). The eastern margin of the flank province is commonly marked by the first small hill rising above the continental rise.

Between 48° N. and 46° N. the eastern margin of the flank province is a pronounced scarp rising 10–25 fathoms above the continental rise, with or without a small marginal hill. The province is 15–40 km wide and has as many as five clusters of hills showing a relief of up to 50 fathoms. These clusters, less than 4 km wide, are separated by a relatively smooth floor having irregularities of less than 5 fathoms. South of 46° N. the province appears to continue these characteristics, but the data are poor.

The scarp or small hill representing the eastern margin of the flank province is the western limit of the continental rise. South of the latitude of Thompson Seamount, however, a transition province occurs between the flank province and the continental rise. It is relatively smooth-floored and has a few large hills of as much as 200 fathoms relief that merge indistinguishably with those of the Blanco Fracture Zone. A scarp rising 10–20 fathoms to the level of the flank province delimits the transition province on the west, but the eastern margin of the latter is less distinct. The border is formed by the west bank of Vancouver Valley as far south as the junction of the valley with Cascadia Seachannel. From there the boundary line runs almost to the eastern end of the Blanco Fracture Zone. The area thus delimited (Fig. 3), although apparently part of the continental rise, has the singular characteristics of a different regional gradient, the presence of large hills, and the occurrence of the section of Cascadia Seachannel entrenched more than 150 fathoms. In addition, the sediment differs from that on the continental rise. As a result, the transition province seems to be an anomalous region of generally low gradient.

In the northwest part of the map area (Fig. 3), a province referred to as "intermontane valleys" is identified. This province is a flat, smooth-floored region resembling the continental rise or an abyssal plain; the bottom gradient is usually less than 1:1000, even along the northern terminus of the Heck Seamount group. Its depth is about 1530 fathoms over most of the area. The shallowest depth of little more than 1500 fathoms occurs east of Explorer Trough at about 49° N. and may represent a small fan that formed where sediment has been carried into the valley. The province becomes deeper in the western part of the map area (Fig. 2). Between its eastern and western parts is the northeast-trending Explorer Trough (Trench on the maps) of 500 fathoms relief with parallel ridges, a probable crestal topography.

REGIONAL SETTING

The description of the topographic margins of Cobb and Gorda rises noted that the tectonic margins are indistinct. One method of delimiting the rises on the west has been by drawing the line at the base of the regional westward bottom gradient (Menard, 1964, p. 118). This method, if applied in the North Atlantic, would with a few large perturbations approximate the limits of the Mid-Atlantic Ridge (*defined by* Heezen and others, 1959, Pl. 20). In the northeast Pacific, however, this method would include the eastern part of the Tufts Plain and most of Alaska Plain in the flank of the rise. These plains have abnormally high gradients for abyssal plains (Hurley, 1960, p. 27) that

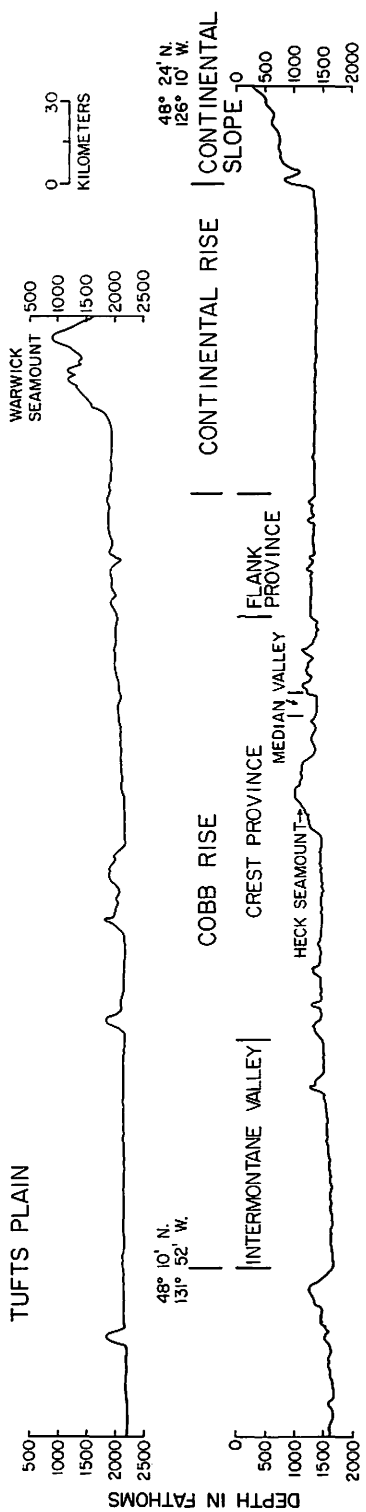


Figure 6. Bottom profile from continental slope to Tufts Plain, northeast Pacific Ocean. Distribution of physiographic provinces west of intermontane valley is uncertain. Vertical exaggeration = 1.2

could be explained by deposition on the flank of an old rise or uplift of the flank of a young rise. In the western part of Alaska Plain occur the guyots that have been interpreted as evidence of a former elevation of the rise (Menard, 1964, p. 135).

At the northeastern end of Cobb Rise, fracture-zone topography occurs along a northwest trend. These narrow ridges are identifiable off the northern end of Vancouver Island as a narrow zone separating the continental slope from Cobb Rise. The continental rise is missing; however, sediment apparently has filled the troughs between the ridges. The fracture-zone topography is assumed to be buried under continental rise sediment to the southeast and northwest, and is marked by a belt of earthquake epicenters. It corresponds to the southern part of the Queen Charlotte Islands fault described by Wilson (1965). The zone may continue north of the Queen Charlotte Fan to the Queen Charlotte Islands, or the low rise paralleling the continental slope off these islands may represent another segment of the oceanic rise, but data are insufficient for more than speculation. There is little data from the deep-sea floor north of the Queen Charlotte Islands to suggest further continuation of either a fracture zone or an oceanic rise. Instead, there is some suggestion of a filled trench (Shor, 1962).

To the south of Gorda Rise is the Mendocino Fracture Zone, a site of tectonic activity evidenced by the sheared and fractured rock samples with slickensides dredged from the fracture zone (Engel and Engel, 1963, p. 1321; Krause and others, 1964). The nature of the movement along the fracture zone has a direct bearing on the regional relationship between Gorda Rise and the sea floor south of it. Determinations of the direction and amount of movement have been based primarily on the pattern of magnetic anomalies (Vacquier and others, 1961), and secondarily, on the bottom topography (*see* Menard, 1964, p. 41–54, for summary). The data, however, are inconclusive, as can be shown by the three different interpretations of the same data: (1) the magnetic anomalies indicate a left-lateral offset across the transcurrent fault of the fracture zone with the absolute movement occurring by means of the northern block moving toward the west (Menard, 1964, p. 342); (2) the magnetic anomalies indicate a left-lateral offset across the transcurrent fault of the fracture zone with the absolute movement occurring by means of both blocks moving toward the east, and the southern block moving faster (Hess, 1965, p. 320); (3) the magnetic anomalies indicate no offset or transcurrent faulting, but normal faulting between segments of the rise (Talwani and others, 1965). Consequently, if the magnetic intensity data can be used to indicate that one block of the crust moved laterally westward past an adjacent stable block, moved laterally eastward in the same direction as the adjacent block, or moved vertically, then the data are too ambiguous to solve the problem of movement on the Mendocino Fracture Zone. Equivalent offset in the magnetic pattern and the bathymetry has been used as corroboration of the offset in the magnetic anomaly pattern (Menard, 1964, p. 49). For the next fracture zone north of the Mendocino, however, the apparent offset of bathymetry and the magnetic anomaly patterns seem diametrically opposite (McManus, 1965c) although a different interpretation is possible (Vine and Wilson, 1965). For the Mendocino Fracture Zone, then, oceanic rise crustal structure adjoins the zone on the north but not on the south, and the sea floor is about 500–600 fathoms deeper to the south.

Several characteristics of the sea floor a few hundred kilometers south of the Mendocino Zone should be noted. The bottom topography includes northward trending hills, partly buried by the Monterey Fan, and a few similarly trending troughs farther west (Menard, 1964). This topography on a general chart is not dissimilar from the topography north of the Mendocino. Guyots similar to those in the Gulf of Alaska are present (Menard, 1964, p. 139); even the typical abyssal hills have been discovered to show a north-south lineation (Loughridge, 1966). All these data suggest a similarity to Cobb and Gorda rises.

DISCUSSION

Gorda Rise

This rise has been recognized as a separate segment of the rise system, even though unnamed, since the discovery of the delimiting Blanco Fracture Zone by Menard (1962). Escanaba Trough, the most prominent feature on the rise was named by McManus (1964) and identified by Menard (1964, p. 121) as the only known possible example of the median rift valley on the oceanic rise system in the eastern Pacific. When compared to the Rift Valley in the Mid-Atlantic Ridge (Heezen and others, 1959, p. 84–92), Escanaba Trough is seen to be a smaller feature, with only degrees of difference (Table 1). Topographically, Escanaba Trough appears to be a smaller rift valley on a smaller segment of the worldwide rise system. The flat floor discovered in the southern part of Escanaba Trough is not characteristic of a rift valley (Heezen and others, 1959; Van Andel and others, 1965), but can be explained as a partial filling of the valley by continental rise sediment (Fig. 3).

The correlation of Escanaba Trough with the rift valley is supported by the results of Raff and Mason's (1961) magnetometer study. The pattern of magnetic anomalies is a series of northeast-trending, narrow belts of successively positive and negative anomalies. A rough parallelism with the topography is apparent, and the largest and broadest positive anomaly extending from 40°40′ N., 127°30′ W. to 42°30′ N., 126°50′ W. corresponds to Escanaba Trough. The 200 gamma anomaly over the trough is comparable in wavelength to the anomalies recorded over the rift valley of the Mid-Atlantic Ridge (Heirtzler and LePichon, 1965), although the amplitude is less. In addition, the bands of anomalies farther away from the trough anomaly have greater wavelength than the nearer ones. A similar relationship was noted by Vine and Matthews (1963) in the anomalies paralleling the rift valley on the Mid-Atlantic Ridge. The flank anomalies on Gorda Rise tend to have slightly lower amplitude than those of the crest. The transition province on the west and the continental rise on the east show even lower amplitude anomalies. The curved border at the southeastern corner of Gorda Rise is also reflected in the curving of the magnetic anomalies, and the right-lateral offset about midlength of Escanaba Trough is represented by an offset in the anomaly pattern, which is roughly aligned with the linear pattern formed by President Jackson Seamount and two others to the northwest. A short fracture zone trending northwestward, therefore, may cross Gorda Rise.

When seismic refraction work in the area (Raitt, 1963) is also considered, the setting of Gorda Rise and the median valley is almost complete. The abnormally low mantle velocities reported by Raitt (1963) from north of the Mendocino Fracture Zone can be correlated with the anomalous mantle reported by Talwani and others, (1965) under the Mid-Atlantic Ridge. The westward extent of this anomalous mantle is unknown, but its presence under the southern end of the crest province, is substantiated by the gravity work of Oregon State University personnel (P. Dehlinger, 1965, personal communication).

The crest of Gorda Rise appears to be seismically active as is the crest along most of the remainder of the worldwide oceanic rise system (Heezen and Ewing, 1963, p. 391). The plot of the epicenters on the bottom topography of Gorda Rise (McManus, 1965c) can be interpreted diversely, however, because associated with the Gorda Rise activity is the neighboring seismic activity of the Blanco Fracture Zone, Mendocino Fracture Zone, and the San Andreas Fault on the continent (Fig. 5). When the epicenters that seem most closely correlated with the fracture zones are deleted, several epicenters remain over the central part of the rise. These can be interpreted to represent seismic activity along the crest of the rise and to be associated with Escanaba Trough. They can also be interpreted, however, to represent the small fracture zone (?) midway along the rise. All epicenters on Gorda Rise, therefore, could be associated with the fracture zones rather than the median valley. This association was proposed by Talwani (1964) and has recently received partial documentation in the southeastern Pacific (Menard, 1966).

The relatively high heat-flow values recorded from Gorda Rise soon led Menard (1960) to compare the rise with the balance of the worldwide rise system. Recent measurements by Von Herzen (1964) show values of 4.60 — 5.79 $\times 10^{-6}$ cal cm^{-2} sec^{-1} over the crest of the rise, a value of 3.9 from the continental rise southeast of the rise, and 4.12 from the transition province east of Klamath Ridge (Fig. 5). These values are typical of the ones obtained on the crest of the oceanic rise system in the Atlantic

TABLE 1. COMPARISON OF MID-ATLANTIC RIDGE RIFT VALLEY AND ESCANABA TROUGH, NORTHEAST PACIFIC OCEAN

	Rift valley of Mid-Atlantic Ridge, North Atlantic*	Escanaba Trough, Gorda Rise, northeast Pacific
Average depth	2000 fathoms	1800 fathoms
Average depth of adjoining ridges	1000 fathoms	1200 fathoms
Relief of valley	700–2100 fathoms	200–1000 fathoms
Width of valley	30–50 km	30 km

* *From* Heezen and others (1959)

and Pacific (Lee and Uyeda, 1965); they are not typical of flank values. A series of measurements across the Mid-Atlantic Ridge by Vacquier and Von Herzen (1964) revealed heat-flow values of this magnitude to occur characteristically within 100 km of the apex of the magnetic anomaly that is correlated with the crest of the rise. The values on Gorda Rise are within 150 km of the central magnetic anomaly.

Gorda Rise topography appears to represent the crest of a large tectonic feature extending westward under the adjacent abyssal hills and plain and eastward against the continent. The flanks of the rise are obscured by the cover of continental rise material on the east and by the hills and plain on the west. The large transition province along the western margin of the rise probably represents that part of the adjacent abyssal plain so affected by the oceanic rise uplift as to be detectably different. The scarp forming the western margin of the transition province may represent the western side of a series of north-south ridges that have ponded the sediment. The transition province may have received sediment both from Cascadia Gap and the east-west passage between the Gorda crestal topography and the Mendocino Ridge.

Cobb Rise

Originally considered a part of the oceanic rise system, this rise was undifferentiated from Gorda because of its shallow depth and the ridge and trough topography (Menard, 1960). Wilson (1965) later based the assignment on the magnetic anomaly pattern. The ridge and trough topography, however, does not have the same relief as that on Gorda Rise, a condition most apparent with regard to the median valley. No linear depression and adjoining ridges having the Escanaba Trough relief are present, but a troughlike depression is encountered just west of the summit on each crossing of Cobb Rise. In the north this trough is partly filled with sediment but still displays half the relief and about 0.2 the width of Escanaba Trough. Farther south, and therefore at shallower depths, the trough has less relief, although maintaining about the same width. In general, considering Escanaba Trough also, the higher the trough stands on the rise, the less it is developed in width and relief. This generalization, however, has several exceptions; for example, near Brown Bear Seamount the trough shows 300–400 fathoms relief at a shallow depth.

Several explanations can be offered for the origin of the trough on Cobb Rise. A single trough can be interpreted to exist as a median valley on the rise; a modified interpretation would consider several genetically identical but unconnected troughs along a common line; still another interpretation is that no median trough is present. Instead, some of the shallow troughs of this ridge and trough topography seem to be aligned. The deeper troughs could be pronounced manifestations of the moats around seamounts because the deeper parts of the suggested median trough occur only near the large seamounts, such as Heck and Brown Bear Seamounts. Less pronounced moats around seamounts in the northeast Pacific have been described by Menard and Dietz (1951). An alternative is that only the shallow trough is the median valley and the larger troughs are associated with the seamounts.

Assistance in evaluating these interpretations is available from the chart of the magnetic anomalies (Raff and Mason, 1961). Those over much of Cobb Rise trend northeastward, parallel to the crestal topography and median valley. One of the positive anomaly bands in the pattern was suggested by Wilson (1965) and Vine and Wilson (1965) to correspond to the broad one associated with the axis, and as a result, the rift valley of the Mid-Atlantic Ridge. A comparable development on Gorda Rise was mentioned previously. This axial magnetic anomaly on Cobb Rise lies along the crest from the Blanco Fracture Zone northeastward to about 47°30′ N. From this point, the anomaly continues northeastward to the fringe of the continental rise, but the crest veers to the north toward Heck Seamount. Between Blanco Fracture Zone and 47°30′ N. the magnetic anomaly and the axis are concordant.

A review of Raff and Mason's (1961) chart reveals that the broad positive anomaly and the adjacent ones are disrupted at about 47°30′ N. In accordance with the distribution of the topographic crest, one can also interpret the median anomaly to turn north at this point and continue northward along the 129th meridian to Heck Seamount. The result of this interpretation would be a crest slightly convex toward the continent and coincident with the anomalies. At the latitude of Heck Seamount both the topography and magnetic anomalies reach the terminus of the northward trend of the arc.

The axial magnetic anomaly on Cobb Rise has been correlated by Wilson (1965) and Vine and Wilson (1965) with that of the oceanic rise system in the rest of the ocean. On the Mid-Atlantic Ridge, however, this anomaly is restricted laterally to the dimensions of the rift valley (Heezen and others, 1959; Heirtzler and LePichon, 1965) although the valley is not present on every crossing. On Cobb Rise the anomaly is about 45 km wide, or more than 10 times the width of the median valley; however, it has about the same dimensions as the one on the Mid-Atlantic Ridge. From this comparison it appears that the magnetic anomaly, although spatially associated with the median valley, is a feature of separate dimensions. The vertical sides of the crustal block of normally magnetized material, proposed to represent the axial anomaly (Vine and Wilson, 1965), do not correspond to the sides of the rift valley.

The interpretation of Vine and Wilson (1965) correlating a single magnetic anomaly with the axis of Cobb Rise differs from that of Heirtzler and LePichon (1965, p. 4028), who recognize several axial anomalies as described from the Mid-Atlantic Ridge in the South Atlantic.

Few additional geophysical measurements are available from Cobb Rise. Heat-flow measurements by Foster (1962) include three observations approximately along the 132nd meridian. The values (Fig. 5) range from normal (1.2 $\times 10^{-6}$ cal cm^{-2} sec^{-1}) to low (0.8–0.7). Two measurements reported in Talwani and others (1965, p. 1115) show high values: 2.62 in the intermontane valley 30 miles northwest of Cobb Seamount and 7.27 in Vancouver Valley at the eastern margin of Cobb Rise (Fig. 5). The wide range in heat-flow values observed on oceanic rises, therefore, is also recorded here. An attempt was made to correlate the heat-flow values with those of the magnetic anomaly at that location, but little importance is attached to the results because the steep sides of the anomalies permit a small error in horizontal positioning or plotting to change the heat-flow station from a positive to a negative anomaly. Consequently, high heat-flow values could be plotted on positive and negative anomalies, and the one low value that could be plotted occurred over a positive anomaly. Possibly significant, however, was the location of the very high value of 7.27 $\times 10^{-6}$ cal cm^{-2} sec^{-1} in the east-west zone of disturbance in the magnetic anomaly pattern corresponding to the change in trend of the rise axis. This location is also at the southern limit of the epicenter belt extending northward into Alaska.

The area of Cobb Rise is delimited by the absence of seismic activity (Fig. 5). Earthquake epicenters along the southern margin of the rise have been associated with the Blanco Fracture Zone (Hurley, 1960; McManus, 1965c). The epicenters along the northern margin have been associated with a northwest-trending transform fault by Wilson (1965), and can be associated with the fracture zone topography between Cobb Rise and the continent (Fig. 5). On the rise proper, away from the marginal zones, only a single epicenter has been listed in the records used to prepare Figure 5; no significance is attached to this solitary plot, but it does fall on the axis of the rise. Cobb Rise appears to offer the best data supporting the suggestion (Talwani, 1964) that the seismic activity on oceanic rises is associated with the fracture zones rather than the rift valley.

Age

An age for Cobb and Gorda rises is closely bound to the deduced method of rise development. The rises are considered to be young—beginning in the Early Tertiary (Menard, 1964, p. 135) or Late Tertiary (Vine and Wilson, 1965). The Early Tertiary age is based on the assumption that the rises formed contemporaneously with the East Pacific Rise as a single system in which there was elevation, extension to the Pacific-Antarctic Ridge, and transverse faulting along the fracture zones. The Late Tertiary age is based on the pattern of magnetic anomalies on Cobb Rise, and the assumption that the pattern of alternating positive and negative anomalies represents normally and reversely magnetized material moving away from the rise axis by sea floor-spreading at a rate of 3 cm/year. The only dates in the area are a K-Ag whole-rock date from Cobb Seamount of 27 (± 6) $\times 10^6$ years (B. J. Enbysk, 1965, personal communication) and Pliocene foraminifera on the sides of a trough in Blanco Fracture Zone (McManus, 1965c). Because Cobb Seamount is similar to others in this area in size, relief, and so on, the Late Oligocene to Early Miocene date from 210 fathoms depth on Cobb may also be applicable to the entire group of seamounts. A Miocene age for the Blanco Fracture Zone is compatible with the age of similarly oriented tectonic features on the adjacent continent (McManus, 1965c). The northwest trend of these structures is repeated in the volcanic ridge branching off Cobb Rise and in the entire group of seamounts aligned northwesterly across the Gulf of Alaska. In addition, a Miocene date for the high-silica, low-potassium tholeiites on Cobb Rise (Engel and Engel, 1963,

p. 1322) and the rock in Blanco Fracture Zone would correspond to or slightly predate the Miocene and Miocene-Pliocene age of the tholeiitic basalt of the Columbia Plateau (Waters, 1962). Consequently, an Early Miocene age for volcanoes on Cobb Rise seems tenable.

According to the hypothesis of Wilson (1963) submarine volcanoes form on the crest of rises; Hess (1965, p. 318) believes most but not all submarine volcanoes form on the crest of rises. Both hypotheses account for the present distribution of volcanoes by sea floor-spreading along the crest of the rise and the conveyance of the volcanoes with time to deeper water. Cobb Seamount and the other volcanoes in this group probably would have been formed on the crest of the rise. Vine and Wilson (1965) in deducing the Late Tertiary date for Cobb Rise, assume sea floor-spreading, which they calculate has produced new crust within 60 km of the rise axis during the past 4×10^6 years and new crust within 175 km of the axis during the past 12×10^6 years.

Cobb Seamount, however, is 110 km from the axis and is at least 27×10^6 years old. If one assumes that volcanoes are formed at the rise crest and moved by the spreading of the sea floor, then the date of Cobb Seamount makes a Late Tertiary age of the rise untenable. Instead, the rise would be at least Miocene in age, and the rate of spreading of the sea floor along the crest would be about 0.8 cm/year, rather than 3 cm/year as assumed (Vine and Wilson, 1965). The workers concluded that a spreading rate as low as 1 cm/year would produce a central anomaly of high-amplitude such as found over the Mid-Atlantic Ridge, instead of the broad and rather inconspicuous anomaly on Cobb Rise. A Miocene age, therefore, and the requisite 1 cm/year spreading rate both cannot be applied to Cobb Rise.

Various exits are open to this apparent dilemma; the author has chosen the following: (1) The volcanoes were not formed on the crest of the rise, but in place in relationship to the rise. Menard (1965, p. 359) presents a capable argument to this effect for other volcanoes and rises. (2) The sea floor has not spread away from the rise axis, although an elevation of the sea floor to produce the rise has occurred. On Cobb Rise the median valley, if present, is ill-defined. The sedimentary layer on Cobb is very thin (Shor and others, 1966), and cores from the crest of the rise have supplied only indurated sediment or rock. Therefore, if the volcanoes and Blanco Fracture Zone represent a Miocene event, then Cobb probably dates from the same time. It is doubtful that the rise is very young, less than 10^6 years old, (*suggested by* Hess, 1965, p. 329) for the entire East Pacific Rise.

Development

At the present stage in the study of Cobb and Gorda rises several histories of development seem tenable. These rises may be considered: (1) an extension of the East Pacific Rise, (2) a local rejuvenation of a rise predating the East Pacific Rise, or (3) an auxiliary rise such as Nasca Ridge and Cocos Ridge in the southeast Pacific.

An extension of the East Pacific Rise is the most common explanation given for Cobb and Gorda rises (Menard, 1960, 1964; Talwani and others, 1965; Wilson, 1965) (Fig. 7a). The dislocation of the rise system is explained by transform faulting, transcurrent faulting, or varying sites of development. These northern rises and the rise in the southeast Pacific are roughly in the same stage of development and segmented along fracture zones, with the segment between the mouth of the Gulf of California and the Mendocino Escarpment unrepresented on the sea floor except as a lower slope of the rise flank.

A local rejuvenation of a rise predating the East Pacific Rise as a second explanation of Cobb and Gorda rises (Fig. 7b) is based on the following observations:

(a) Cobb and Gorda have ridge and trough topography on their crests, as do all the Pacific rises other than the East Pacific Rise. Such crestal topography characterizes the Darwin Rise (Menard, 1964, p. 138), the Galapagos Rise (Menard and others, 1964), and Melanisian Rise (Menard, 1964, p. 146). On the East Pacific Rise the ridge and trough topography occurs on the flanks (Menard, 1960).

(b) As a consequence of observation (a), a median valley has been identified on the crest of the northern rises, but not on the East Pacific Rise.

(c) Guyots, seamount terraces, and pebble-covered fault ridges interpreted as former elevations of the sea bottom to permit surf action on these now-drowned features, are found on the sea floor from Baja California to the Aleutian Trench, but not on the East Pacific Rise (Menard, 1964, p. 139–140).

(d) The topography for much of the area south of the Mendocino Escarpment to Baja California is similar to that of an oceanic rise

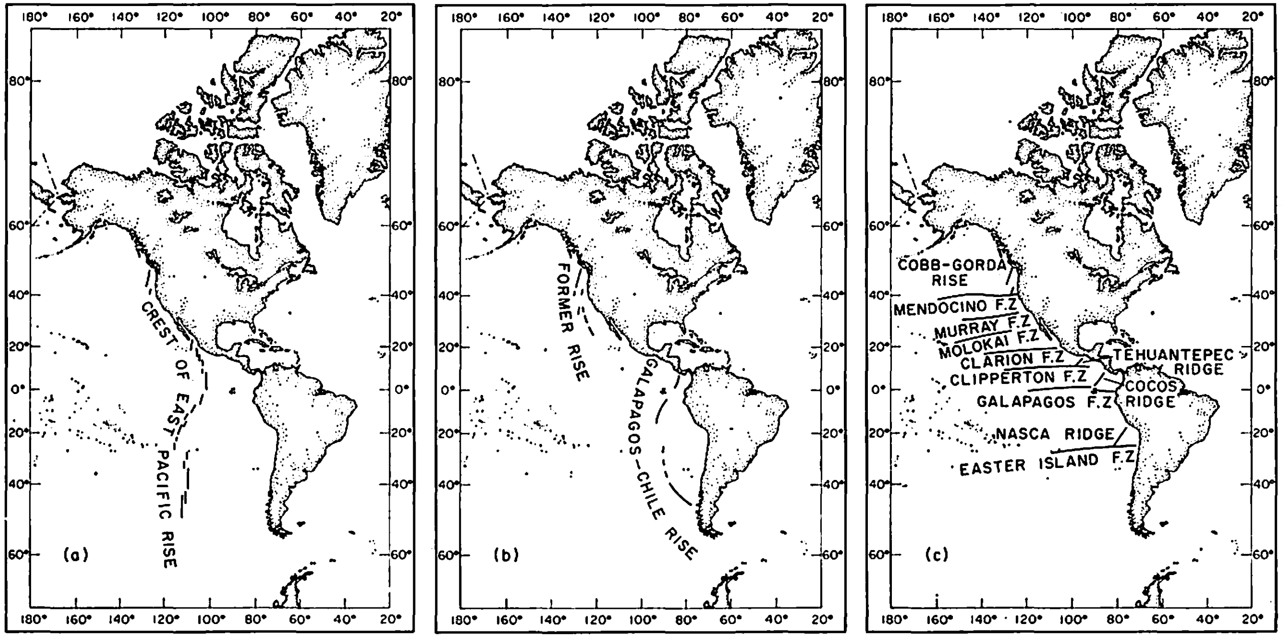


Figure 7. Three interpretations of regional relationships of Cobb and Gorda rises, northeast Pacific Ocean: (a) as part of crest of the East Pacific Rise, (b) as rejuvenated part of a former arcuate rise predating East Pacific Rise, and (c) as an auxiliary ridge adjoining major fracture zone

rather than of typical abyssal hills. In this region is a large area south of the Murray Fracture Zone that has ". . . unusual abyssal hills with more relief than elsewhere in the northeastern Pacific . . ." (Menard, 1965, p. 341). The explanation given is the same crustal tension explaining the topography on Cobb and Gorda rises (Menard, 1965, p. 341–342), and consequently, one can assume the topography to be very similar. It is bordered on the east by an area of guyots, and just east of these is the area of "typical" abyssal hills recently discovered to show a north-south lineation (Loughridge, 1966).

These observations suggest a closer similarity in history may exist between the areas north and south of the Mendocino Zone than previously believed. Possibly an oceanic rise bordered North America along the west coast in the same arcuate manner that the Galapagos Rise borders South America. The more recent East Pacific Rise then developed, but in the north its axis was on the east side of Baja California rather than on the west where the older rise had been. Farther north, however, the new rise was coincident with that part of the old one represented by Gorda and Cobb rises. The somewhat subdued topographic response to this rejuvenation by Cobb Rise, as compared to Gorda Rise, could be due in part to its being partly downbowed to the east by the subsiding wedge of continental rise sediment. Future geophysical studies of the area between the Mendocino and Clarion Fracture zones should consider the possibility of the existence of a former rise here.

The third explanation of Cobb and Gorda rises is that they form an auxiliary ridge such as Nasca Ridge and Cocos Ridge (Fig. 7c). Certain characteristics common to Nasca, Cocos and Tehuantepec ridges have been listed by Menard (1965, p. 343), and also apply to Gorda and Cobb rises. Each ridge trends northeasterly from a major east-west fracture zone, abuts a convex westward extension of the continent into the ocean basin, is separated from the continent to the east by a triangular basin, is an asymmetrical ridge with the steep side toward the continent although this flank of Cobb and Gorda rises is partly buried, and each has numerous volcanoes associated with it. Reports on other observations are incomplete, but Tehuantepec Ridge is seismically active (Menard and Fisher, 1958, p. 249), as are Gorda and Cobb. Heat-flow measurements on and near Cocos Ridge and on Tehuantepec Ridge obtained high values (Von Herzen and Uyeda, 1963; Langseth and others, 1964), as on Gorda and Cobb. Seismic refraction studies in the basin behind Tehuantepec Ridge can be interpreted to indicate low velocity anomalous mantle material if the individual station solutions of Shor and Fisher (1961, p. 725) are used. Similar material has been detected under Gorda Rise. It should be noted, however, that other solutions for the structural computations of Shor and Fisher (1961, p. 726) are possible, such as that based on regional uniformity of velocities. These topographic and geophysical observations suggest that the similarity among the auxiliary ridges is more than one of geometry.

The development of the auxiliary ridges in the equatorial Pacific has been associated with the movement of crustal blocks between fracture zones (Menard, 1964, p. 135), which, in turn, have been related to the development of the East Pacific Rise (Menard, 1960) and indirectly, therefore, the development of the auxiliary ridges has been associated with the oceanic rise. Data and arguments have been presented for some time, however, that offsets of hundreds of kilometers in the rise crest along the major fracture zones are questionable (*see*, for example, Talwani and others, 1965). Recent studies suggest that the East Pacific Rise and major fracture zones may not be genetically related (Menard, 1966). Hess (1965) associates the fracture zones with the older Darwin Rise. Consequently, the development of Gorda and Cobb rises as an auxiliary ridge associated with the Mendocino Fracture Zone can be considered separately from that of the East Pacific Rise. If Cobb and Gorda rises form a feature separate from the East Pacific Rise, then the East Pacific Rise is not identified as a deep-sea feature north of the Gulf of California; *i.e.*, there is no reappearance on the sea floor farther north. The development of Cobb and Gorda rises in the interpretation must be similar to that of each of the other auxiliary ridges, but further discussion of this interpretation is excessively speculative.

SUMMARY AND CONCLUSIONS

Two small oceanic rises separated by a fracture zone are present near the Washington-Oregon coast. Physiographic provinces are best developed on Gorda Rise, which is probably Miocene or older. The provinces are similar to those on the Mid-Atlantic Ridge rather than those on the East Pacific Rise, and include a crest province with a well-developed median valley, a flank province, and a transition province passing into the continental rise on the east and abyssal plains or hills on the west. Similar provinces on Cobb Rise are poorly developed. Cobb Rise is slightly convex toward the continent, and is separated from the continent, at the northern end, by a fracture zone. Smaller fracture zones may cross each rise.

These northeast-trending rises, isolated from the others of the worldwide rise system, are located at the southeast terminus of a series of northwest-trending volcanic ridges extending across the Gulf of Alaska. A deeper branch of Cobb Rise, apparently, is part of this volcanic ridge system. The rises also are located on the margin of the only part of the Pacific floored with extensive abyssal plains and having a well-developed continental rise which may represent a filled trench. The rises, therefore, can be interpreted as Early Tertiary features in a comparably old area of sea-floor morphology.

The rises previously have been considered part of the East Pacific Rise, and its Early Tertiary age has been based on the age of features in the Gulf of Alaska. By considering the East Pacific Rise to extend only as far north as the Gulf of California, it may be assigned a much younger age, Cobb and Gorda rises may retain their Early Tertiary age, and the difference between the topographic characteristics of the two rises can be resolved. Cobb and Gorda rises are, therefore, considered to represent a rise system distinct from the East Pacific Rise, although recent rejuvenation associated with the East Pacific system may be active. Data are insufficient to determine whether Cobb and Gorda rises are related in their development to the guyots in the Gulf of Alaska, whether the rises were part of a former arcuate rise off the west coast of North America, or whether the rises actually form an auxiliary ridge associated with the Mendocino Fracture Zone and are unrelated to the oceanic rise system.

REFERENCES CITED

Enbysk, B. J., and Budinger, T. F., 1960, Cobb Seamount, a deep-sea feature off the Washington coast: Univ. Washington Dept. Oceanography Tech. Rept. 60, 88 p.

Enbysk, B. J., and Cooper, S. C., 1965, Biogenic elements in surface sediments of Cascadia Basin, northeast Pacific, p. 251–252 *in* The Geological Society of America, Abstracts for 1964: Geol. Soc. America Special Paper 82, 400 p.

Engel, C. G., and Engel, A. E. J., 1963, Basalts dredged from the northeastern Pacific Ocean: Science, v. 140, p. 1321–1324

Foster, T. D., 1962, Heat-flow measurements in the Northeast Pacific and in the Bering Sea: Jour. Geophys. Research, v. 67, p. 2991–2993

Heezen, B. C., and Ewing, M., 1963, The mid-ocean ridge, p. 388–410 *in* Hill, M. N., *Editor*, The Sea, ideas and observations on progress in the study of the seas: New York, Interscience Publishers, 963 p.

Heezen, B. C., Tharp, M., and Ewing, M., 1959, The floors of the oceans; I: The North Atlantic: Geol. Soc. America Special Paper 65, 122 p.

Heirtzler, J. R., and LePichon, X., 1965, Crustal structure of the mid-ocean ridges; 3: Magnetic anomalies of the Mid-Atlantic Ridge: Jour. Geophys. Research, v. 70, p. 4013–4034

Hess, H. H., 1965, Mid-oceanic ridges and tectonics of the sea-floor, p. 317–334 *in* Whittard, W. F., and Bradshaw, R., *Editors*, Submarine geology and geophysics, Colston Papers 17: London, England, Butterworths, 464 p.

Hurley, R. J., 1960, The geomorphology of abyssal plains in the northeast Pacific Ocean: Scripps Institution of Oceanography Tech. Rept. (SIO Reference 60–7), 105 p.

Krause, D. C., Menard, H. W., Jr., and Smith, S. M., 1964, Topography and lithology of the Mendocino Ridge: Jour. Marine Research, v. 22, p. 236–249

Langseth, M. C., Grim, P. J., and Ewing, M., 1964, Heat-flow measurements in the East Pacific Ocean: Jour. Geophys. Research, v. 70, p. 367–380

Lee, W. H. K., and Uyeda, S., 1965, Review of heat flow data, p. 87–190 *in* Lee, W. H. K., *Editor*, Terrestrial Heat Flow, Geophysical Mon. 8: Washington, Am. Geophys. Union, 276 p.

Loughridge, M. S., 1966, Topography and magnetic anomalies observed near the ocean bottom in the Pacific off California (Abstract): Am. Geophys. Union Trans., v. 47, p. 124

McManus, D. A., 1964, Major bathymetric features near the coast of Oregon, Washington, and Vancouver Island: Northwest Science, v. 38, p. 65–82

—— 1965a, Bottom sediment types in Cascadia Basin, northeast Pacific Ocean, p. 264 *in* The Geological Society of America, Abstracts for 1964: Geol. Soc. America Special Paper 82, 400 p.

—— 1965b, Physiography of the sea floor between the Mendocino Ridge and Vancouver Island, northeast Pacific Ocean, p. 132 *in* The Geological Society of America, Abstracts for 1964: Geol. Soc. America Special Paper 82, 400 p.

—— 1965c, Blanco Fracture Zone, Northeast Pacific Ocean: Marine Geology, v. 3, p. 429–455

Menard, H. W., Jr., 1960, The East Pacific Rise: Science, v. 132, p. 1737–1746

—— 1962, Correlation between length and offset on very large wrench faults: Jour. Geophys. Research, v. 67, p. 4096–4098

—— 1964, Marine geology of the Pacific: New York, McGraw-Hill Book Co., 271 p.

—— 1965, Sea floor relief and mantle convection, p. 315–364 *in* Ahrens, L. H., Press, F., Runcorn, S. K., and Urey, H. C., *Editors*, Physics and chemistry of the earth, v. VI: London, England, Pergamon Press, 510 p.

—— 1966, Fracture zones and offsets of the East Pacific Rise: Jour. Geophys. Research, v. 71, p. 682–685

Menard, H. W., Jr., and Dietz, R. S., 1951, Submarine geology of the Gulf of Alaska: Geol. Soc. America Bull., v. 62, p. 1263–1286

Menard, H. W., Jr., and Fisher, R. L., 1958, Clipperton fracture zone in the northeastern equatorial Pacific: Jour. Geology, v. 66, p. 239–253

Menard, H. W., Jr., Chase, T. E., and Smith, S. M., 1964, Galapagos Rise in the southeastern Pacific: Deep-Sea Research, v. 11, p. 233–242

Nayudu, Y. R., 1964, Carbonate deposits and paleoclimatic implications in the northeast Pacific Ocean: Science, v. 146, p. 515–517

Nayudu, Y. R., and Enbysk, B. J., 1964, Biolithology of northeast Pacific surface sediments: Marine Geology, v. 2, p. 310–342

Raff, A. D., and Mason, R. G., 1961, Magnetic survey off the west coast of North America, 40° N. latitude to 52° N. latitude: Geol. Soc. America Bull., v. 72, p. 1267–1270

Raitt, R. W., 1963, Seismic refraction studies of the Mendocino Fracture Zone (Abstract), p. 71 *in* International Union of Geodesy and Geophysics, XIII General Assembly, Abstract of Papers, v. 5: Internat. Assoc. Physical Oceanography, Berkeley, Calif.

Shor, G. G., Jr., 1962, Seismic refraction studies off the coast of Alaska, 1956–1957: Seismol. Soc. America Bull., v. 52, p. 37–57

Shor, G. G., Jr., and Fisher, R. L., 1961, Middle America Trench: Seismic-refraction studies: Geol. Soc. America Bull., v. 72, p. 721–730

Shor, G. G., Jr., Dehlinger, P., and French, W. S., in press, Seismic-refraction studies off Oregon and northern California, *in* The Geological Society of America, Abstracts for 1966: Geol. Soc. America Special Paper

Talwani, M., 1964, A review of marine geophysics: Marine Geology, v. 2, p. 29–80

Talwani, M., LePichon, X., and Ewing, M., 1965, Crustal structure of the mid-ocean ridges; 2: Computed model for gravity and seismic refraction data: Jour. Geophys. Research, v. 70, p. 341–352

Talwani, M., LePichon, X., and Heirtzler, J. R., 1965, East Pacific Rise: the magnetic pattern and the fracture zones: Science, v. 150, p. 1109–1115

Vacquier, V., and Von Herzen, R. P., 1964, Evidence of connection between heat flow and the Mid-Atlantic Ridge magnetic anomaly: Jour. Geophys. Research, v. 69, p. 1093–1101

Vacquier, V., Raff, A. D., and Warren, R. E., 1961, Horizontal displacements in the floor of the northeastern Pacific Ocean: Geol. Soc. America Bull., v. 72, p. 1251–1258

Van Andel, Tj. H., Bowen, V. T., Sachs, P. L., and Siever, R., 1965, Morphology and sediments of a portion of the Mid-Atlantic Ridge: Science, v. 148, p. 1214–1216

Vine, F. J., and Matthews, D. H., 1963, Magnetic anomalies over oceanic ridges: Nature, v. 199, p. 947–949

Vine, F. J., and Wilson, J. T., 1965, Magnetic anomalies over a young oceanic ridge off Vancouver Island: Science, v. 150, p. 485–489

Von Herzen, R. P., 1964, Ocean floor heat-flow measurements west of the United States and Baja California: Marine Geology, v. 1, p. 225–239

Von Herzen, R. P., and Uyeda, S., 1963, Heat-flow through the eastern Pacific Ocean floor: Jour. Geophys. Research, v. 68, p. 4219–4250

Waters, A. C., 1962, Basalt magma types and their tectonic association—Pacific northwest of the United States, p. 158–170 *in* MacDonald, G. A., and Kuno, H., *Editors,* The crust of the Pacific Basin: Am. Geophys. Union, 195 p.

Wilson, J. T., 1963, Evidence from islands on the spreading of ocean floors: Nature, v. 197, p. 536–538

—— 1965, Transform faults, oceanic ridges and magnetic anomalies southwest of Vancouver Island: Science, v. 150, p. 482–485

Manuscript Received by the Society October 15, 1965
Revised Manuscript Received June 13, 1966
Contribution No. 377 (RLO-1725-68) of the Department of Oceanography, University of Washington, Seattle, Washington