gave different results; any leakage in the closed system grossly distorted sound calibration below 1 khz, whereas at frequencies higher than 6 khz calibration for the open loudspeaker was affected. This difficulty could be avoided by placing the loudspeaker close to the bird's ear (12 cm).
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Fissure Basalts and Ocean-Floor Spreading on the East Pacific Rise

Bonatti has suggested (*1*) that a continuous single band of basaltic lava, 40 to 60 km wide, crops out along the crest of the East Pacific Rise (EPR) for a distance greater than 800 km between 6° and 14°S. The evidence for such a band is largely deduced from the character of echo-sounding records along four transverse profiles in the region, corroborated by dredging and bottom photographs which established exposed rock at some localities on the sea floor. My purpose is to introduce evidence from heat flow and other measurements which makes it (i) unlikely that the hypothesized outcrop is as broad or as continuous as Bonatti implies and (ii) probable that other modes of magmatic emplacement may be equally important.

Between 12½° and 15°S, near the southern part of the region under discussion, there are three published profiles of relatively detailed heat-flow measurements across the EPR crest (*2*). The average spacing between these measurements is about 40 to 45 km. At the stations along these profiles, there was little difficulty in obtaining at least 2 m of sediment penetration by a temperature gradient probe. Similar profiles of heat-flow measurements on the Rise crest have been obtained at 8°S (*3*) and also at 17°S (*4*). On a few stations of the latter profile, the corer struck hard rock after penetrating a few meters of sediment, but these stations were geographically scattered along the profile which otherwise provided a continuous sequence of successful measurements across the EPR crest.

A result of the heat-flow measurements is that the highest values are not always found at the Rise crest, but rather along two or more bands, similar in width to the outcrop suggested by Bonatti. These bands may be relatively continuous and approximately parallel to the trend of the Rise. The uniform sediment cover and lack of other surface evidence for these heat-flow bands led Von Herzen and Uyeda (*2*) to postulate cooling from subsurface dikes at relatively shallow depths beneath the sea floor. It may be that Bonatti's investigations have revealed several places where one or more of these dikes crop out at the sea floor, although the lack of position coordinates on his profiles precludes a direct comparison. However, my subsequent personal communication with Bonatti suggests that the rock outcrop region on his profile *AA′* closely coincides with a high heat-flow band *east* of the Rise crest, and those on profiles *CC′* and *DD′* with a similar band to the *west*. The rock outcrop along profile *BB′* may be closer to the Rise crest, although there are no heat-flow profiles in the vicinity.

The topographic relief along profiles between 12½° and 15°S, and at 8°S, is similar to that shown by Fig. 2 of Bonatti (*1*). On profiles at 8°S, 12½°S, and 18°S, there is one region near the Rise crest, ranging from about 20 to 30 km in width, which generally shows a strong and reverberant echo from the 12-khz depth sounder and is less than 3000 m in depth. Presumably, this is the type of reflection from outcropping rock noticed by Bonatti, although he did not define the characteristics of the reflections. On the other profiles near 14½°S no such regions were detected, other than an occasional hill several hundred fathoms in height above the surrounding level of the sea floor.

Therefore, the basalt band is apparently of smaller width and not as continuous as implied by Bonatti, as deduced from the relatively close spacing of heat-flow measurements and the nature of the echo-sounding records cited above. Bonatti did not discuss whether all of his dredge hauls and bottom photographs from the hypothesized outcrop band indicated rock, and conversely, whether any samplings outside of this band indicated only sediments. I agree that 12-khz echo-sounding records are useful to distinguish hard rocks from smooth sediments at the sea floor, but, as the records are susceptible to electronic nuances and subjective interpretation, they cannot be considered infallible.

It is curious that the band characterized by strong and reverberant echoes frequently appears smoother than sedimented regions near the Rise crest. The echo-sounding records for the sedimented regions generally show numerous overlapping echoes from hills 10 to 40 m in height and 0.2 to 2 km in width. If the band of strong echoes represents newly formed rock near the Rise axis, its relative smoothness appears inconsistent with constant sea-floor spreading, because sedimentation on the spreading sea floor should only produce further smoothing. It may be that the extrusion of rock on the sea bottom produces a relatively smooth surface on this scale, and that this process is relatively unusual on this part of the EPR. Perhaps intrusion of relatively thin and viscous dikes to produce the myriad of small hills on the EPR is a more common process.

If Bonatti's assumed sedimentation rate of 1 cm per 10^3 years has been reasonably constant and uniform over the Rise crest, most rock outcrops on the relatively smooth topography of the crest should be fairly well covered with sediment within 10^5 years or so. At a spreading rate of 4 cm/year for this part of the Rise (5), within 10^5 years any point on the sea floor would have moved only 4 km away from the ridge crest—or less if stagnation occurs (6). Therefore, an outcrop band 20 to 80 km in width is unlikely to be produced by a steady process associated with uniform sea-floor spreading. If the rocks in the band are emplaced over a relatively short time ($< 10^5$ years) and contribute to the magnetic anomaly field, the magnetic evidence for sea-floor spreading might be confused. Alternatively, dike intrusions away from the ridge axis would have the same effect. Unlike other profiles farther south (7), unpublished profiles of magnetic anomalies across the EPR crest in this vicinity (expeditions Risepac and Amphitrite, Scripps Institution of Oceanography) show only small magnetic anomalies (maximum 200 to 300 gammas) ($1\gamma = 3 \times 10^5$ oersted), which are not obviously symmetrical and are difficult to correlate with a sea-floor spreading model. Thus either widespread lava extrusion on this part of the EPR crest or thinner dike intrusion away from the crest, or both, may be important, but their relative importance is not evident.

I concur with Bonatti and others (8) that the lack of rift valley and apparently high rate of sea-floor spreading suggest a different rheology for crust and mantle of the EPR as compared to other ridges. Rather than a single centrally located continuous band of extruded rock, as may be inferred from Bonatti's report, it is more likely that the infusion of new rock into this part of the Rise, as related to sea-floor spreading, is more complex in both space and time.

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When hard rocks rather than soft sediments outcrop at the sea floor, characteristic, strong, and reverberant echoes are recorded by a 12 khz precision depth recorder (PDR). Echoes of this type were recorded on the crestal zone of the East Pacific Rise (EPR) during cruise P6702. At all sites where sampling was attempted in the axial zone of strong reverberating echoes, evidence of hard rock outcropping was obtained (Table 1). I agree that echo-sounding records are not infallible; however, within relatively smooth topography, like that on the EPR, the distinction between a "hard rock" type reflection, in contrast to soft-sediment, normal reflection is clear-cut and does not leave much room for subjective interpretation, except in transitional zones.

The crossings of the crest of the EPR during cruise P6702 were not limited to the four shown in Fig. 2 of my report (*1*). Track lines with continuous PDR echo-sounding are shown in Fig. 1.

Strong reverberant echoes due to a basaltic bottom were recorded at the crest of the EPR continuously between 12°50′S and 11°35′S during cruise P6702. During Scripps cruise Amphitrite, outcropping basalt had been recorded for about 90 km (50 nautical miles) in southward course from station Amph D-3 (12°52′S and 110°-58′W). Thus, from a few kilometers north of 14° to 11°35′S the continuity of the band is certain. Between 11°35′ and 6°S, the crest of the EPR was transected during P6702 at 10°, 9°03′, 8°15′, 8°20′, 7°10′, and 6°20′S. At all these crossings, with the exception of the one at 8°20′S, the band of outcropping basalt was detected near the crest. In addition, the band was followed continuously from 9°20′ to 8°40′S while we were on a northward course close to the crest of the EPR and nearly parallel to its elongation. I think the aforementioned data justify the suggestion (*1*) that an almost continuous band of basalt outcrops on the EPR between 14° and 6°S; the band of strong and reverberant echoes observed by Von Herzen (2) across the EPR crest at 12°30′ and 8°S adds further evidence in favor of this suggestion. The break in continuity of the band in the region between 8° and 9°S could be due to one or more small transform faults displacing the EPR crest; but more work is required to clarify the situation (2). The lack of the

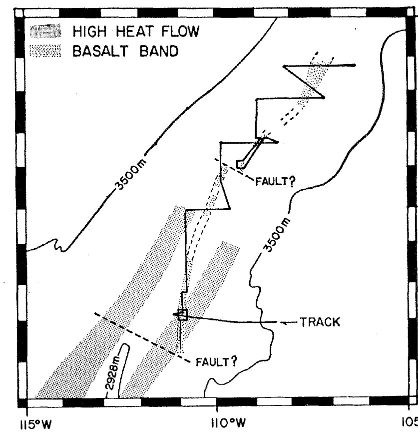

Fig. 1. Track of the R.V. *Pillsbury* on the EPR during cruise P6702 and relation between the band of outcropipng basalt and the two bands of high heat flow. The position of the heat flow bands is according to Von Herzen and Uyeda (*3*). The north-south track line south of 12°50′S is where strong reverberant echoes were obtained during cruise Amphitrite. Bathymetric contours are after Menard (*14*) and Von Herzen and Uyeda (*3*). The < 2928 m (1600-fathoms) zone between 14° and 12°S follows closely the basalt band. The square at about 12°50′S indicates an area surveyed in detail with anchored radar buoys as reference.

hard rock band at 14°30′S indicated by Von Herzen is perhaps due to a similar circumstance: in fact Von Herzen and Uyeda (*3*) proposed that there is a major fault in this general area, which displaces the topographic axis of the EPR.

Photographs of the bottom (*1*) show that small pockets of sediment are present within the basaltic pavement at the axis of the EPR. Toward the edge of the basalt band the sediment cover probably becomes more frequent and eventually continuous. A transitional zone commonly exists toward the edges of the basaltic band, where the bottom echoes show characters intermediate between those typical of hard rock bottom and those typical of sediment. Subjective interpretation of such transitional echoes is possible and may result in discrepancies of a few kilometers in the estimated width of the basaltic band.

Of all the sites of heat-flow measurements made by Von Herzen and Uyeda (*3*), one only (Ris 87) appears to be close to the eastern margin of the proposed basalt band. Therefore, the fact that sediment was found at such sites does not exclude that the width of the band in this portion of the EPR is as I suggested. In fact, the width of the basalt band is quite variable; it is at least 80 km in a profile at 6°S and less than half as much in profiles at 10° and 12°S (*4*).

Von Herzen implies that, given a sedimentation rate of 1 cm per 10^3 years and a spreading rate of 4 cm/year, the crest of the EPR should be covered by sediment, except for an axial band 8 km wide. This calculation is based on the assumption that 10^5 years are sufficient to produce a continuous sediment cover (1 m at the proposed deposition rate). However, it is doubtful that a layer of sediment "theoretically" 1 m thick will produce a continuous cover; the accumulation of deep-sea sediments has been found to be very inhomogeneous, with respect to area, on a small scale, even in relatively smooth topography, owing to topographic irregularities and to reworking of the sediment by bottom currents, faunal activity, and other forces (*4*, *5*). Thus, several times 10^5 years may be required to produce a continuous sediment blanket (*4*); accordingly, an axial basalt band wider than 8 km does not in itself exclude steady spreading in this area.

An additional consideration is that the very fluid fissural basalt flows erupted on the EPR can travel on the sea floor for appreciable distances beneath glass skins or previous thin flows before they cool down (*6*); the width of the lava field would thus be significantly larger than that of the zone of injection of the magma (*7*). Lateral motion of the lava flows on the sea floor would smooth out the Vine-Matthews pattern of magnetic anomalies. Magnetic profiles recorded by us across the EPR during P6702 show only small amplitude anomalies, like those observed by Von Herzen. It is not possible to determine whether the poor development of the magnetic patterns is due to the lateral flow of the lava on the sea floor or to basalt injections away from the EPR axis. Actually, it could be explained by the fact that the portion of the EPR under consideration is close to the equator and elongated in a direction close to north-south (*8*). Even if the injection of basalt occurs only within a band 12 km wide, as computed for other oceanic ridges (*9*), a width of 40 km or more, as I observed for the outcropping basalt band on the EPR, is not unreasonable (*10*). Thus, I suggest that an outcrop band of the width I observed (*1*) could have been produced by a steady process associated with uniform sea-floor spreading.

Table 1. Location of sites where direct evidence of hard rock outcropping in the zone of strong reverberating echoes was obtained. Two stations from Scripps cruise Amphitrite are included.

Station	Location S	Location W	Basalt evidence
P6702–27	12°46′	110°52′	Dredged
P6702–29	12°17′	110°44′	Dredged
P6702–31	10°01′	110°15′	Cored
P6702–32	10°01′	110°06′	Dredged
P6702–38	8°51′	109°08′	*
P6702–39	9°02′	109°19′	Dredged
P6702–40	8°16′	108°50′	Dredged
P6702–41	8°16′	108°51′	†
P6702–42	7°08′	107°30′	Dredged
P6702–44	6°21′	107°25′	Dredged
Amph D3	12°52′	110°58′	Dredged
Amph D4	18°24′	113°19′	Dredged

* Dredge damaged by hard bottom. † Core nose damaged by hard bottom.

The two bands of high heat flow discovered by Von Herzen and Uyeda (*3*) are parallel to the general elongation of the EPR; however, according to their Fig. 6, the bands are neither parallel nor symmetrical to the finer topographic trend of the narrow central zone of the EPR, represented by the 1600 fathoms isobath; also, they don't seem to be displaced by the fault at about 14°S (Fig. 1) which displaces the 1600-fathom zone laterally by nearly 100 km. The band of outcropping basalt north of 14°S, on the contrary, appears to follow very closely the 1600-fathom crestal zone; the position of the basalt band is probably related to the zone of tensional fissures within the crust as a result of the spreading. The fact that the bands of high heat flow apparently are located independently of fine crustal features may indicate that their origin lies below the crust and is not due to cooling of shallow subsurface dikes. If there are convection cells in the upper mantle, the two bands of high heat flow could correspond to the zone where the diverging branches of the cell come closer to the surface; such zones may be located several tenths of kilometers away from the ridge axis (*11*). A similar alternative explanation has already been offered (*3*).

Von Herzen's (*2*) suggestion that intrusion of thin and viscous dikes produces the myriad of small hills observed off the EPR crest seems improbable. Since basalts are the only magmas erupted both on or near the EPR at these latitudes (*12*), it is unlikely that viscous magmas, as required by Von Herzen to produce the observed topography, are at all common in this region. Basaltic injection off the EPR crest should result either in smooth surface flows, just as on the crest, or in subhorizontal sills within the sediments; both modes of emplacement could not form the topographic features under discussion. I suggest that the surface morphology of an active ridge could be regarded as resulting from the balance between two major processes: constructional processes, primarily the eruption of basaltic melts along an axial zone of the ridge, and tectonic processes, mainly faulting and rifting in the crust in response to the spreading motions. On the EPR, the constructional processes have been prevalent within the axial band at least during the last million years; as a result, the topography of the axial zone is smooth. Away from the EPR axis, where basalt injections are infrequent and the crust is older, stresses due to nonlinear increase in spreading rate and producing a series of normal faults (*13*) could show up as the topographic roughness noticed by Von Herzen.

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