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THE JUAN DE FUCA RIDGE--HOT SPOT--PROPAGATING RIFT SYSTEM: NEW TECTONIC, GEOCHEMICAL, AND MAGNETIC DATA

John R. Delaney, H. Paul Johnson, and Jill L. Karsten

Department of Oceanography, University of Washington, Seattle, Washington 98195

Abstract. Underway geophysics, deep tow camera work, and preliminary geochemical and magnetic studies, from a 1980 cruise to the Juan de Fuca Ridge, allow the following interpretations: (1) the central third (between 45.5°N and 46.5°N) of the ridge is now actively spreading from a zone which is 10 to 20 km west of the axis bisecting the Brunhes-Matuyama magnetic reversal boundary, (2) the apparent terminus of surficial igneous activity at the northern tip of the active 'Cobb Propagator' has been identified by dredging and camera work; the tip appears curved, or offset slightly, to the west, does not correspond to the northernmost tip of the central magnetic anomaly [Elvers et al., 1974], and spreading has been initiated beneath sediments farther north, and (3) iron and titanium in fresh glasses from the active volcanic zone exhibit a progressive enrichment northward, then a pronounced reversal to more 'normal' concentrations in the vicinity of the Cobb Offset.

Introduction

The Juan de Fuca Ridge (Figure 1), between the Blanco and the Cobb Offset fracture zones, spreads at a half rate of 30 mm/yr and exhibits the following characteristics: (1) generally positive axial bathymetry, in sharp contrast to a pronounced axial valley along the adjacent northern Gorda Ridge (also spreading at 30 mm/yr) [Melson, 1969; Elvers et al., 1974], (2) major associated hot spot-generated seamounts forming a roughly linear chain west of the ridge [Morgan, 1972], (3) a series of left-lateral offsets in the magnetic anomaly patterns converging in V-shaped patterns on the active ridge, (4) iron- and titanium-enriched basalts which are particularly concentrated near the Juan de Fuca-Blanco Fracture Zone intersection [Vogt and Byerly, 1976], and (5) high-amplitude magnetic anomalies (600 to 1200 γ) [Elvers et al., 1974; Vogt and Byerly, 1976].

During August 1980, the R/V T. G. Thompson cruise surveyed and sampled the 400-km length of the Juan de Fuca Ridge from the Blanco Fracture Zone to just north of the Cobb Offset. Figure 1 summarizes the accomplishments of the field program.

Recent Shift of the Active Volcanic Zone

The northern and southern thirds of the Juan de Fuca Ridge display bathymetric and magnetic symmetry about an axis which bisects the Brunhes-Matuyama (B-M) magnetic reversal boundaries (Figures 1 and 2, line 1). Dredging along this centerline yields fresh volcanic glass from recognizable axial features. Within the entire central third of the ridge, neither fresh glass, symmetrical axial bathymetry, nor a definitive axial magnetic signal is found along the magnetic reversal bisector. Instead, evidence of recent volcanism was consistently found to the west of the axes projected from the symmetrical portions of the ridge.

A transitional zone between the symmetrical portion and the asymmetrical, offset portion of the ridge is represented in line 9 (Figure 2), where the magnetic profile is slightly asymmetric and there is no pronounced axial feature. Fresh glassy basalt was recovered 10 km north of line 9 on an axially symmetrical volcanic feature. Line 10 is clearly asymmetrical in terms of bathymetry; the associated magnetic profile is nearly symmetrical, but lacks the central high observed on line 1. The symmetry axis intersects the western

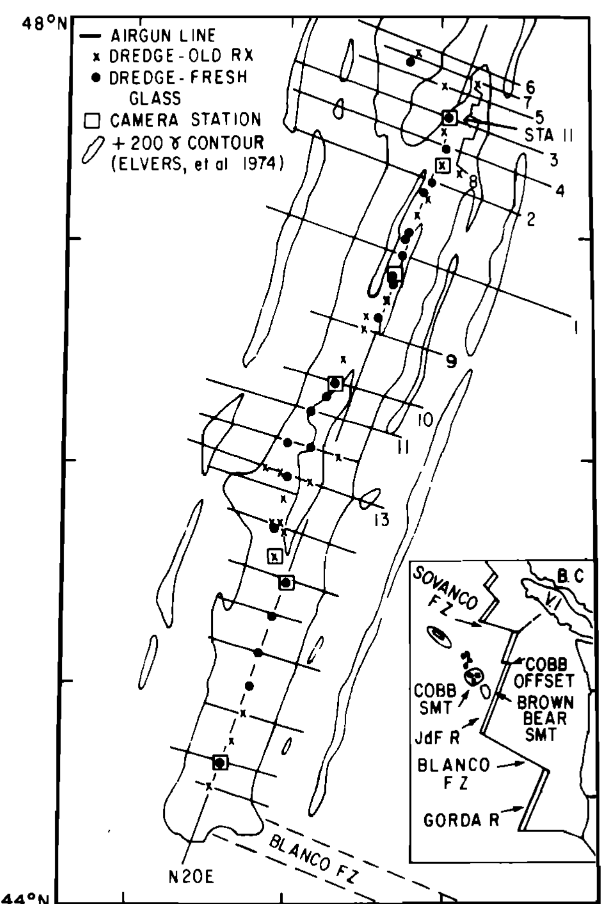

Fig. 1. Inset map showing northeastern Pacific and Vancouver Island and magnetic anomaly index map (+200 γ contour) [from Elvers et al., 1974] for Juan de Fuca Ridge from Blanco Fracture Zone to just north of the Cobb Offset. Note the overall N 20E axis of the ridge and the distribution of fresh glass with respect to the axis.

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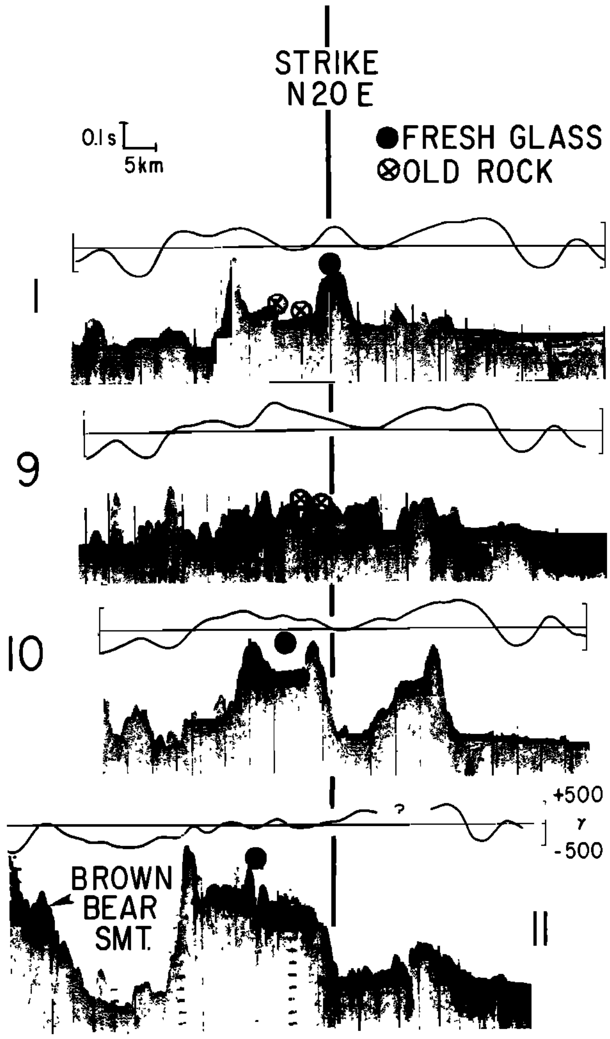

Fig. 2. Magnetometer and seismic reflection profiles oriented perpendicular to the ridge axis. The change from symmetrical to asymmetrical features correlates closely with the presence of fresh glass (solid circles). The vertical line is the projection through each profile of the symmetrical axis of the overall ridge which trends N 20E.

margin of a sediment pond on the line 10 profile; dredging near this intersection yielded mud and manganese crusts but no fresh basalt. Camera surveying and dredging in a small symmetrical valley 13 km west of the intersection confirmed the presence of fresh, unsedimented basalt.

The bathymetry of line 11 reflects a mass excess, other than Brown Bear Seamount, which is also distinctly offset to the west of the projected symmetrical axis. Fresh basaltic glass was retrieved from the center of this offset volcanic mass.

These data are consistent with the interpretation that the central third of the ridge is an elongate, active volcanic zone which is shifted to the west of the projected axes but is distinct from Brown Bear Seamount. This offset ridge segment shoals to within 1400 m of the surface and as much as 50 km of the segment rises to within 2000 m of the sea surface. The offset segment with its mass excess is not reflected in the B-M boundaries on either side of the ridge and is therefore apparently younger than 700,000 years. This configuration is best interpreted as a recent shift in the volcanic activity and, possibly, in the position of the spreading center along the central portion of the ridge. Our data do not presently constrain the geometry or the mechanism of the offset. It may be a single ridge segment 110 km long bounded by two short transform faults; it may be a series of short en echelon ridge segment transform fault features. The present configuration may have arisen from progressive asymmetric spreading. Our preferred interpretation is that coincidence of the offset ridge segment with the intersection between the ridge and the hot spot-generated seamount chain, suggests that renewed output from the hot spot, after completion of Brown Bear Seamount, has shifted the zone of active spreading westward. Conceivably, the offset ridge segment was shorter initially, and active rift propagation has extended it northward and southward.

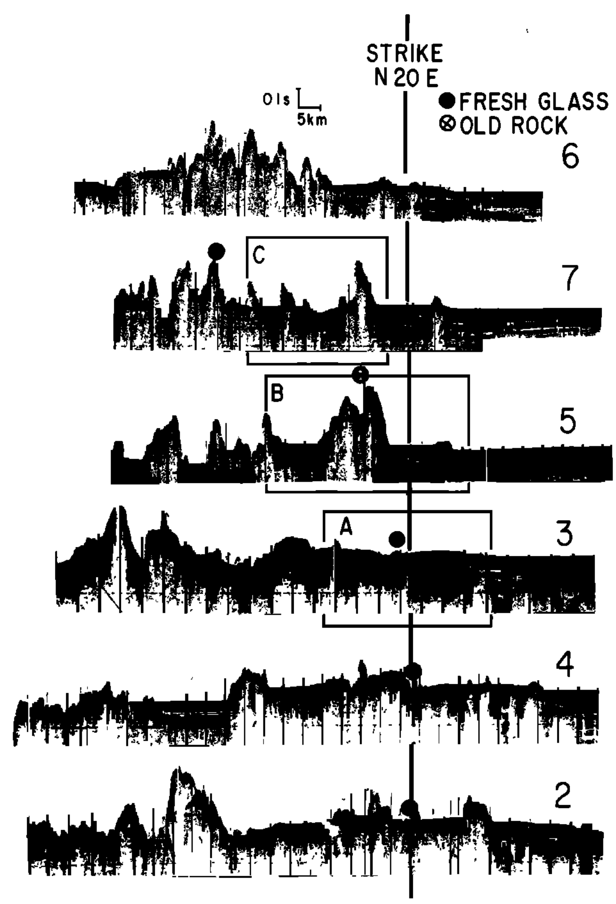

Fig. 3. Seismic reflection profiles across the Cobb Offset of the Juan de Fuca Ridge. Fresh glass dredged from the small hills west of the projected axis of the ridge is consistent with the hypothesis of a westward shift in the present day ridge terminus [Hey et al., 1980]. Note that the projected ridge axis intersects a sequence of gently arched sediments. See enlargements of A, B, and C in Fig. 4.

The Nature of the Cobb Offset

The Cobb Offset is the focus of a series of left lateral magnetic anomaly offsets which converge northward and has been most recently explained by Hey [1977] as the result of rift propagation.

Projection of the symmetrical ridge axis northward toward the Cobb Offset intersects line 3 at the western edge of a series of layered reflectors which are probably sediments (Figure 3). A cluster of low hills (20-40 m relief) located 2-3 km west of the intersection yielded some of the freshest glassy basalt recovered on the cruise. Details of the reflection profile (Figure 4) demonstrate that the hills are underlain by a zone of chaotic reflectors in contact with a series of gently arched, layered reflectors on the east. To the west, there is a suggestion of sedimentlike layering as well, and on both sides the topmost reflector appears to overlap the more chaotic material in the center. Extensive camera surveying of this zone, coupled with 3.5-kHz seismic reflection work, indicated that highly fractured, well-indurated sediments surround these small hills to the north, east, and west. Geologic mapping of the photographic coverage indicates fissure orientations in these sediments are much more diverse than those mapped farther to the south along the normal portion of the ridge. This sediment-flanked, chaotic reflector zone is interpreted as a site of incipient spreading and the northernmost surface expression of the actively northward propagating rift. The offset of this zone to the west is consistent with the geometric prediction of Hey et al. [1980] that active propagators curve toward the dying rift. Line 5 (Figures 3 and 4) reveals sediments in apparent depositional contact with a large, notched bathymetric high. Older, weathered basalts with thin glassy margins were dredged from the notch of this feature. This notched volcanic feature may have formed to the west on the still active portion of the dying northern rift. Subsequent spreading may have moved the feature eastward where it is now caught in the 'tranform zone' associated with the 'Cobb Propagator'.

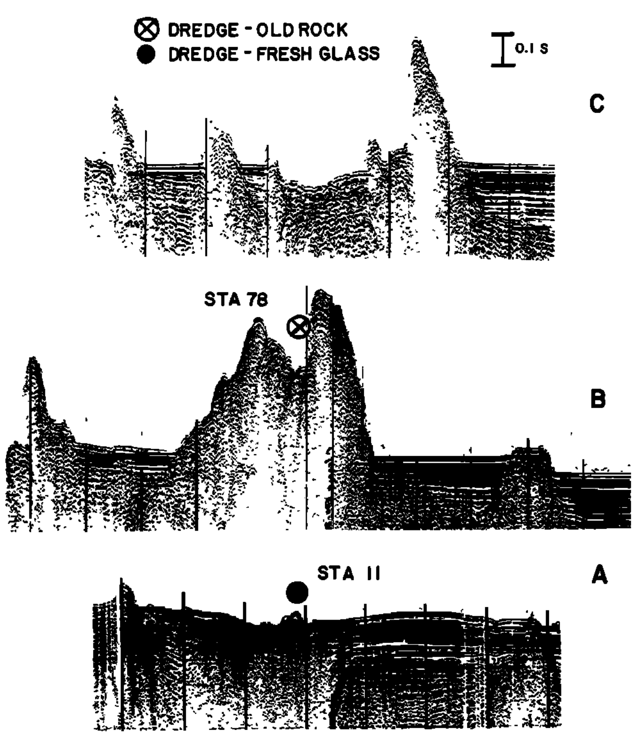

Fig. 4. Enlargements of portions of lines 3, 5, and 7 from Figure 3. (a) Note the contact between small volcanic hills and overlapping sedimentlike reflectors. Also of interest is the gentle arching of sediments. This zone of disturbed reflectors adjacent to sediments is interpreted as an area of incipient spreading and is probably the northernmost surface extension of the active volcanic zone. (b) This notched bathymetric feature is interpreted to have formed at the dying ridge to the west. (c) The sedimented grabenlike feature shows no evidence of volcanic activity based on 3.5 kHz profiling.

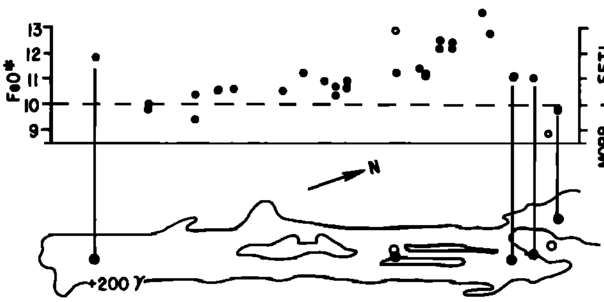

Fig. 5. Iron and titanium enrichment along the active volcanic zone of the Juan de Fuca Ridge. The FeTi values drop sharply near the Cobb Offset, but seem to reach a maximum at a point behind the present terminus of the propagating rift.

Farther north, along line 7 (Figures 3 and 4), an unusual valleylike feature was discovered offset even farther to the west of the projected ridge axis. Additional profiling with a 3.5-kHz system indicated that this gentle depression contains multiple, downdropped but coherent blocks of sediment which define a grabenlike structure and represent a classical extension feature. We conclude that spreading has been initiated beneath this zone, although there is no indication of current volcanic activity in the immediate area. Fresh glass was recovered from an axial zone just west of the graben, positioned along the northern segment of the Juan de Fuca Ridge. This nonvolcanic, grabenlike feature contrasts with the actively propagating rift on line 3 where incipient spreading correlates with volcanic activity.

Geochemistry and Magnetics

Electron microprobe analyses of fresh glass from 22 new dredge locations along the ridge axis show a progressive enrichment in iron and titanium northward from the central third of the ridge (Figure 5). A pronounced decrease in FeTi enrichment to MORB values occurs across the Cobb Offset, with maximum FeTi values occurring 20 to 30 km south of the northernmost volcanic activity of the propagating rift. Figure 5 illustrates the relationship between zero-age FeTi basalts and the actively propagating Cobb Offset. Although the hot spot influence is not readily discernible in the FeTi values observed, these data, in concert with previous studies [Melson et al., 1969; Moore, 1970; Kay et al., 1970; Vogt and Byerly, 1976], demonstrate that the entire active length of the Juan de Fuca Ridge is a FeTi province with FeO* (total iron as FeO) values greater than 10% and therefore distinctly higher than normal MORB values. Vogt and Byerly's [1976] compilation demonstrates that the remarkably high values (>15% FeO*) near the Blanco Fracture Zone correspond to another propagating rift which has recently merged with the fracture zone [Hey et al., 1980].

Christie and Sinton [1981] and Sinton et al. [1981] outline a genetic model to account for the distribution of FeTi basalts along propagating rifts which posits shallow level fractional crystallization as the principal mechanism of FeTi enrichment. The leading tip of the propagating rift is a zone of relatively small magma chambers which are too short lived to allow significant fractional crystallization. Well behind the propagating tip, continual magma replenishment produces a long term steady state condition which buffers the system at MORB compositions. Between these two extremes, magma chambers of intermediate duration but infrequent magma mixing events allow effective fractional crystallization to occur. FeTi enrichment would be best developed in lavas erupted an intermediate distance behind the propagating tip.

Measurements of magnetization intensity of the dredged basalt samples from 13 stations in the northern part of the axis were compared with two stations north of the Cobb Offset. Stations south of the offset had an average intensity to 52 $\times 10^{-3}$ emu/cm^3 compared to 24 $\times 10^{-3}$ emu/cm^3 for those stations north of the propagator. This is similar to values of (27-39) $\times 10^{-3}$ emu/cm^3 obtained for zero-age basalts from the Mid-Atlantic Ridge [Johnson and Atwater, 1978]. A cause-and-effect relationship between FeTi enrichment, high magnetization in surface rocks and high amplitude magnetic anomalies is not clearly demonstrated by these data. Magnetic anomaly amplitudes on the NOS map [Elvers et al., 1974] do not vary substantially north and south of the propagator trace, despite the strong decrease in FeTi content and basalt magnetization north of the offset along the presently active volcanic zone.

SUMMARY AND CONCLUSIONS

Preliminary results from the 1980 Juan de Fuca Ridge cruise indicate that (1) the central third of the ridge may now be actively spreading from a zone which is 15 to 20 km west of the centerline between the B-M magnetic reversal boundaries, (2) the present surface expression of the tip of the propagating rift at the Cobb Offset is either curved or offset to the west in the sense predicted by Hey et al. [1980]; the tip of the central magnetic anomaly (line 6, Figure 1) is nearly 30 km from the actual volcanic terminus of the ridge and is covered with considerable sediment, (3) freshly erupted ridge axis basalts exhibit a progressive increase in iron and titanium which reaches a maximum approximately 20-30 km south of the northernmost volcanic activity, and (4) despite the changes in FeTi character and rock magnetization across the present ridge offset at the propagator tip, the magnetic anomaly amplitudes do not seem to change dramatically across the propagator trace [see Elvers et al., 1974].

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