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HEAT FLOW MEASUREMENTS ON A HYDROTHERMALLY-ACTIVE, SLOW-SPREADING RIDGE: THE ESCANABA TROUGH

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Abstract. Maximum heat flow measurements at three locations in the sediment-filled Escanaba Trough of the Gorda ridge exceed 1200 mW/m^2. At other ridge crests with thick sediment cover, heat flow values of this magnitude are accompanied by high temperature hydrothermal vent activity and massive sulfide deposition. A dredge haul from the southernmost high heat flow location recovered pyrrhotite, thereby confirming the presence of recent high temperature venting.

Introduction

The Escanaba Trough is a slow spreading ridge with a total opening rate of 3.0 cm/yr [Riddihough, 1980]. At the time that this study was proposed, no active high temperature (> 100° C) hydrothermal vents had ever been found on a slow spreading ridge. Since that time, high temperature 'black smokers' have been found at two locations on the slow-spreading mid-Atlantic ridge [P. Rona, 1985; Weisburd, 1986]. These discoveries have destroyed the myth that massive-sulfide deposition at the sediment-water interface requires a rapid spreading rate [Skinner, 1983].

The Escanaba Trough differs in one fundamental respect from the areas of high temperature activity on the mid-Atlantic ridge. Unlike most ridge crest areas, most of the axis of the southern Gorda ridge is covered with over 100 meters of sediment. Consequently, sedimentary heat flow measurements could be used to determine the level of hydrothermal activity in the Escanaba Trough.

Tectonic Setting

Sedimentation on the Gorda ridge is dominated by turbidites originating on the North American continental margin and entering the rift valley at its southern end [Moore, 1970]. The thick sediment cover allowed us to perform detailed measurements of the heat flow along the axis, the first such study of a sediment-covered, slow spreading ridge. Prior to our study, fewer than 5 heat flow measurements had been made within 20 kilometers of the axial valley [Wilde et al., 1979].

The sediment-filled Escanaba Trough is punctuated by 6 major volcanic edifices, labelled A through F from north to south (Figure 1). According to one theory [Francheteau and Ballard, 1983], local topographic highs on the ridge crest are the locations of the most recent and most intense hydrothermal activity. Because the most recent areas of voluminous volcanic extrusion are the least likely to be buried by sediment, local highs are usually the youngest portions of a sediment-covered ridge crest. Consequently, we concentrated our heat flow studies on the two highest volcanic edifices with sufficient sediment cover, B and D.

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Measurement Technique

Total heat flow is the thermal gradient multiplied by the sedimentary thermal conductivity. Temperatures were determined by standard techniques [Anderson et al., 1979], with the exception of a correction for frictional heating of the thermistors by penetration into the sediment. We were unable to perform precise corrections for frictional heating because our unusually heavy corehead sank slowly into the bottom sediments for the duration of most stations. Fortunately, we could use previous heat flow results from 'normal' heat flow stations in terrigenous sediments to estimate the maximum errors which could result from ignoring frictional heating. At all of the Escanaba stations, we measured the thermal gradient 6 minutes or more after the initial penetration. Once past the first 2 minutes at a 'normal' heat flow station, the maximum amplitude of the temperature change caused by frictional heating is at most 0.05° C. The average amplitude is 0.01° C. At the sites with the lowest thermal gradients, this could produce a maximum error of 20% and an average error of 4%. This error is quite small, and its major effect is that we cannot determine if any non-linearities in the thermal profile are caused by water advection through the sediment. This error would not obscure the regional variability in heat flow, given by the ratio of the minimum to the maximum heat flow, equal to 1: 10.3 (Table 1).

Other potential sources of error in the thermal gradient measurements include bottom water temperature changes, lance bending, non-vertical penetration, and high sedimentation rates. Because the average errors in the linear regressions of the thermal gradients are 3.7% (Table 1), the first two can be eliminated as major causes of error. The minimum sedimentation rate in the southernmost Escanaba

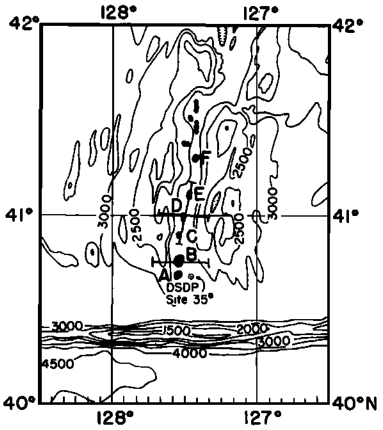

Fig. 1. Map of the survey area. Volcanic edifices A through F are along the axis of the Escanaba Trough north of the Mendocino Fracture Zone. Dotted circle: DSDP site 35 Lines: cross sections in Figures 2 through 4. Bathymetry after Wilde et al. [1979]. Contour interval 500 meters.

TABLE 1. Heat flow measurements from the Escanaba Trough. Column headings are from left to right: station number, heat flow, error in linear regression line fit of temperature versus depth, total error in heat flow, latitude of station, longitude of station, and number of thermistors in the bottom (number of thermistors on scale if different). Individual temperatures are accurate to ± 0.005 ° C [Anderson et al., 1979]. Starred linear regression errors were not included in the calculations of the average error. Starred errors are derived from the known variations in the penetration depth of the heat flow lance or the average linear regression error itself. Heat flow values are starred to designate the instrument tilt during the station: 0 -10° = no stars (tilt error ± 0.5%); 10-40° = one star (tilt error ± 15%); 40-60° = two stars (tilt error ± 35%). Because of our heavy corehead, tilts in excess of 60° would cause the instrument to fall over. Stations 22-28 are transponder navigated. The remainder are Loran C navigated.

Sta. #	Heat Flow, mW/m^2	Lin. Regr. Err., %	Total Error, %	Latitude Deg N	Long. Deg W	Therm. in Bott. (on Sc.)
1	225	2.6	± 5.8	40.749	127.40	4
2	240*	8.6	± 28.	40.750	127.40	4
3	316*	4.7	± 24.	40.751	127.42	4
4	371*	6.6	± 26.	40.748	127.43	4
5	389*	4.1	± 23.	40.745	127.45	4
6	340*	5.2	± 24.	40.742	127.47	4
7	250*	3.3	± 22.	40.740	127.49	4
8	256*	6.4	± 26.	40.742	127.50	4
9	236*	4.4	± 23.	40.741	127.53	4
10	299*	4.5	± 23.	40.744	127.54	4
11	1656*	3.7*	± 22.	40.737	127.55	3 (2)
12	576	1.2	± 4.4	40.737	127.57	3 (2)
13	832*	17*	± 38.	40.740	127.58	3 (1)
14	907*	17*	-38 +∞	40.746	127.60	3 (0)
15	341*	8.9	± 28.	40.747	127.62	3
16	329*	0.98	± 19.	40.757	127.66	3
17	386**	3.4	± 43.	40.753	127.66	3
18	302*	1.3	± 20.	40.757	127.67	3
19	313*	0.71	± 19.	40.756	127.69	3
20	352*	3.1	± 22.	40.980	127.54	4
21	302	0.62	± 3.8	40.996	127.54	4
22	472*	0.52	± 19.	41.000	127.53	4
23	192**	1.8	± 41.	41.002	127.52	4
24	1586**	3.7*	± 44.	41.009	127.51	4 (1)
25	463**	1.3	± 40.	41.021	127.47	4
26	235**	0.37	± 39.	41.002	127.47	3
27	274*	6.8	± 26.	41.005	127.47	4
28	1804*	3.7*	± 44.	41.008	127.47	4 (3)
29	280*	4.2	± 23.	41.023	127.47	4
30	176*	6.3	± 25.	40.940	127.51	3
31	299*	1.2	± 19.	40.928	127.52	3
32	219*	3.7*	± 22.	40.914	127.52	3 (2?)
33	511**	3.7*	± 44.	40.911	127.49	2
34	213**	7.2	± 48.	40.911	127.48	3

Trough is 560 m/my [McManus et al., 1970], enough to cause an 8% lowering of the thermal gradients in the sediment column [Langseth et al., 1981]. Sedimentation rates are somewhat lower at edifices B and D.

Thermal conductivity was determined using the methods of Lachenbruch and Marshall [1966]. The average thermal conductivity at 230 cm depth is 0.803±0.021 mW/mK-m in rift valley wall sediments (stations 16-19) and 0.882±0.021 mW/mK-m in rift valley sediments (all other stations).

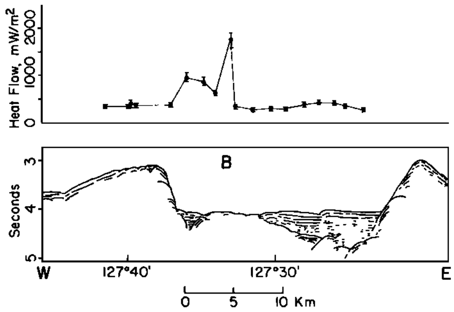

Fig. 2. Top, heat flow from west to east at 40.75° N (edifice B) in the Escanaba Trough. Heat flow stations 1-19 (Table 1). Bottom, Seismic reflection profile in seconds of two-way travel time along the same west-east line as the heat flow profile.

Total error in the heat flow, Th, is: Th =(El) (Ec) (Et), where El is the error in the linear regression of temperature change versus subbottom depth, Ec is the error in the thermal conductivity (± 2.6%), and Et is the error due to instrument tilt (0.5 to 35%). The maximum error at any one station is ± 48% (Table 1). If the true heat flow did not vary among different stations, this error could produce a spurious ratio of minimum to maximum heat flow of 1: 2.85. This spurious ratio would not obscure regional heat flow trends.

Results

The heat flow values obtained near edifices B and D have been plotted on two east-west cross sections (Figures 2, 3). At edifice B (Figure 2), the high heat flow zone is displaced somewhat to the west of the center of the rift valley. At edifice D (Figure 3), the high heat flow zones are near the edge of the volcanic edifice. On both of these profiles, the highest heat flow values (>550 mW/m^2) are within 4 km of the volcanic edifices.

The maximum heat flow values at both edifices are in excess of 1200 mW/m^2. At all other well-studied, sediment-covered ridge crests, the Guymas basin [Williams et al., 1979] and Middle Valley [E. Davis, personal communication], preliminary surveys measured a maximum heat flow in excess of 1200 mW/m^2. Later surveys in both

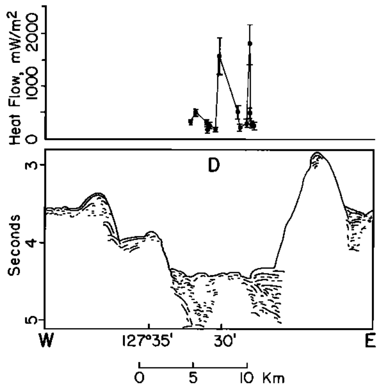

Fig. 3. Top, heat flow from west to east at 41° N (edifice D) in the Escanaba Trough. Heat flow stations 20-34 (Table 1). Bottom, seismic-reflection profile in seconds of two-way travel time along the same east-west line as the heat flow profile.

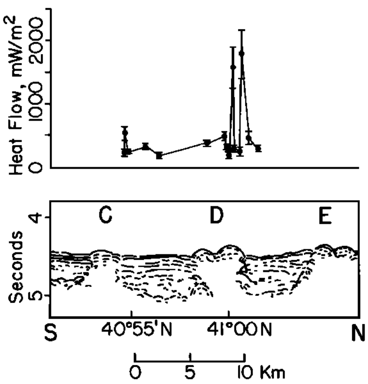

Fig. 4. Top, heat flow in mW/m^2 from south to north along the axis of the Escanaba Trough. Heat flow stations 1-15, 20-34 (Table 1). Bottom, Seismic reflection profile in seconds of two-way travel time along the same north-south line as the heat flow profile. Volcanic edifices C through E are labeled above the line.

areas found 'black smokers', active high-temperature, hydrothermal vents which discharge sulfide minerals. This implies that the Escanaba Trough also has 'black smoker' vents. Samples from dredge hauls provide supporting evidence for ongoing high temperature activity in the Escanaba Trough. Dredges at both edifice B and D recovered fresh basaltic glass. One dredge at edifice B recovered samples of pyrrhotite [Holmes and Morton, 1986], a sulfide mineral formed during diagenesis at temperatures ≥ 300° C [Gieskes et al., 1982].

Unfortunately, our heat flow measurements from the area between edifices B and D are inconclusive with respect to high temperature hydrothermal activity. All of these measurements between edifices are from the center of the axial valley (Figures 1, 4). If we had confined our efforts at edifice B to the center of the valley, we would not have measured any heat flow values in excess of 1200 mW/m^2. Consequently, further measurements are necessary before we can gage the amount of geothermal activity in the remainder of the Escanaba Trough.

Conclusions

The maximum heat flow measurements at volcanic edifices B and D in the Escanaba Trough exceed 1200 mW/m^2. These high values, coupled with dredged pyrrhotite and fresh basaltic glass, indicate that high-temperature (> 100° C) hydrothermal venting is very likely to be occurring in this area. We cannot evaluate the geothermal potential of the rest of the Escanaba Trough on the basis of our present data. However, these results confirm that slow spreading ridges can produce intense hydrothermal activity at the sediment-water interface.

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