Bulletin of the Geological Survey of Japan, vol. 39(1), p.63-70, 1988 550.36 : 551.352 (528.1)

Heat flow in the Sumisu Rift, Izu-Ogasawara (Bonin) Arc

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YAMAZAKI,T. (1988) Heat flow in the Sumisu Rift, Izu-Ogasawara (Bonin) Arc. *Bull. Geol. Surv. Japan*, vol. 39 (1), p. 63-70.

Abstract : Eleven heat flow measurements have been completed, the first from the Sumisu Rift. The values range from 38 to 700 mW/m². Existence of very high values and large variability can be explained by intensive hydrothermal circulation. This strongly supports the idea that the Sumisu Rift is in an incipient stage of back-arc spreading. Measurements at five sites closely spaced (0.5 to 1km) across a normal fault revealed that high heat flow values occur near the base of the fault scarp. A thick sedimentary layer (maximum 1500m) in the Sumisu Rift is cut by many small normal faults (the surface vertical displacement is 50m or less). They would enhance the permeability of the sediments in a bulk sense, which enables the hydrothermal circulation in the thick sedimentary layer.

1. Introduction

The Izu-Ogasawara (Bonin) Arc, extending from 24°N to 35°N (Fig. 1), is a well-developed island arc. It continues southward to the Mariana Arc, which has an active back-arc basin, the Mariana Trough (KARIG, 1971). Topographic depressions, first noted by MOGI (1968), exist just behind the volcanic line (Shichito Ridge) of the northern half of the Izu-Ogasawara Arc. KARIG and MOORE (1975) considered that these depressions are young extensional basins. HONZA and TAMAKI (1985) showed the distribution of these segmented small basins, and discussed the possibility of active extensional tectonics based on their seismic reflection profiles and bottom sampling. The Sumisu Rift is one of these basins (Fig. 1) named after a nearby volcanic island, Sumisu Jima (HONZA and TAMAKI (1985) 's "Sumisu Depression").

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The purpose of this study is to confirm active extensional tectonics on the Sumisu Rift by heat flow, and to present basic data for considering how tectonic fractures might affect the hydrothermal circulation. No heat flow data from the Sumisu Rift has been published yet. Eleven measurements including those at five closely spaced sites across a normal fault have been completed successfully.

2. Geological Setting

The Sumisu Rift is bounded by normal faults on both the east and west walls. The basin is separated into the northern, narrower sub-basin and the southern, wider sub-basin (Fig. 2) by intra-rift volcanoes (BROWN and TAYLOR, 1988). The water depth of the former is 2000 to 2100m and that of the latter is 2200 to 2300m. The Sumisu Rift is structurally asymmetric. The eastern end of the basin seems to have subsided most. No basement topography like a spreading center

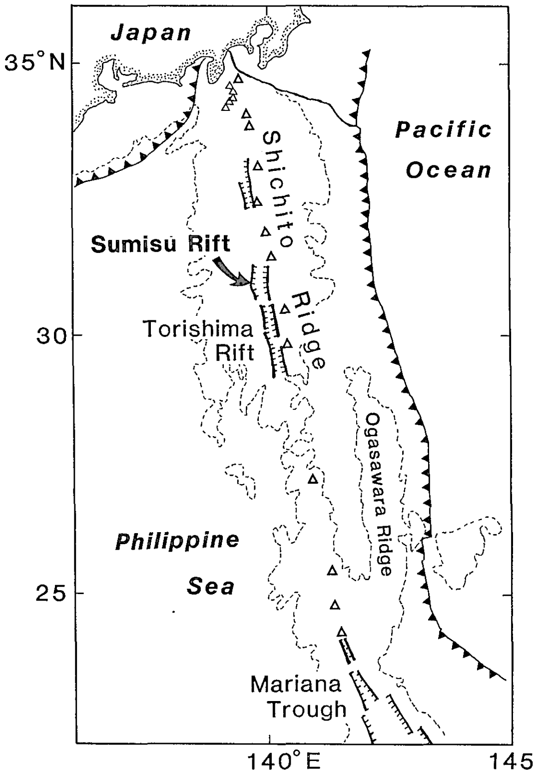

Fig. 1 Location of the Sumisu Rift in the Izu-Ogasawara (Bonin) Arc. In the northern half of the arc, segmented rift basins exist just behind the volcanic line. Triangles are Quaternary volcanoes. Dotted line represents 3000m iso-depth.

can be recognized. The basement would be subsided island-arc crust, not oceanic crust.

The basement in the basin is covered with sediments. Rapid deposition of volcaniclastics derived from nearby arc volcanoes may have occurred. The thickness of the sedimentary layer exceeds 1000m in the eastern part of the south basin. The surface sediments, which is acoustically transparent in records of 3.5 kHz sub-bottom profiler, consist mainly of volcanic ash and clayey silt. Many normal faults which cut through the sedimentary layer occur in the south basin. The surface vertical displacement of the faults is usually less than 50m. Detailed description of the structure of the Sumisu Rift based on seismic reflection profiles is given by MURAKAMI (1988).

3. Heat Flow Measurements

3.1 Instruments and data reduction

For measuring the thermal gradient, two instruments were used. One was briefly described by MATSUBAYASHI (1982). The second is conceptually similar but has larger memory capacity. By these instruments, temperature data are digitized every 15 or 30 seconds. The resolution of the above two instruments are 4 and 1 mK, respectively. Three thermistor probes were mounted in outrigger fashion with about 0.6m intervals along a 2m long gravity corer. A 1.5m long lance with thermistors of 0.5m intervals was used at two sites (H206 and H207).

Thermal gradient measurements were successfully completed at eleven sites. The location of these sites are shown in Fig. 2. Superficial volcanic ash layer was rather hard to be penetrated. Several measurements failed because the corer fell down at or immediately after the impact on the bottom. At about a half of the eleven successful sites, the probes penetrated only 1m or less. Our instruments have no tilt sensor, but visual inspection of the cored sediments did not show any evidence of largely inclined penetration.

Decay of frictional heating of the thermistors during the penetration into sediments was monitored for about 10 minutes. Equilibrium temperature of each thermistor was obtained by the extrapolation using cylindrical decay function $F(\alpha, \tau)$ of BULLARD (1954). A typical example (Site H179) is shown in Fig. 3. The decay origin time was adjusted by trial and error to get linear $F(\alpha, \tau)$ decay (DAVIS *et al.*, 1984). Large frictional heating during penetration into the 'hard' sediments in the Sumisu Rift causes relatively large error in the extrapolation, about ± 10 mK at maximum. Thermal disturbances due to the movement of the probe dur-

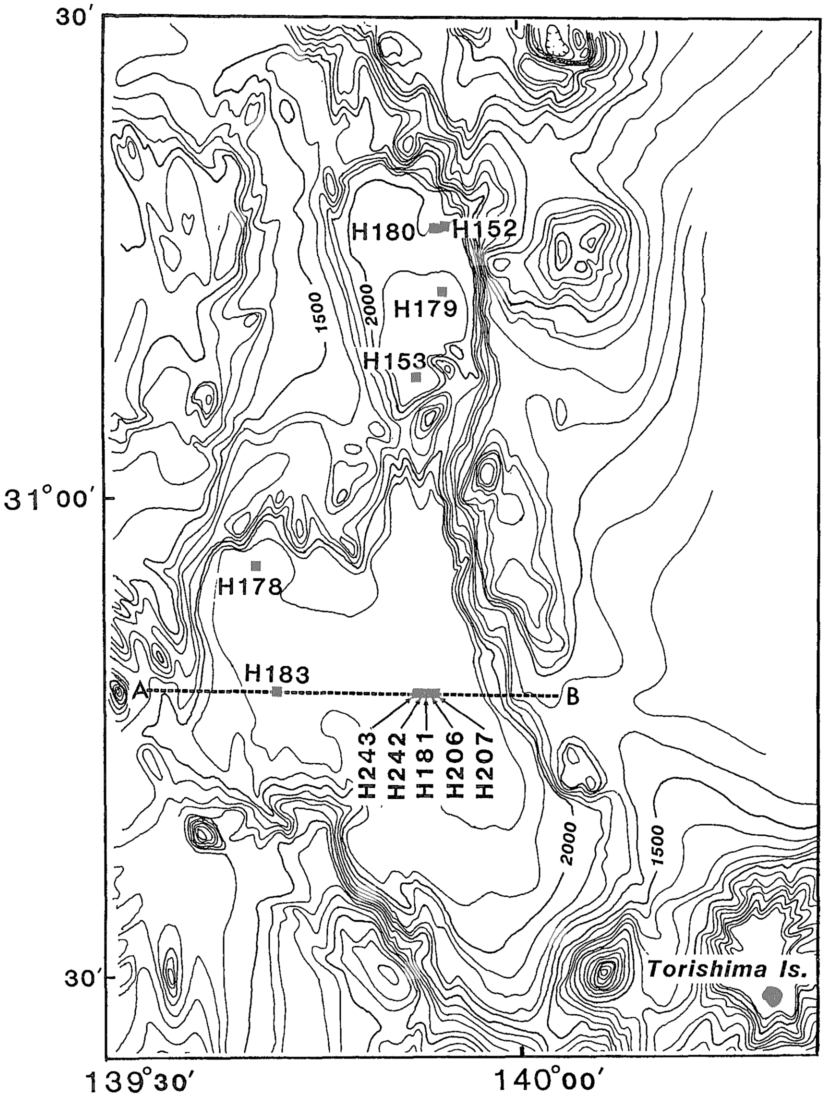

Fig. 2 Location of heat flow sites superimposed on a topographic contour map of the Sumisu Rift. Broken line A-B refers to Fig. 5.

ing the frictional decay monitoring cause non-linear, anomalous F(α, τ) decay plots, and these measurements were discarded.

Thermal conductivity measurements were performed on the retrieved cores by QTM (Quick Thermal conductivity Meter, Showa Denko Co.). The accuracy of this instrument is within ± 5%. Cores were split in halves and covered with thin plastic film (commercial transparent food-wrapping film) to prevent evaporation of pore water before the measurements were carried out. The effect of this film on the conductivity is negligible (SASS *et al.*, 1984). Measurements were done on board as soon as the thermal steady state was attained at about 24°C a few hours after the core was retrieved. The values measured in the laboratory were corrected to in situ conditions of temperature and pressure following RATCLIFFE (1960).

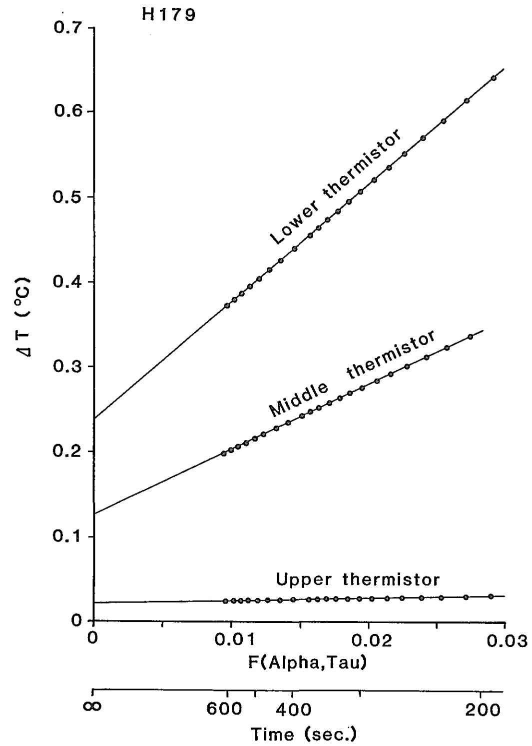

Fig. 3 Extrapolation of frictional heating decay using F(α, τ) of BULLARD (1954).

Real-time navigation of the ship was done by Loran-C, which was calibrated by satellite fixes. Absolute accuracy of the ship's position is about 100m. The positioning of the heat flow sites with respect to topographic features would be better.

3.2. Results

Eleven successful heat flow measurements are summarized in Table 1. Thermal conductivity values in parentheses are estimated from the nearest measurement because no sediments were obtained at these sites. Thermal gradient values in parentheses are less reliable (H181 and H207). For H181, the corer fell down before the frictional decay monitoring could be completed. In the case of H207, some thermal disturbances were recognized in the frictional decay plots.

The resulting temperature profiles are presented in Fig. 4. As the accurate depth to which the corer penetrated could not be known, the distance from the upper thermistor is given in the figure. One site (H178) out of five at which temperatures at three different depths were obtained shows signifi-

Table 1 Summary of heat flow data in the Sumisu Rift.

Station	Position+ Lat.(N)	Lon.(E)	Water Depth	Gradient (mK/m)	Ng	Conductivity (W/mK)	Nc	Heat flow (mW/m^2)
H152	31°16.95′	139°54.65′	1985	284	2	(0.850)		241
H153	31°07.67′	139°52.76′	2135	86	2	0.840±0.027 (1σ)	6	72
H178	30°55.73′	139°41.23′	2220	114*	3	0.826±0.022	7	94
H179	31°12.92′	139°54.63′	2123	187	3	0.838±0.011	8	156
H180	31°16.87′	139°53.99′	2045	139	3	0.850±0.010	5	118
H181	30°47.86′	139°53.56′	2293	(482)	2	0.831±0.008	6	(401)
H183	30°47.94′	139°42.72′	2235	43	3	0.871±0.009	3	38
H206	30°47.94′	139°54.03′	2290	842	2	(0.831)		700
H207	30°47.95′	139°54.32′	2288	(149)	2	(0.831)		(124)
H242	30°47.97′	139°53.13′	2270	337	3	0.934±0.088	8	315
H243	30°47.97′	139°52.44′	2260	315	2	0.839±0.017	4	264

Ng : Number of thermistors used for calculation of temperature gradient.
Nc : Number of thermal conductivity measurements.
* : Temperature gradient is significantly non-linear. See text.
+ : Based on the Tokyo Geodetic Datum.
Thermal conductivity values were corrected to in situ temperature and pressure conditions by Ratcliffe (1960).

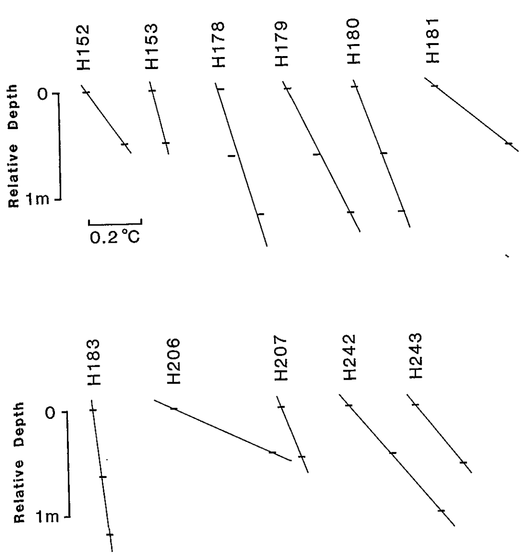

Fig. 4 Sediment temperature profiles. Depth axis represents distance from the upper thermistor.

cant non-linear gradient. Several naturally occurring phenomena can be responsible for a non-linear temperature gradient (NOEL,1984). It is difficult to say clearly the cause of the non-linearity from only one observation. For this reason, the thermal gradient value in Table 1 was calculated by fitting a straight line using the least-squares method. If, however, the non-linearity is due to fluid convection in sediments, downward flow of about 10^{-7} m/s and net heat flow (convective heat flux was subtracted) of about 25mW/m² are estimated from the equations (4) and (5) of WILLIAMS *et al.* (1979). A large thermal conductivity contrast was not observed. Changes in bottom water temperature would cause a time-varying non-linear gradient which should be coherent over a wide area such as the whole Sumisu Rift. Other two measurements (H179 and H180) on the same day, however, did not show non-linearity. Retrieved sediments were similar in lithology to those of other sites in the south basin (except for H242), and any evidence of slumping or heat absorptive layer could not be recognized.

Site H242 hit a fault scarp in the south basin. The retrieved sediment core, which contains calcareous clay, is different in lithology from the surface sediments of nearby sites. The subsurface layer would be exposed on the scarp by recent movement of the fault. The calcareous sediments caused the higher thermal conductivity (Table 1).

4. Discussion

Heat flow variability is very large in the Sumisu Rift. Eleven heat flow values range from 38 to 700 mW/m². Conductive effects (for example, effects of surface topography and basement topography) cannot explain such large variability. The most probable explanation of the largely variable heat flow distribution is hydrothermal circulation in the crust (e. g. LISTER, 1972). High heat flow values are measured in the areas of upwelling fluid and low ones in areas of downwelling. This can also account for the existence of a non-linear temperature profile. It is well known that heat transport is dominated by hydrothermal circulation in the crust near oceanic spreading centers (WILLIAMS *et al.*, 1974). Largely variable heat flow distribution is commonly observed there, for example on flanks of the Juan de Fuca Ridge (DAVIS *et al.*, 1980) and East Pacific Rise at 21°N (BECKER and VON HERZEN, 1983). Active high-temperature hydrothermal vents have been found on both ridges (NORMARK *et al.*, 1983 ; MACDONALD *et al.*, 1980). The observed heat flow distribution in the Sumisu Rift strongly supports the idea that the Sumisu Rift is in the incipient stage of back-arc spreading (KARIG and MOORE, 1975; HONZA and TAMAKI, 1985).

Next, tectonic control of heat flow distribution is discussed. Five closely spaced (0.5 to 1 km intervals) measurements were performed across a normal fault in the south basin (Fig. 5). The sediment thickness around these sites, about 1500m, is largest in the Sumisu

Rift. Two features in the heat flow distribution can be pointed out. High heat flow values occur near the base of the fault scarp. Wavelength of the local heat flow variation may be several kilometers. The wavelength is similar to the distance among the normal faults (Fig. 5). This observation suggests that the normal faults have some influence on the pattern of the hydrothermal circulation like those on the Juan de Fuca Ridge (DAVIS *et al.*, 1980). But the surface displacements of the faults in the Sumisu Rift are much smaller and the basement is not exposed on the fault scarps, and sediment cover is thicker.

Deposition of sedimentary layer prevents the convective exchange of heat from the oceanic crust to the ocean because the sedimentary layer is much less permeable than the oceanic crust (ANDERSON and SKILBECK, 1981). Sediment cover of 200 to 300m in thickness seals the hydrothermal circulation on the flank of spreading centers (ANDERSON *et al.*, 1977 ; LANGSETH *et al.*, 1983). In the Sumisu Rift, however, the thick 'impermeable' sediments, about 1500m at maximum, do not inhibit hydrothermal circulation. Permeability may be relatively higher at normal faults. Existence of the many normal faults may have enhanced the permeability of the whole sedimentary layer in a bulk sense, which enables the hydrothermal circulation in the thick sedimentary layer. Viscosity of

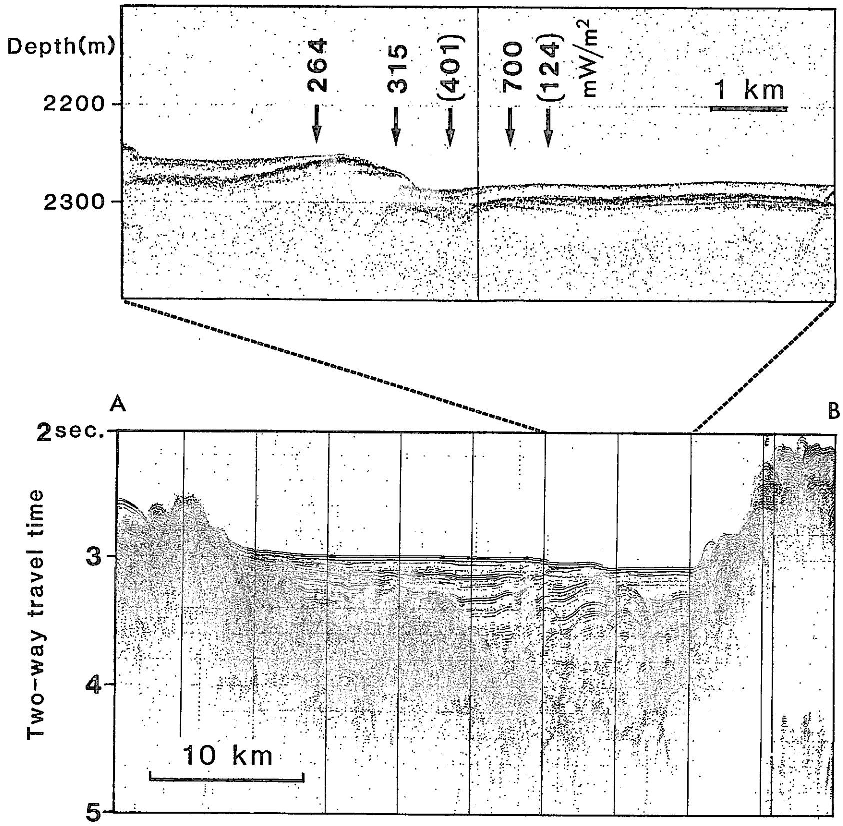

Fig. 5 Five closely spaced heat flow sites across an active normal fault. (Upper) Record of 3.5 kHz subbottom profiler and distribution of heat flow. Values in parenthese are less reliable. (Bottom) Seismic reflection profile. Location of the record is shown in Fig. 2. Several normal faults can be recognized on the profile.

pore water may be reduced by the high temperature gradient in the Sumisu Rift. This would also contribute to allow convection to occur (STRAUS and SCHUBERT, 1977).

Acknowledgements : The measurements could not be performed without cooperation of all scientists, officers and crew of R/V Hakurei-maru cruises GH85-1, GH85-3 and GH86-1. I wish to thank A. NISHIMURA, F. MURAKAMI and M. YUASA for assistance and advice. I also thank M. YAMANO, O. MATSUBAYASHI, Y, SHIMAZAKI and G. BROWN for their critical readings of the manuscript and valuable comments. This work was supported by the special research program, "Submarine Hydrothermal Activity in Izu-Ogasawara Arc", funded by the Agency of Industrial Science and Technology.

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伊豆・小笠原弧，スミスリフトにおける熱流量

山崎俊嗣

要旨

スミスリフトにおける初めての熱流量値を報告する．11点の測定値は38-700mW/m²である．700mW/m²という非常に高い値の存在と，値の大きな分散から熱水循環系の存在が推定される．これはスミスリフトが背弧拡大の初期にあるとする考えを支持する．正断層を横切る密な間隔（0.5-1km）による5点の測定の結果は，断層崖下の前面に高熱流量域が存在することを示した．スミスリフトでは最大1500mに及ぶ厚い透水率の低い堆積層が存在するにもかかわらず熱水循環系が存在しているのは，堆積層を切る多数の正断層の存在により，堆積層全体としての透水率が大きくなっているためと推定される．

（受付：1987年4月9日；受理：1987年11月6日）