BULLETIN OF THE EARTHQUAKE
RESEARCH INSTITUTE
UNIVERSITY OF TOKYO
Vol. 65 (1990) pp. 571-588

Heat Flow Measurements in the Southern and Middle Okinawa Trough on R/V Sonne in 1988

Masataka KINOSHITA[1], Makoto YAMANO[2], Johannes POST[3] and Peter HALBACH[4]

1) School of Marine Science and Technology, Tokai University
2) Earthquake Research Institute, University of Tokyo
3) Preussag AG
4) Technical University of Clausthal, Institute for Mineralogy and Mineral Raw Materials

(Received March 31, 1990)

Abstract

A detailed heat flow survey was carried out near the axis in the southern and middle Okinawa Trough on cruise SO56 of R/V Sonne in 1988, and 50 new heat flow values were determined. Emphasis was put on closely-spaced heat flow measurements around knolls and small basins near the trough axis in order to clarify the nature of thermal anomalies, which were expected to be related to hydrothermal activity.

In the axial graben of the southern Okinawa Trough, heat flow values obtained within 2 km of an axial volcano (the Yaeyama Central Knoll) were less than 50 mW/m^2 and showed large scatter. These low heat flow values can be explained as they are measured in the recharge area of the hydrothermal circulation, which is presumed to discharge at the Yaeyama Central Knoll.

In the axial part of the middle Okinawa Trough, heat flow values measured in a basin to the east of the Natsushima-84 Deep, which was known to have high heat flow, were 710$\pm$690 mW/m^2. This indicates that the thermally active area extends along the central axis of the trough.

High and variable heat flow (360$\pm$220 mW/m^2) was also found in a cauldron, about 35 km to the south of the axis of the middle Okinawa Trough. Heat flow increases toward the northeastern wall of the cauldron, where the hydrothermal ore deposits were discovered.

1. Introduction

An extensive and systematic survey for hydrothermal vents and ore deposits was carried out in the Okinawa Trough during cruise SO56 by R/V Sonne in June, 1988. This cruise was conducted as a Japanese-German cooperative research program consisting of geological, geochemical and geophysical studies, i. e. dredge hauls, grab sampling, box coring, seafloor observation with deepsea TV and CTD towing, Sea Beam mappings and heat flow measurements.

The Okinawa Trough, an active backarc basin of the Ryukyu Arc (Fig. 1), is believed to be on the rifting stage of the continental crust (KATSURA *et al.*, 1986 ; SIBUET *et al.*, 1987). Along the central axis of the middle to the southern part of the trough, there are many volcanic knolls, from which very recent volcanic rocks have been sampled (*e.g.* KATSURA *et al.*, 1986). On one of these knolls in the axial depression in the middle Okinawa Trough, called the "Iheya Deep" (Area 2 in Fig. 1), active hydrothermal mounds have been found (*e.g.* KIMURA *et al.*, 1988). The main objective of this cruise was to ascertain if indeed hydrothermal ore deposits were formed in these areas of the backarc region, where thermal anomalies could be identified by heat flow measurements and other deep tow surveys.

Surveyed areas are enclosed by boxes in Fig. 1 ; Area 1 and Area 2 in the middle Okinawa Trough, and Area 5 in the southern Okinawa Trough. We tried 82 heat flow measurements at 38 stations. Heat flow values were determined for 48 penetrations.

Several heat flow measurements were made in Area 2 by one of the authors (M. K.) in September, 1988 during cruise KT88-17 of R/V Tansei-Maru, Ocean Research Institute, University of Tokyo. Two heat flow data were obtained during that cruise ; they are also included in this report.

2. Method of Measurement

2.1. Determination of heat flow stations

The GPS, along with the transit satellite navigation system, was used to determine the ship's position to the high accuracy which was required to achieve the above stated objective. When the GPS was not available, real-time Sea Beam mapping and 3.5 kHz echo-sounder profile were utilized to know the exact location by comparing them with the Sea Beam map that had been preliminarily obtained on this cruise. The Sea Beam and 3.5 kHz profiler data were used also to decide the heat flow stations during

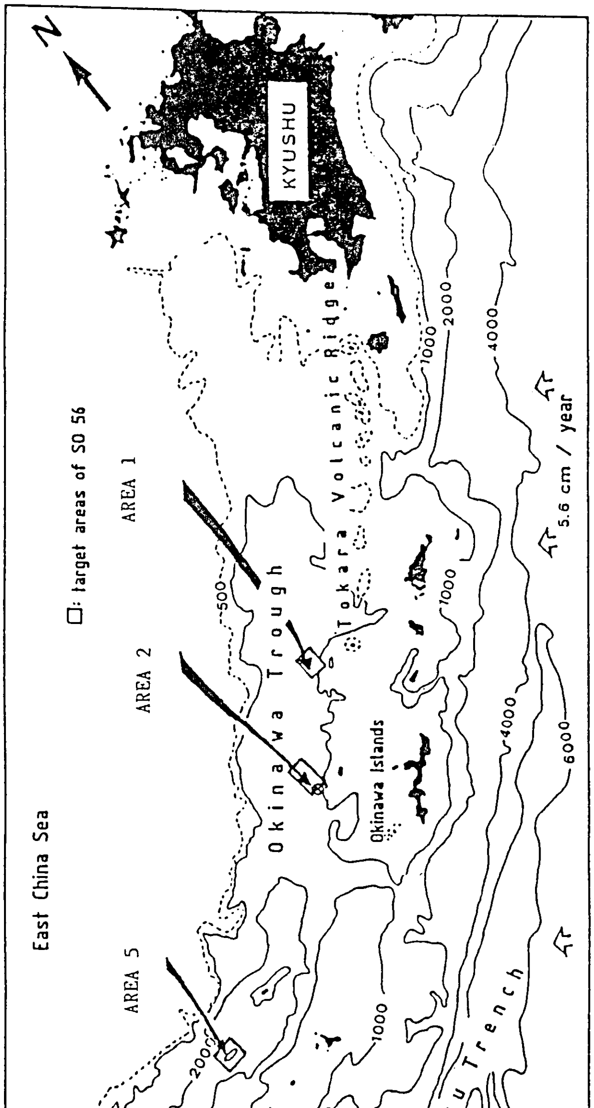


Fig. 1. Index map for the surveyed area during cruise SO56 by R/V Sonne in 1988. Surveys were done in Areas 1, 2 and 5.

site surveys.

2.2. Measurement and determination of heat flow values

The value of heat flow on the seafloor is determined as the product of vertical geothermal gradient and thermal conductivity, both of which are measured within a few meters below the seafloor.

We used two Ewing type (GERARD *et al.*, 1962) instruments (HFM and HFK). The "HFM" probe, prepared by the Earthquake Research Institute, has a 4.5 m long lance and a 500 kg weight with seven temperature sensors (thermistors). Each thermistor is sealed inside a stainless tube 3.5 mm in diameter. The sensors are outriggered to the lance at intervals of 50 to 80 cm. The probe allows multiple penetrations into seafloor sediment within one lowering operation, which improves the efficiency of data collection and makes closely-spaced measurements possible. The temperature recording system was made by the Woods Hole Oceanographic Institution. The data, including instrument tilt, were not only recorded in the IC memory but also telemetered with 12 kHz acoustic pulses to the ship for real-time monitoring so that we could save time by recognizing unsuccessful penetrations. Since thermal conductivity values were impossible to obtain with this instrument, we used the nearby values measured on "HFK" samples or obtained through other cruises (*e.g.* YAMANO *et al.*, 1986a; b). Therefore, the estimated heat flow values may contain errors up to about 10% due to variation of thermal conductivity for seafloor sediments in this area. This probe was also used on cruise KT88-17.

The "HFK" probe, prepared by Preussag AG, has a box core sampler (kasten corer) with 3 m (HFK3) and 5 m (HFK5) lengths (HALBACH *et al.*, 1989b). The probe is equipped with five sediment thermistors, one bottom water temperature sensor, a pressure sensor and a tilt meter. The thermal conductivity was measured on board on the box core samples using the needle probe method (von HERZEN and MAXWELL, 1959).

The temperature gradient was determined using the least squares fit of the obtained temperature versus depth data to a straight line after correcting for the instrument tilt. Results are shown in the appendix and the determined heat flow values are listed in the Table for both cruises SO56 and KT88-17. The accuracy of the measured temperature difference between sensors is estimated to be about 0.01 deg, and the temperature gradient value has an error of 5 to 10%. Therefore, the heat flow value in the Table may contain error of 10 to 20%.

Table. Results of Heat Flow Measurements.

Station	Latitude	Longitude	D m	PEN m	N	G mK/m	K W/m/K	Q mW/m^2
Area 1								
29HFM-A	28°14.4'N	127°43.1'E	1100	2	4	80	0.84*	
B	28°14.6'N	127°43.4'E	1035	1.5	3	(63)	0.84*	
30HFM-A	28°13.1'N	127°44.4'E	1125	fell				
B	28°13.1'N	127°44.4'E	1125	fell				
C	28°13.0'N	127°44.5'E	1115	fell				
D	28°13.0'N	127°44.5'E	1118	fell				
E	28°13.0'N	127°44.5'E	1117	fell				
31HFM-A	28°16.8'N	127°50.1'E	1178	1	2	(18)		
B	28°16.8'N	127°50.3'E	1171	3.5	4	(1)		
C	28°16.8'N	127°50.4'E	1171	fell				
D	28°16.8'N	127°50.5'E	1173	fell				
32HFK3	28°16.9'N	127°51.2'E	1170	fell				
114HFM	28°15.0'N	127°41.8'E	1059	2.5	4	298	0.84*	
115HFK3	28°14.0'N	127°42.7'E	1103			95	0.94	
116HFM-A	28°13.6'N	127°42.5'E	1095	5	7	227	0.84*	
B	28°13.8'N	127°42.7'E	1098	5	7	202	0.84*	
C	28°13.9'N	127°42.7'E	1100	5	7	94	0.84*	
117HFK5	28°16.3'N	127°44.4'E	1147			11	0.88*	
118HFM-A	28°16.5'N	127°45.0'E	1144	1t	3	(>87)	0.88*	
B	28°16.6'N	127°45.1'E	1144	4	5	99	0.88*	
C	28°16.7'N	127°45.2'E	1148	4	4	83	0.88*	
Area 2 (Iheya Deep)								
3HFM-A	27°33.8'N	126°55.7'E	1555	1.5	3	83	0.86*	71
B	27°33.8'N	126°55.93E	1550	2	4	64	0.86*	55
C	27°33.9'N	126°55.88E	1550	2	4	60	0.86*	52
4HFK5	27°33.8'N	126°55.8'E	1558				0.86	
78HFK5	27°34.5'N	126°56.8'E	1545			182	0.86	157
79HFM-A	27°31.9'N	126°59.0'E	1510	fell				
B	27°32.0'N	126°59.2'E	1575	fell				
80HFK3	27°31.5'N	126°59.6'E	1601	fell				
86HFM-A	27°35.0'N	127°12.6'E	1750	4.5	6	1152	0.80*	922
B	27°35.2'N	127°12.8'E	1744	4.5	6	391	0.80*	313
C	27°34.9'N	127°12.5'E	1746	4.5	6	730	0.80*	584
D	27°35.0'N	127°12.6'E	1744	4	6	629	0.80*	503
92HFK5	27°34.8'N	127°12.9'E	1740			524	0.87	456
93HFM-A	27°34.8'N	127°12.0'E	1743	4.5	6	601	0.80*	481
B	27°35.0'N	127°12.1'E	1752	4.5	7	764	0.80*	611
99HFM-A	27°34.5'N	127°11.7'E	1730	3.0t	4	(>1468)	0.80*	
B	27°34.6'N	127°11.8'E	1771	1.5	3	3529	0.80*	2823
C	27°34.7'N	127°11.8'E	1752	2.5t	4	(>2079)	0.80*	
100HFK5	27°35.3'N	127° 9.3'E	1759			431	0.87	376
101HFM-A	27°34.9'N	127°13.0'E	1737	2.5	4	832	0.80*	666
B	27°35.0'N	127°13.1'E	1739	2.5	4	831	0.80*	665
C	27°35.1'N	127°13.4'E	1733	1	2	(696)	0.80*	

(to be continued)

3. Results and Discussion

3.1. Area 5: Yaeyama Central Knoll (Fig. 2)

The southern Okinawa Trough, about 100 km in width and 2000 m in depth, is generally believed to be on the rifting stage of the continental crust. Some east-west trending grabens develop along the axial part of the southern Okinawa Trough (*e.g.* KATSURA *et al.*, 1986). LU *et al.* (1981) reported a high and variable heat flow distribution in the southern Okinawa

Table. (continued)

Station	Latitude	Longitude	D m	PEN m	N	G mK/m	K W/m K	Q mW/m^2
(Izena Cauldron)								
138HFM-A	27°15.7'N	127° 3.6'E	1654	1.5	4	427	0.87*	371
B	27°15.7'N	127° 3.7'E	1670	3.5	4	395	0.87*	344
C	27°15.7'N	127° 3.7'E	1665	2.5	4	551	0.87*	479
139HFK3	27°15.6'N	127° 3.7'E	1668			176	0.87	153
140HFM-A	27°14.95N	127° 3.92E	1627	fell				
B	27°14.96N	127° 3.90E	1656	fell				
C	27°15.07N	127° 3.89E	1666	fell				
D	27°15.05N	127° 3.92E	1671	fell				
141HFK5	27°15.4'N	127° 3.7'E	1657			119	0.91	108
146HFM-A	27°15.2'N	127° 3.6'E	1670	1.5	3	111	0.91*	101
B	27°15.3'N	127° 3.6'E	1682	3	5	341	0.91*	310
C	27°15.4'N	127° 3.5'E	1677	3	5	268	0.91*	244
153HFM-A	27°15.0'E	127° 4.5'E	1572	2.5	4	144	0.9 *	130
B	27°15.1'N	127° 4.5'E	1608	2.5	4	260	0.9 *	234
C	27°15.2'N	127° 4.6'E	1582	2.5	4	514	0.9 *	463
D	27°15.3'N	127° 4.6'E	1581	4	5	535	0.9 *	482
154HFK5	27°15.7'N	127° 4.2'E	1648	bad records				
155HFM-A	27°14.9'N	127° 2.5'E	1464	4	7	175	0.9 *	158
B	27°14.8'N	127° 2.4'E	1480	3.5	6	150	0.9 *	135
161HFM-A	27°14.1'N	126°59.8'E	1508	4	6	171	0.9 *	154
B	27°14.1'N	126°59.9'E	1513	4	6	354	0.9 *	319
C	27°14.1'N	127° 0.0'E	1517	4	6	128	0.9 *	115
D	27°14.2'N	127° 0.1'E	1519	4	6	159	0.9 *	143
162HFK3	27°15.5'N	127° 4.0'E	1641			993	0.92	913
KT88-17 HF1A	27°14.5'N	127° 4.7'E	1600	2.5t	3	(>397)	0.9 *	
B	27°15.0'N	127° 4.9'E	1600	3t	3	(>237)	0.9 *	
C	27°14.7'N	127° 5.8'E	1600	3	3	601	0.9 *	540
D	27°14.8'N	127° 5.2'E	1600	2	4	571	0.9 *	514
KT88-17 HF2A	27°17.4'N	127° 5.2'E	1110	fell				
B	27°17.4'N	127° 5.2'E	1180	fell				
KT88-17 HF3A	27°20.1'N	126°59.4'E	1510	fell				
B	27°20.1'N	126°59.4'E	1510	fell				
C	27°20.6'N	126°59.6'E	1510	fell				
D	27°20.8'N	126°59.7'E	1470	fell				
(Others)								
28HFK3	27°28.1'N	127°42.5'E	1108			60	0.90	54

(to be continued)

Trough. According to YAMANO *et al.* (1989), heat flow appears to be lower in the central rift zone than in the surrounding area. However, their data were sparse for detailed discussion of the hydrothermal activity in this area.

There is an E-W elongated basaltic volcanic ridge called the Yaeyama Central Knoll at the axis of one of the above grabens (the Yaeyama Graben). It is composed of fresh pillow basalts (HALBACH *et al.*, 1989b), and a thick sediment cover exists around the knoll. We expected to find hydrothermal activity on the knoll and related heat flow anomalies around it.

Thirteen heat flow values were obtained within 10 km around the Yaeyama Central Knoll (Fig. 2). They are low and variable (36 ± 12 mW/m^2). Particularly, the heat flow is lower than 50 mW/m^2 within 2 km of the knoll. A value reported in the close vicinity of the knoll is also low, Table. (continued)

Station	Latitude	Longitude	D m	PEN m	N	G mK/m	K W/m K	Q mW/m2
Area 5								
58HFK3	25°16.8'N	124°24.3'E	2267			54	0.80	43
59HFM-A	25°14.6'N	124°24.7'E	2270	4	6	46	0.98*	45
B	25°14.4'N	124°25.0'E	2265	4	6	40	0.98*	39
C	25°14.3'N	124°25.3'E	2256	4	6	38	0.98*	37
60HFM-A	25°15.8'N	124°20.7'E	2294	4.5	6	33	0.84*	27
B	25°15.7'N	124°20.8'E	2301	4.5	6	28	0.84*	24
C	25°15.6'N	124°20.9'E	2292	4	7	13	0.84*	11
61HFK5	25°12.8'N	124°24.6'E	2195			58	1.03	60
68HFM-A	25°11.4'N	124°21.6'E	2147	3	5	56	0.94*	53
B	25°11.5'N	124°21.5'E	2152	1	2	(33)		
C	25°11.5'N	124°21.6'E	2150	3	5	58	0.94*	55
69HFK5	25°11.6'N	124°25.3'E	2154			78	0.94	73
70HFM-A	25°16.5'N	124°29.4'E	2285	4.5	7	66	0.98*	65
B	25°16.5'N	124°29.4'E	2285	4.5	7	66	0.98*	65

Notes:
The 'HFM' and 'HFK' stations are for cruise SO56.
D: Water depth in meters.
PEN: Length of the probe or corer below the sediment (meters). 'fell' indicates unsuccessful penetration, and 't' means that the probe penetrated but tilted by more than 40 degrees.
N: Number of sensors used to estimate the temperature gradient.
G: Estimated temperature gradient. Values in parentheses are less reliable. '>' indicates that the probe tilted by more than 40 degrees.
K: Thermal conductivity value. (★) means nearby value.
Q: Heat flow value estimated as the product of G and K.

45 mW/m² (shown by a circle in Fig. 2; Hydrographic Department, 1987). It should be noted that the heat flow values differ by more than a factor of two within 500 m near the western end of the Yaeyama Central Knoll. As mentioned above, the knoll is of very fresh origin and it should heat up the surrounding sediments (the time constant for thermal diffusion over 1 km is on the order of 10^5 years). Therefore, the low (and scattered) heat flow values suggest the existence of hydrothermal activity on and around the knoll and that recharge of sea water into the sediment occurs around the knoll, which reduces the heat flow to the observed value. If that is the case, the discharge area should be near the crest of the knoll, because the topographic high area tends to be a discharge area (HARTLINE and LISTER, 1981). Unfortunately, heat flow measurements were not possible on the knoll because of the lack of sediment for penetration, and hydrothermal vent activity could not be found through other surveys during cruise SO56. KATSURA *et al.* (1986), however, reported the existence of biological communities and flickering phenomena on the outcrop of the Yaeyama Central Knoll, which may support this speculation.

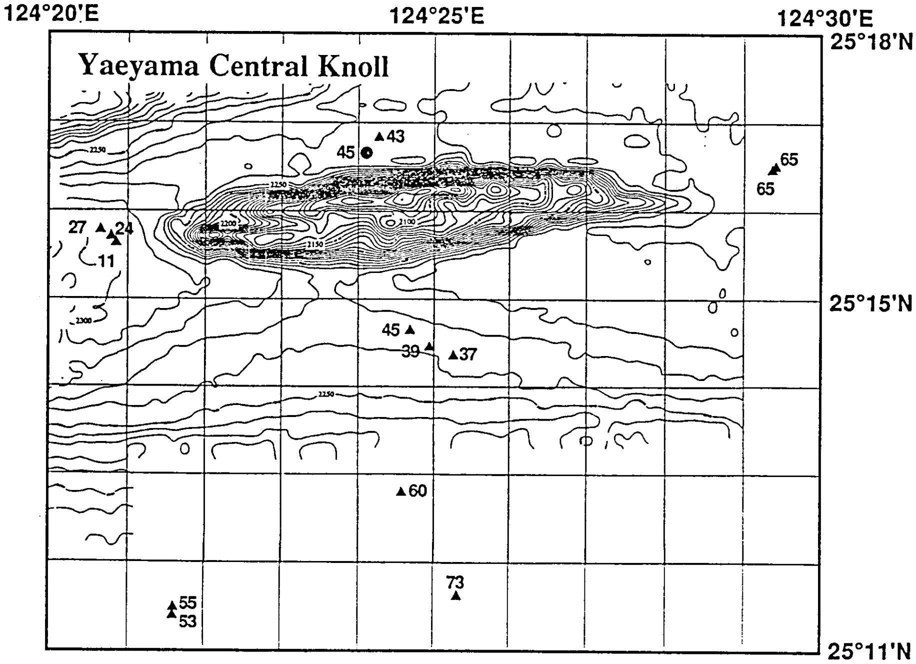


Fig. 2. Heat flow results in Area 5 (the Yaeyama Central Knoll, southern Okinawa Trough) plotted on a Sea Beam map obtained on cruise SO56. Contour interval is 10 m. Circle: previous study (Hydrographic Department of Maritime Safety Agency, 1987); triangles: this study. Units of mW/m^2.

3.2. Area 1

Area 1 lies around 150 km north of Okinawa Island and has an extension of 22×18 km. The morphology is characterized by submarine ridges and seamounts of different sizes, which reach up to 600 m in water depth. This area was chosen because a very high methane anomaly was discovered during the former Sonne cruise (SO55) in 1988.

We obtained fourteen geothermal gradient data in this area, some of which show quite low values. Due to the shallow water depth (shallower than 1200 m) in this area, the effect of bottom water temperature variation on the temperature field below the seafloor may not be negligible, and the measured geothermal gradient may not represent the real heat flow. Therefore, the heat flow value was not determined in this area.

3.3. Area 2: Iheya Deep (Fig. 3)

In Area 2 we had two target areas. One of them, the Iheya Deep area, includes an ENE-WSW elongated ridge (hereafter called the Iheya

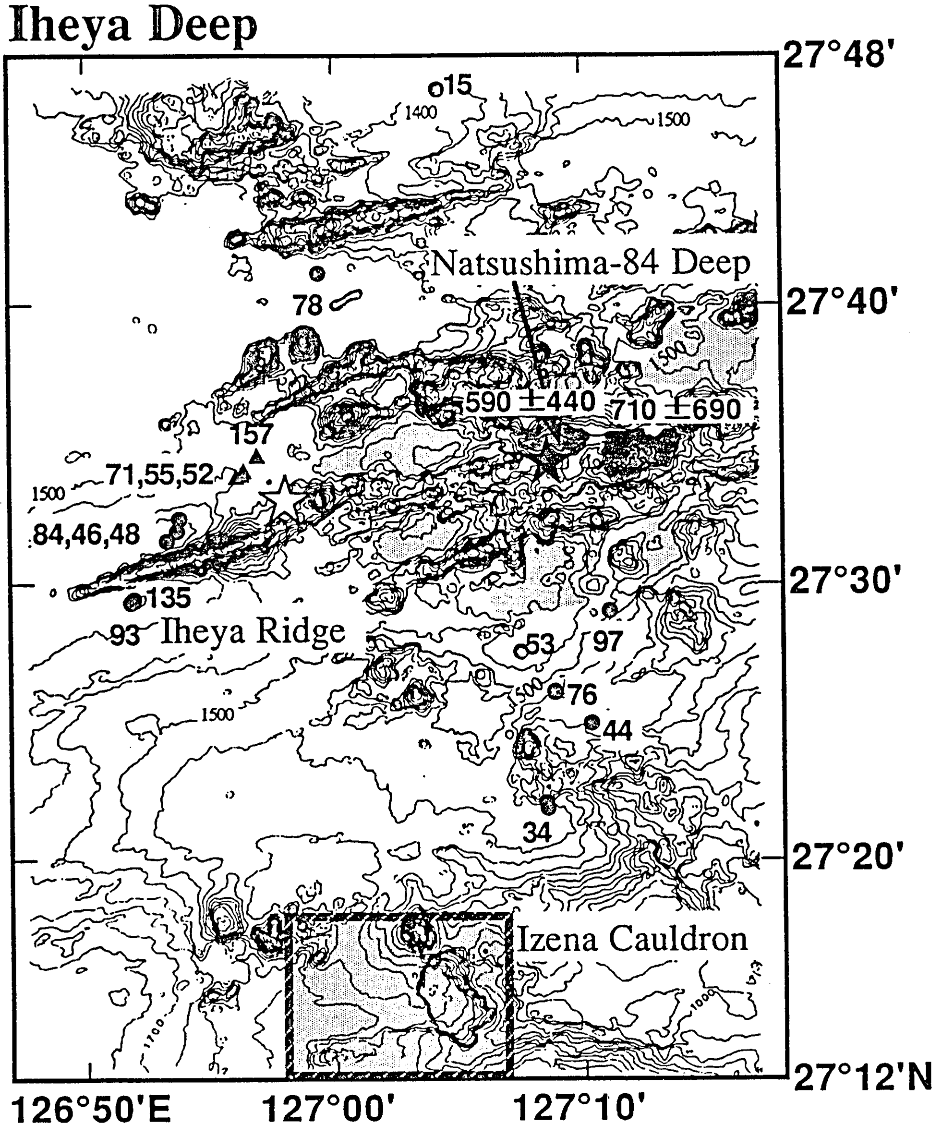


Fig. 3. Heat flow results in Area 2 (middle Okinawa Trough), except for the Izena Cauldron area (hatched box att he bottom; detailed heat flow map is given in Fig. 4) plotted on a Sea Beam map (OSHIMA *et al.*, 1988). Contour interval is 50 m. Circles: previous study (compiled by YAMANO *et al.*, 1989); triangles: this study. The Natsushima-84 Deep and the basin to the east of it are darkly shaded, and the heat flow average and the standard deviation are written. Units of mW/m^2. The open star represents the hydrothermal vent area on the flank of the Iheya Ridge, and the solid star indicates the hydrothermal mounds to the south of the Natsushima-84 Deep. Basins around the central axis are lightly shaded.

Ridge; 27°31′N, 126°55′E) and some basins and knolls to the east along the trough axis. The Iheya Ridge is composed of basalts and andesites whose K–Ar ages are less than 1 Ma (KIMURA *et al.*, 1986). A remarkable high heat flow anomaly had been found in a small axial basin called the "Natsushima-84 Deep" (27°35′N, 127°09′E, water depth 1750 to 1800 m, extension of 4 km × 1 km) in the Iheya Deep (YAMANO *et al.*, 1986a; b; 1989). Active hydrothermal mounds were discovered by a "Shinkai 2000" diving investigation to the south of the Natsushima-84 Deep (solid star in Fig. 3; KIMURA *et al.*, 1988). However, the extent of this heat flow anomaly along the trough axis had not been clarified. Therefore, we planned to make heat flow measurements around the Iheya Ridge area and in a small basin (27°35′N, 127°12′E, water depth 1750 to 1800 m; hereafter called the eastern basin) just east of the Natsushima-84 Deep in order to investigate the distribution of heat flow anomalies and to construct a hydrothermal circulation model including these axial basins.

Results of heat flow measurements are presented in Fig. 3. Near the Iheya Ridge we tried eight penetrations; five were successful and others (located on the southeastern side of the ridge) were not because of the coarse sediment. Heat flow values are not so high, but vary from place to place (82 ± 40 mW/m^2). An active hydrothermal venting (temperature as high as 220°C; open star in Fig. 3) was discovered on the flank area of the ridge by a "Shinkai 2000" diving survey performed after this cruise (TANAKA *et al.*, 1989). The morphological and thermal situation around the Iheya Ridge is quite similar to that in the Yaeyama Central Knoll in the southern Okinawa Trough. Therefore, interstitial water circulation is expected to be occurring beneath and around the Iheya Ridge. The recharge process in the surrounding area could bear low and scattered heat flow.

We made thirteen heat flow measurements in the eastern basin and one (station "100HFK5") in the Natsushima-84 Deep. The obtained heat flow values in the eastern basin were very high and scattered (710 ± 690 mW/m^2), similar to the values in the Natsushima-84 Deep to the west (590 ± 440 mW/m^2). These data and hydrothermal vent activity at the Iheya Ridge indicate that the high heat flow anomaly zone extends along the axis. Especially in the western part of this eastern basin we obtained a heat flow value as high as 2800 mW/m^2 (station "99HFM-B"). Although only three sensors were in the sediment (see appendix), the temperature versus depth profile at this station seemed to be slightly concave upward as observed in the Natsushima-84 Deep (YAMANO *et al.*, 1986b). This profile may be caused by a downward water flow into the sediment.

3.4. Area 2: Izena Cauldron (Fig. 4)

The Izena Cauldron, having about 4 km in diameter and 1600 to 1650 m in water depth on the flat area, is located about 35 km to the south of the central axis, and anomalously high temperature gradient (5.6 deg/m) had been found on a central small knoll by a "Shinkai 2000" diving survey (open star in Fig. 4b; KATO *et al* ., 1989).

We obtained fifteen heat flow values on the flat area within the Izena Cauldron, and six to the west of it. Results are presented in Figs. 4a and 4b. The heat flow within the cauldron is high and variable (360 ± 220 mW/m^2), similar to the Iheya Deep area. It should be noticed that the heat flow within the cauldron tends to increase toward the northeastern wall (from about 100 mW/m^2 up to about 900 mW/m^2), and that we found massive sulfide deposits on that wall by sea floor observations, dredge hauls, and TV-grab samplings during this cruise (HALBACH *et al.*, 1989a). These may indicate that the heat source for hydrothermal deposits causes a thermal influence on the flat area.

On outside the cauldron to the west, the heat flow values are lower, around 150 mW/m^2, as compared with those measured inside (Fig. 4a). However, at the westernmost station it varies from 115 to 320 mW/m^2, possibly related to another hydrothermal activity.

4. Conclusions

A detailed heat flow survey was carried out in and around some ridges and basins in the southern and middle Okinawa Trough by R/V Sonne in 1988 in order to clarify characteristics of local thermal anomalies related to the hydrothermal circulation.

Heat flow values around the Yaeyama Central Knoll at the axis of the southern Okinawa Trough are less than 50 mW/m^2 and variable, implying the recharge of hydrothermal activity around the knoll. However, the hydrothermal vent activity on the knoll has not been confirmed. A more widely spread survey around the knoll is necessary for delineating the heat flow distribution and the thermal influence of the knoll.

In the Iheya Deep area, middle Okinawa Trough, the heat flow in the small basin east of the Natsushima-84 Deep shows a high and scattered distribution (710 ± 690 mW/m^2), similar to the Natsushima-84 Deep. This suggests that strong hydrothermal activity is occurring along the axis. However, the extent of this heat flow anomaly away from the axis, which is necessary for geophysical modeling of the hydrothermal circulation around the axial part, still remains unknown.

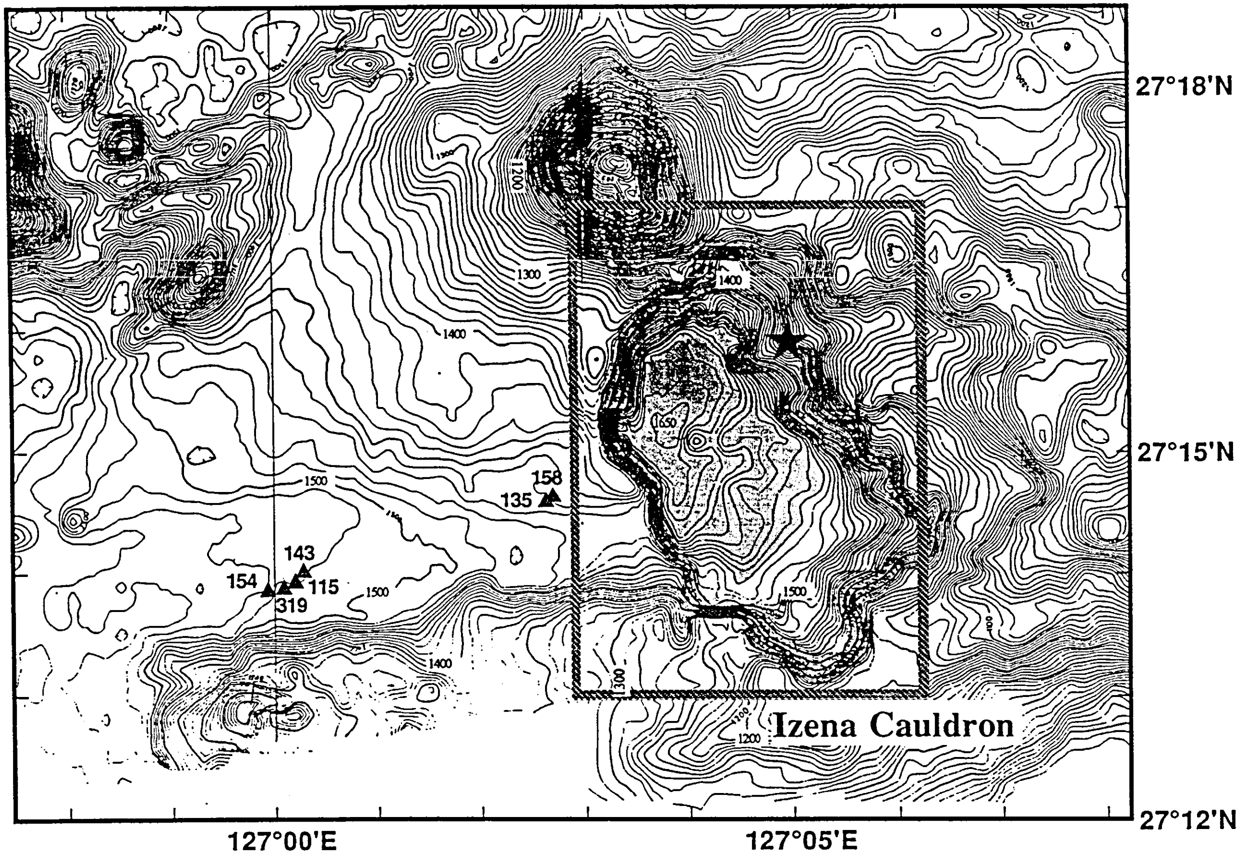


Fig. 4. (a) Heat flow results around the Izena Cauldron plotted on a Sea Beam map (OSHIMA *et al.*, 1988). Contour interval is 10 m. The extent of this map corresponds to the hatched box in Fig. 3. Units of mW/m^2. The star represents the location of the ore deposits. Heat flow values in the cauldron (shaded area) are not shown.

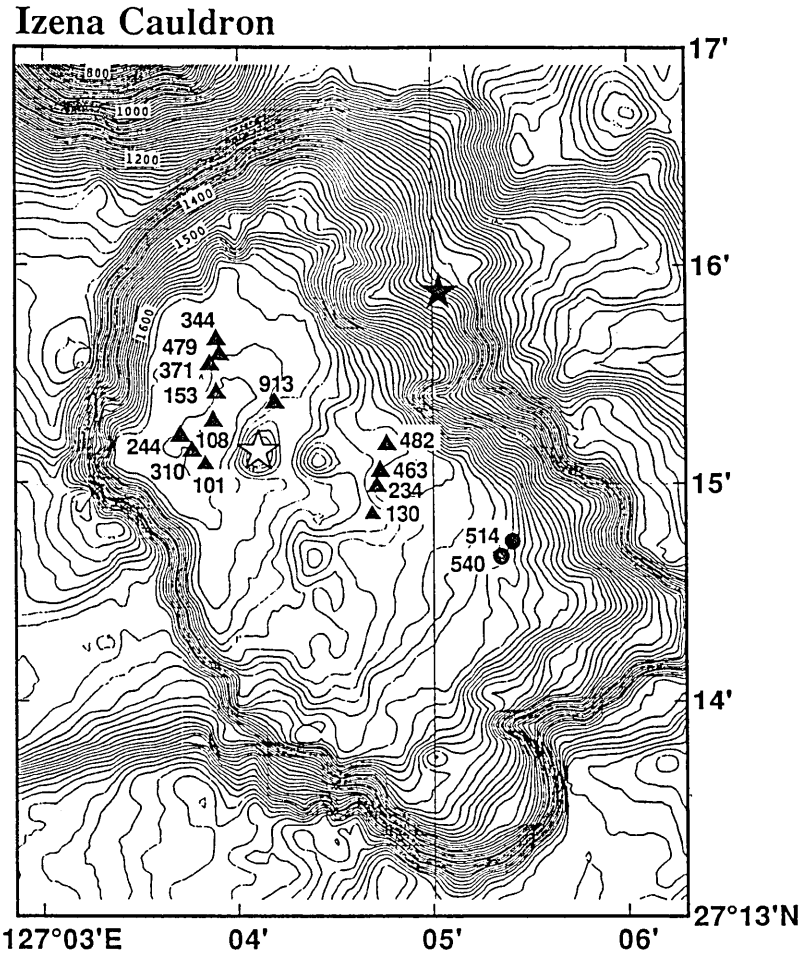


Fig. 4(b) Heat flow distribution in the rectangular area in Fig. 4a. Triangles : cruise SO56 ; circles : cruise KT88-17. Solid star : location of ore deposits; open star; location of high geothermal gradient (5.6 deg/m ; KATO *et al.*,1989).

The heat flow in the Izena Cauldron is scattered and high (360±220 mW/m^2) and increases toward the northeastern wall of the cauldron, where hydrothermal ore deposits were discovered during this cruise. Then, the heat flow distribution just around the ore deposits on the wall is vital for depicting the image of the ore body and related hydrothermal circulation. Also, a comprehensive survey in other depressions in the middle Okinawa Trough is necessary to understand the origin of the heat flow anomaly in backarc regions.

Acknowledgements

We are grateful for the efficient cooperation of the crew and scientific party of R/V Sonne. We are also obliged to the Geological Survey of Japan for arranging this cruise. We would like to thank the crew of R/V Tansei-Maru and the director Hitoshi Sakai for providing us a chance for the heat flow measurement. The Japanese part of the operation was partially supported by Grant-in-Aid No. 60420013 of the Ministry of Education, Science and Culture, Japan and Dynamics and Evolution of the Lithosphere Project (DELP).

References

GERARD, R., LANGSETH, M.G., Jr. and EWING, M., 1962, Thermal gradient measurements in the water and bottom sediments of the western Atlantic, *J. Geophys. Res.*, 67, 785-803.

HALBACH, P., NAKAMURA, K., WAHSNER, M., LANGE, J., SAKAI, H., KASELITZ, L., HANSEN, R.-D., YAMANO, M., POST, J., PRAUSE, B. SEIFERT, R., MICHAELIS, W., TEICHMANN, F., KINOSHITA, M., MÄERTEN, A., ISHIBASHI, J., CZERWINSKI, S. and BLUM, N., 1989a, Probable modern analogue of Kuroko-type massive sulfide deposits in the Okinawa Trough back-arc basin, *Nature*, 338, 496-499.

HALBACH, P., WAHSNER, M., LANGE, L., KASELITZ, L., HANSEN, R.-D., POST, J., PRAUSE, B., SEIFERT, R., TEICHMANN, F. and MÄRTEN, A., 1989b, First Interim Report of the Research Project 03R 386A (HYDROMIN I; SO56), German Ministry for Research and Technology.

HARTLINE, B.K. and LISTER, C.R.B., 1981, Topographic forcing of supercritical convection in a porous medium such as the ocean crust, *Earth Planet. Sci. Lett.*, 55, 75-86.

HYDROGRAPHIC DEPARTMENT OF JAPAN MARITIME SAFETY AGENCY, 1987, Data Report of Hydrographic Observation, *Ser. Continental Shelf Survey*, No. 3.

KATO, Y., NAKAMUYA, K., IWABUCHI, Y., HASHIMOTO, J. and KANEKO, Y., 1989, Geology and topography in the Izena Hole of the middle Okinawa Trough—the results of diving surveys in 1987 and 1988—, *JAMSTECTR Deepsea Research*, 163-182 (in Japanese with English abstract).

KATSURA, T., OSHIMA, S., OGINO, T., IKEDA, K., NAGANO, M., UCHIDA, M., HAYASHIDA, M., KOYAMA, K. and KASUGA, S., 1986, Geological and geophysical characteristics of the southwestern Okinawa Trough and adjacent area, *Rept. Hydrographic Res.*, 21, 21-47 (in Japanese with English abstract).

KIMURA, M., UYEDA, S., KATO, Y., TANAKA, T., YAMANO, M., GAMO, T., SAKAI, H., KATO, S., IZAWA, E. and OOMORI, T., 1988, Active hydrothermal mounds in the Okinawa Trough backarc basin, Japan, *Tectonophysics*, 145, 319-324.

LETOUZEY, J. and KIMURA, M., 1986, The Okinawa Trough: Genesis of a back-arc basin developing along a continental margin, *Tectonophysics*, 125, 219-241.

LU, R.S., PAN, J.J. and LEE, T.C. 1981, Heat flow in the southwestern Okinawa Trough, *Earth Planet. Sci. Lett.*, 55, 299-310.

OSHIMA, S., TAKANASHI, M., KATO, S., UCHIDA, M., OKAZAKI, I., KASUGA, S., KAWASAKI, C., KANEKO, Y., OGAWA, M., KAWAI, K., SETA, H. and KATO, Y., 1988, Geological and geophysical survey in the Okinawa Trough and the adjoining seas of Nansei

Syoto, *Rept. Hydrographic Res.*, 24, 19-43 (in Japanese with English abstract).

SIBUET, J.-C., LETOUZEY, J., BARBIER, F., CHARVET, J., FOUCHER, J.P., HILDE, T.W.C., KIMURA, M., LING-YUN, C., MARSSET, B., MULLER, C. and STEPHAN, J.-F., 1987, Back are extension in the Okinawa Trough, *J. Geophys. Res.*, 92, 14041-14063.

TANAKA, T., MITSUZAWA, K. and HOTTA, H., 1989, "Shinkai 2000" diving surveys in the east of Iheya Small Ridge in the central Okinawa Trough, *JAMSTECTR Deepsea Research*, 267-281 (in Japanese with English abstract).

von HERZEN, R.P. and MAXWELL, A.E., 1959, The measurement of thermal conductivity of deep-sea sediments by a needle-probe method, *J. Geophys. Res.*, 64, 1557-1563.

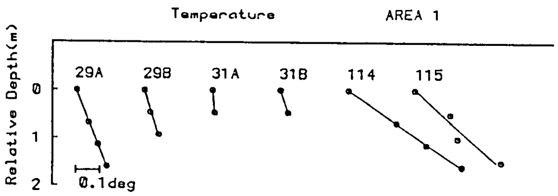
YAMANO, M., UYEDA, S., FURUKAWA, Y. and Ali DEHGHANI, G., 1986a, Heat flow measurements in the northern and middle Ryukyu Arc area on R/V SONNE in 1984. *Bull. Earthq. Res. Inst.*, 61, 311-327.

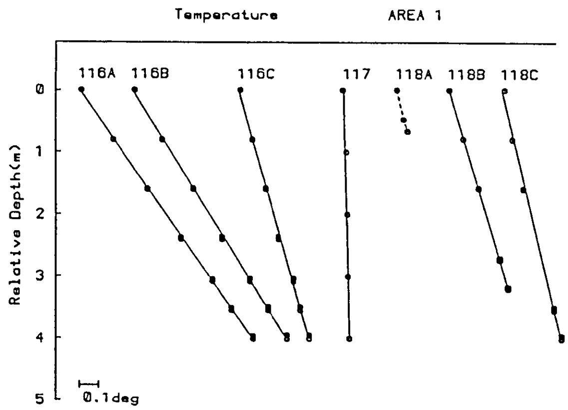
YAMANO, M., UYEDA, S., KINOSHITA, H. and HILDE, T.W.C., 1986b, Report on DELP 1984 cruises in the middle Okinawa Trough, Part IV: Heat flow measurements, *Bull. Earthq. Res. Inst.*, 61, 251-267.

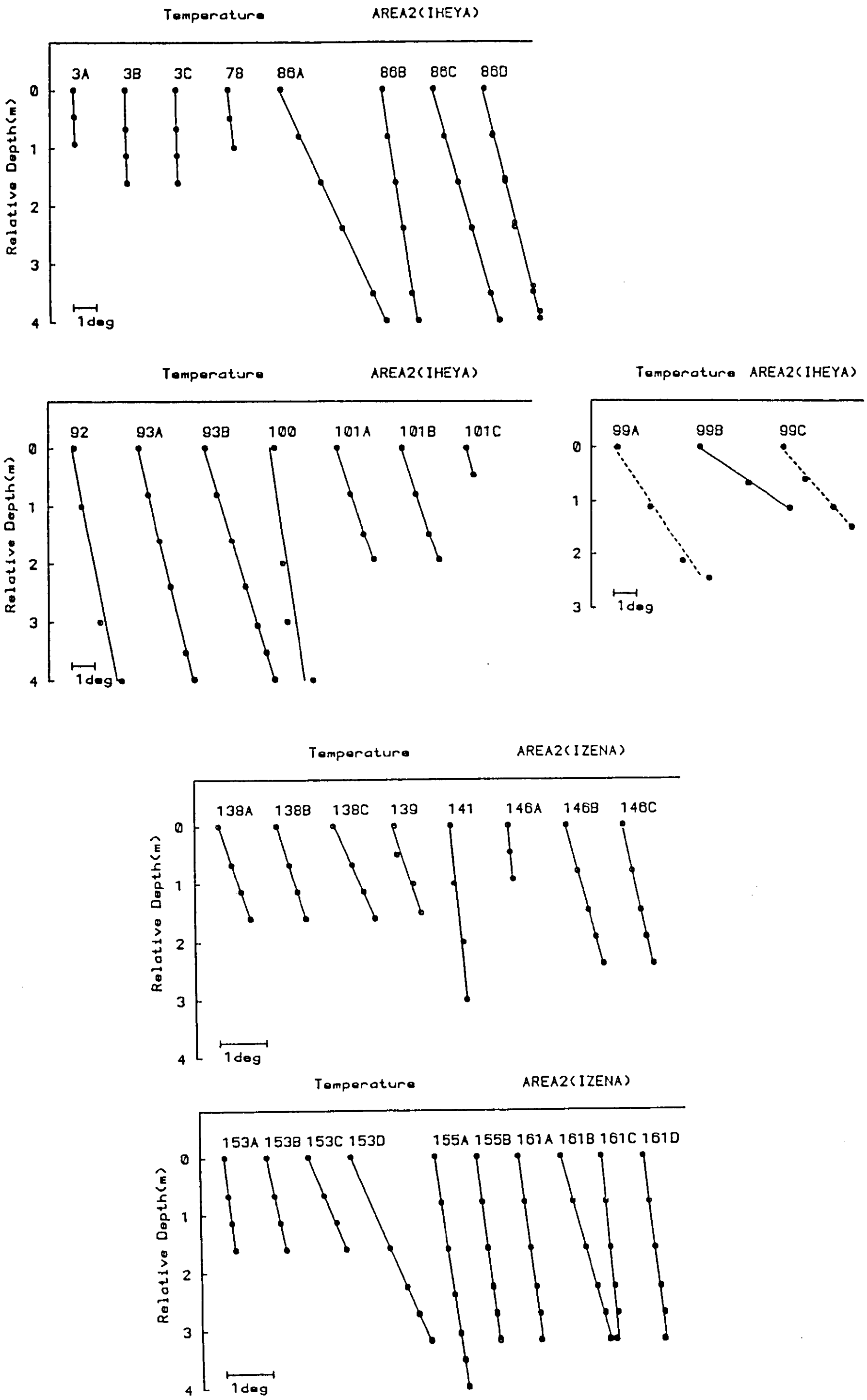
YAMANO, M., UYEDA, S., FOUCHER, J.-P. and SIBUET, J.-P., 1989, Heat flow anomaly in the middle Okinawa Trough, *Tectonophysics*, 159, 307-318.

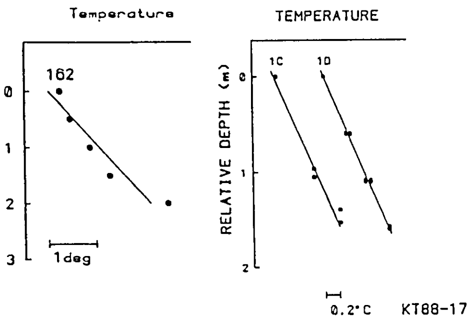
Appendix

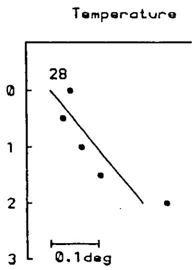
Temperature versus depth profiles obtained during cruises SO56 and KT88-17. Data are presented after sorted according to their belonging areas.

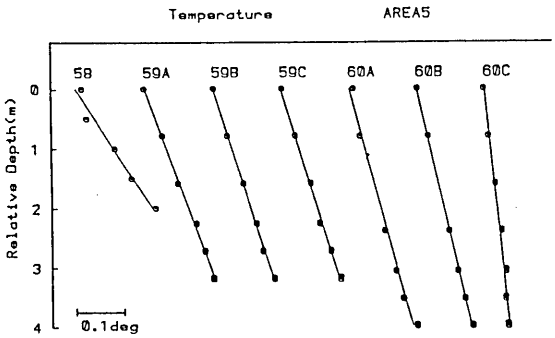


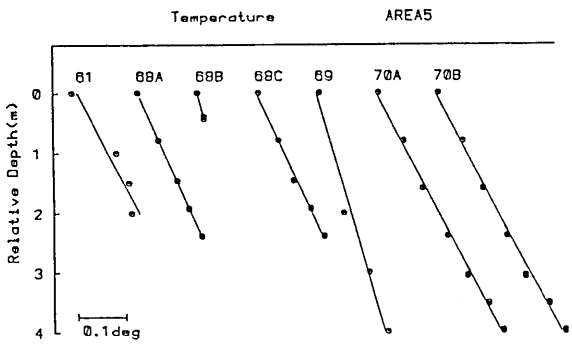



Temperature AREA2(IHEYA)
3A 3B 3C 78 86A 86B 86C 86D
Relative Depth(m)
0 1 2 3 4
1deg
Temperature AREA2(IHEYA)
92 93A 93B 100 101A 101B 101C
Relative Depth(m)
0 1 2 3 4
1deg
Temperature AREA2(IHEYA)
99A 99B 99C
0 1 2 3
1deg
Temperature AREA2(IZENA)
138A 138B 138C 139 141 146A 146B 146C
Relative Depth(m)
0 1 2 3 4
1deg
Temperature AREA2(IZENA)
153A 153B 153C 153D 155A 155B 161A 161B 161C 161D
Relative Depth(m)
0 1 2 3 4
1deg


Temperature
162
0
1
2
3
1deg
TEMPERATURE
RELATIVE DEPTH (m)
1C
1D
0
1
2
0.2°C
KT88-17


Temperature
28
0
1
2
3
0.1deg


Temperature
AREA5
Relative Depth(m)
58
59A
59B
59C
60A
60B
60C
0
1
2
3
4
0.1deg


Temperature
AREA5
Relative Depth(m)
61
68A
68B
68C
69
70A
70B
0
1
2
3
4
0.1deg

1988年 Sonne 号航海による南部・中部沖縄トラフでの地殻熱流量測定

東海大学海洋学部　木下正高
東京大学地震研究所　山野　誠
Preussag 社　J. POST
Clausthal 工科大学　P. HALBACH

1988年6月に行われた研究船 Sonne 号による航海において，南部・中部沖縄トラフでの地殻熱流量測定を行った。本航海では，以下に示すようないくつかの小区域において，シービームによる地形調査，OFOS（海底曳航式 TV・カメラ）による海底観察，ドレッジ・グラブ・ボックスコアラーによる採泥調査，採水およびマルチゾンデによる地球化学的観測，地殻熱流量測定が詳細に行われ，背弧海盆における熱水活動とそれに伴う熱水性鉱床の探索がなされた．

南部沖縄トラフの八重山中央海丘周辺の海盆で得られた13点での熱流量は，すべて 60 mW/m^2 以下の低い値を示した。これは海丘を discharge とした熱水循環系を考えた場合に，海丘に隣接したこの海盆では海水がしみこんでいるためと考えられるが，その直接的証拠はまだみつかっていない．中部沖縄トラフでは，伊平屋海凹・伊是名海穴などで調査を行った．伊平屋海凹では1984年の Sonne 号航海などで高熱流量が発見されている「なつしま—84海凹」の東に接する中軸部の小海盆で熱流量測定を行い，同様の高熱流量を得た (710±690 mW/m^2)．伊是名海穴内では，本航海後に行われた淡青丸による KT88-17 航海での値も含め，350 mW/m^2 程度の高い熱流量が得られ，またそれが海穴の北東側の壁に向かって高くなる傾向を示した．これはこの方向に何か熱いものが存在することを示唆したが，実際本航海中熱水のでている現場を確認し，硫化物鉱床とみられる試料を得た．