Bulletin of the Earthquake
Research Institute
University of Tokyo
Vol. 61 (1986) pp. 311-327

Heat Flow Measurements in the Northern and Middle Ryukyu Arc Area on R/V SONNE in 1984

Makoto Yamano, Seiya Uyeda, Yoshitsugu Furukawa
Earthquake Research Institute, University of Tokyo
and
G. Ali Dehghani
Institute of Geophysics, University of Hamburg

(Received April 18, 1986)

Abstract

Multiple penetration heat flow measurements were made using Ewing type and violin bow type instruments on the cruise of R/V SONNE in 1984. The studied areas are the Ryukyu Trench between the Kyushu-Palau Ridge and the Amami Plateau, the northernmost part of the Okinawa Trough, and the middle Okinawa Trough around 127°E. In the Ryukyu Trench area, the heat flow is 50 to 65 mW/m^2 near the trench axis and it seems to be lower on the landward wall. The heat flow could not be determined in the northern Okinawa Trough, because the temperature profiles were very non-linear probably due to variations in the bottom water temperature. In the middle Okinawa Trough, extremely high heat flow values were observed in a depression called the Natsushima-84 Deep located in the central rift region. Combined with the results of the DELP-84 WAKASHIO cruise, the average of heat flow in the depression is about 500 ± 400 mW/m^2. The very high and variable heat flow, as well as non-linear temperature profiles, suggest the existence of hydrothermal activity. North and south of the Natsushima-84 Deep the obtained heat flow values were not so anomalous.

1. Introduction

A detailed geophysical study was carried out in the northern and middle Ryukyu arc area on two legs of the German R/V SONNE in September and October, 1984 as a Japan-Germany cooperative research. On the first leg, an extensive seismic survey was made along the two lines, parallel and perpendicular to the Ryukyu arc (P1 and P2 in Fig. 1), with a large number of ocean bottom seismometers, air-guns, and explosives. On the second leg, heat flow surveys were made together with gravity and geomagnetic total force measurements.

The heat flow measurements on this cruise had two main objectives.

One was to take heat flow profiles along the two lines, P1 and P2. The results may be combined with the seismic, gravity, and magnetic data to give a thermal structure model beneath the Ryukyu arc. The other objective was to obtain more heat flow data in and around a depression tentatively called "the Natsushima-84 Deep" which lies in the Iheya Deep, the central rift zone of the middle Okinawa Trough (point A in Fig. 1). Extremely high heat flows (400 to 1600 mW/m^2) were measured in this depression on the DELP-84 WAKASHIO cruise in August and September of the same year (YAMANO *et al.*, 1986). We intended to confirm

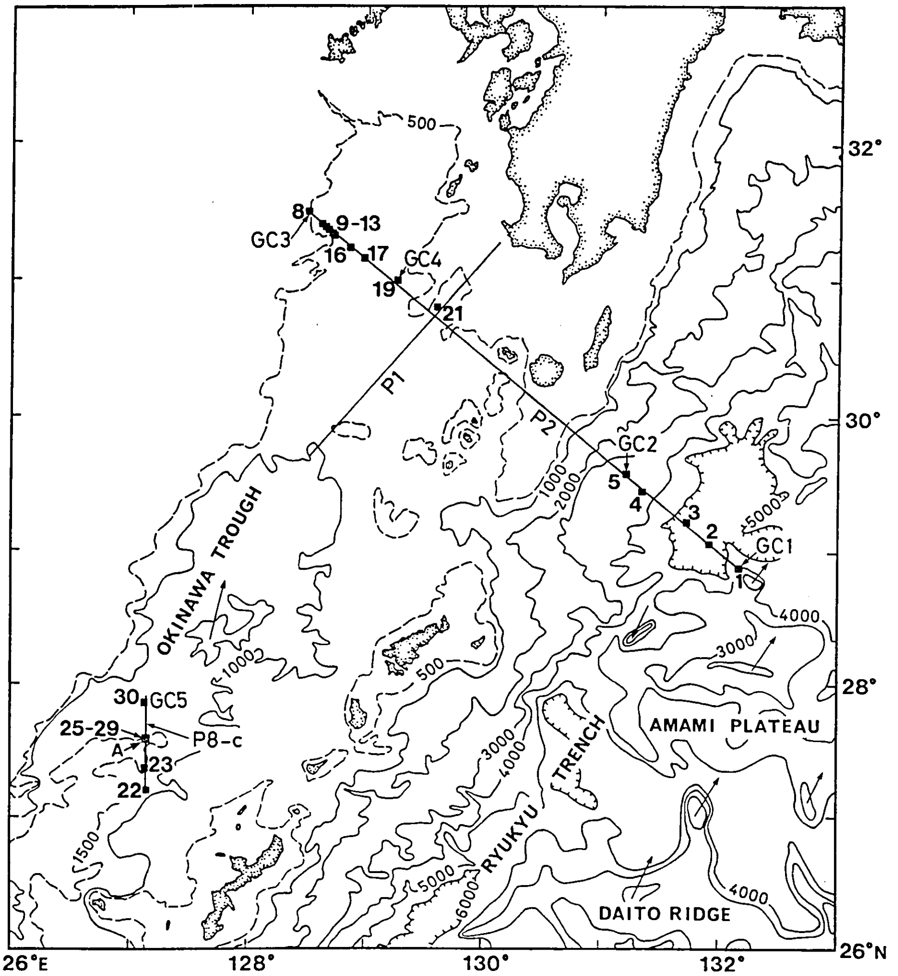


Fig. 1. Locations of heat flow (1 to 30) and gravity core (GC1 to GC5) stations. Solid lines (P1, P2 and P8-c) are profiles along which heat flow measurements were attempted. Point A shows the location of the Natsushima-84 Deep. Depth in meters. Arrows mean topographic high.

the existence of the extremely high heat flow area and delineate its areal extent. Thus, measurements were made in the depression and along a north-south profile across the depression (P8-c in Fig. 1).

2. Locations of Heat Flow Measurements

The positions of the heat flow stations were selected on 3.5 kHz subbottom profiler records. We attempted 67 penetrations at 32 stations

Table 1. Results of heat flow measurements.

Station	Latitude N	Longitude E	D m	PEN m	N	G mK/m	K W/m K	Q mW/m^2
Ryukyu Trench Area								
SONNE84-1A	28°53.1'	132°10.1'	4840	1.7	3	32	0.89	29
1B	28°52.8'	132°10.1'	4870	2.0	2	(42)	0.89	(37)
2A	29°03.9'	131°54.7'	5640	4.8	5	66	0.77*	51
2B	29°03.9'	131°55.0'	5650	4.9	5	68	0.77*	52
3B	29°13.4'	131°43.0'	5100	0.9	2	(72)	0.80*	(58)
4A	29°27.7'	131°20.6'	3810	3.0	4	(41)	0.85*	(35)
4B	29°27.7'	131°20.6'	3800	2.7	4	(41)	0.85*	(35)
5A	29°35.0'	131°12.6'	3380	1.3	2	(68)	0.85	(58)
5B	29°35.0'	131°12.6'	3380	1.4	2	(65)	0.85	(56)
Shallow Sea Area								
SONNE84-8A	31°30.2'	128°29.9'	570		6			
8B	31°30.2'	128°29.9'	570		6			
9	31°19.9'	128°42.7'	670		6			
10	31°20.8'	128°41.7'	650		6			
11	31°22.2'	128°39.8'	600		6			
12	31°23.1'	128°38.6'	600		6			
13	31°24.6'	128°36.6'	590		6			
16A	31°14.3'	128°51.1'	690		4			
16B	31°14.3'	128°51.0'	680		4			
17A	31°09.7'	128°58.1'	680		3			
19A	30°59.7'	129°15.2'	790		5			
19C	31°00.1'	129°14.7'	790		5			
21	30°48.1'	129°35.1'	610		6			
Middle Okinawa Trough Area								
SONNE84-22	27°12.0'	127°09.2'	1440	5.1	6	138	0.88*	121
23A	27°21.8'	127°08.3'	1470	>4.1	6	38	0.88*	34
23C	27°22.0'	127°08.3'	1470	4.3	6	38	0.88*	34
25A	27°35.8'	127°08.2'	1760	3.3	4	1125	0.84	945
25B	27°36.0'	127°08.0'	1760	3.1	4	1108	0.84	931
25C	27°36.1'	127°07.9'	1750	2.5	4	1260	0.84	1058
26	27°35.8'	127°09.2'	1740	1.9	5	269	0.84	226
28C	27°35.4'	127°09.5'	1780	3.9	5	541	0.84	455
29A	27°35.3'	127°08.6'	1770	4.8	6	262	0.84	220
29B	27°35.4'	127°08.5'	1770	3.9	5	582	0.84	489
29C	27°35.5'	127°08.4'	1770	4.8	6	305	0.84	257
29D	27°35.6'	127°08.4'	1760	4.7	6	266	0.84	223
30A	27°51.3'	127°08.1'	1240	4.5	5	135	0.82	111
30B	27°51.4'	127°08.1'	1240	4.7	6	133	0.82	109

D is the water depth on the assumption that sound velocity is 1500 m/s; PEN is the estimated penetration of the lowermost active thermistor; N is the number of active thermistors in mud; G is the temperature gradient; K is the thermal conductivity (* represents values measured at nearby stations); Q is the heat flow. Values in parentheses are less reliable.

in three areas described below. Thirty six of the penetrations were successful. The main reason for failure was that the bottom was too hard for penetration. The successful stations are listed in Table 1 and shown in Fig. 1.

Stations SONNE 84-1 to 5 are located along the line P2 which perpendicularly crosses the Ryukyu Trench. Heat flow measurements were made on the seaward side of the trench between the Kyushu-Palau Ridge and the Amami Plateau, around the trench axis, and on the landward wall of the trench. Northwest of the trench slope break at a depth of about 2000 m the probe could not penetrate into the bottom due to coarse sediments.

SONNE 84-8 to 21 also lie along the profile P2, landward of the volcanic arc. This area is thought to be a northern end part of the Okinawa Trough where extensional tectonics is underway. The 3.5 kHz profiler records indicate that there are many normal faults and rift-like structures. Penetrations were made mainly around the possible rifts, expecting some thermal anomalies. Near the volcanic arc, the probes frequently bounced off. In the following, we term this area "the shallow sea area" since the water depths are shallower than 800 m.

In the middle Okinawa Trough we made measurements SONNE 84-22 to 30 along a north-south striking profile, P8-c, across the Natsushima-84 Deep where anomalously high heat flows had been obtained on the DELP-84 WAKASHIO cruise (Yamano *et al.*, 1986). Among SONNE 84-22 to 30 stations, SONNE 84-25 to 29 were taken within this depression. Penetrations failed in the central rift region except in the depression.

Along the profile P1, no successful stations were taken due to hard bottom and rough weather.

We took five gravity core samples, two in the Ryukyu Trench area, two in the shallow sea area, and one in the middle Okinawa Trough. Their locations are shown in Table 2 and Fig. 1.

Table 2. Thermal conductivity measurements.

Station	Latitude N	Longitude E	D m	LEN m	K W/m K
GC1(SONNE84-1)	28°53.3'	132°10.5'	4880	0.6	0.89±0.04
GC2(SONNE84-5)	29°35.0'	131°12.7'	3380	0.8	0.85±0.02
GC3(SONNE84-13)	31°24.6'	128°36.6'	600	1.3	0.81±0.02
GC4(SONNE84-19)	31°00 '	129°15 '	790	1.2	0.82±0.02
GC5(SONNE84-30)	27°51.7'	127°08.3'	1230	0.9	0.82±0.03

D is the water depth on the assumption that sound velocity is 1500 m/s; LEN is the length of the obtained core; K is the average thermal conductivity and the standard deviation.

3. Measurement Techniques

We mainly used a 4.5 m long Ewing type probe (GERARD *et al.*, 1962) for tempeature gradient measurements. It originally weighed about 450 kg, but 300 kg weights were added during the cruise. The electronics and pressure case of this system were made by Lamont-Doherty Geological Observatory of Columbia University. Digital temperature data of six thermistors and instrument tilt were recorded on a cassette magnetic tape and acoustically transmitted to the ship. We could monitor the data using the transducer of the ship for 12 kHz echo-sounder. The temperature resolution was about 0.001°C.

A violin bow type probe (HYNDMAN *et al.*, 1979), which was manufactured by the Applied Microsystems Ltd., was used only at one station (SONNE 84-26). It weighed about 120 kg and the length of the sensor tube was 2 m. Seven thermistors were equally spaced in the sensor tube and temperatures were recorded on a magnetic tape with a resolution of about 0.002°C.

Temperatures in the sediments were measured with reference to the water tempereture recorded just above the sea floor. In the Ryukyu Trench area and the middle Okinawa Trough, the accuracy of temperature difference among thermistors is estimated to be 0.001 to 0.002°C. In the shallow sea area (SONNE 84-8 to 21), vertical gradients in water temperature above the bottom are large, which result in relatively unstable records of water temperatures. Moreover, temperature variations along the probe due to vertical temperature gradients in the bottom water should be corrected. This correction increases error in temperature determination. Considering these factors, the accuracy of relative temperature in the shallow sea area varies from 0.003 to 0.01°C from station to station.

Temperature records in the sediments are extrapolated to the equilibrium assuming that temperature decay is described by a function described by BULLARD (1954). For the Ewing type probe, we used the inverse of time after penetration as an approximation of this function because the sensor tubes were very thin (3.5 mm in diameter). Although most of the temperature records can be fitted well to the reciprocal of time after penetration, anomalous variations of temperature were recorded at some stations. Temperature decreased for several minutes after the penetration, then increased. One possible explanation for such temperature variations is slow successive downward movements of the probe in the sediment. In such cases, errors in the equilibrium temperatures are larger. The total errors in the relative temperatures in the sediments generally range from 0.004 to 0.006°C, and in some cases, reach 0.01 to

0.02°C. In the shallow sea area, they are 0.005 to 0.02°C.

Thermal conductivities of the sediments were measured by the needle probe method (VON HERZEN and MAXWELL, 1959) on samples taken by a gravity corer. Corrections to in-situ conditions were made following RATCLIFFE (1960).

4. Results

All the obtained temperature versus depth profiles are shown in Fig. 2. The profiles in the shallow sea area (Figs. 2(b) and 2(c)) are clearly affected by temporal changes in the bottom water temperature. It is not possible to calculate reliable heat flow values from these profiles without sufficient hydrographic data.

Most of the temperature profiles measured in the Ryukyu Trench area and in the middle Okinawa Trough are linear (Figs. 2(a), (d), (e), (f)). Temperature gradients were calculated by the least squares fit to a straight line and presented in Table 1. Solid lines in Fig. 2 show the best fit lines. The penetration depth in Table 1 was estimated from the temperature profiles and bottom water temperatures. In the cases of SONNE 84-25A, 25B, and 29B, the probe penetrated to a depth of more than 4.5 m, but the temperature of one or two thermistors was higher than the instrument could record due to very high temperature gradient. As a consequence, the temperature data of these thermistors were not available.

Thermal conductivities measured on gravity core samples are plotted against depth in Fig. 3. There seem to be no significant variations in conductivity with depth. The means and the standard deviations for each core are given in Table 2. The mean values were used in heat flow calculations. At SONNE 84-25 to 29, we used the conductivity value measured on the core taken in the Natsusnima-84 Deep on the DELP-84 WAKASHIO cruise. At the stations where no core samples were taken, the conductivities were estimated from the values for samples cored in the vicinity.

Heat flow values in Table 1 were calculated simply by multiplying the best fit linear temperature gradients by thermal conductivities. We estimate the accuracy of the heat flow values to be about 18% where the temprature profiles are linear. The accuracy is lower where the profiles are non-linear or the temperature gradients are determined from the readings of only two thermistors.

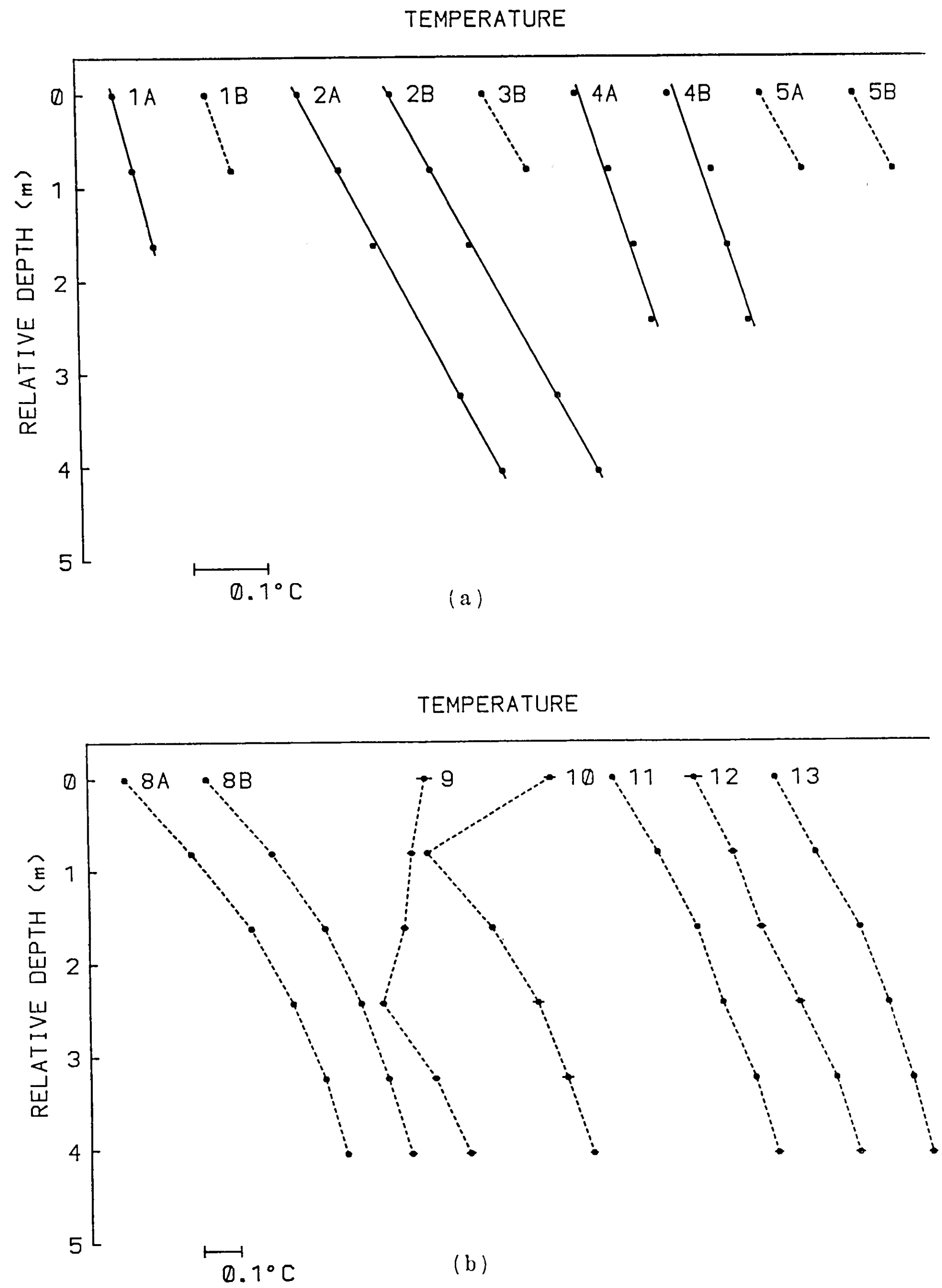
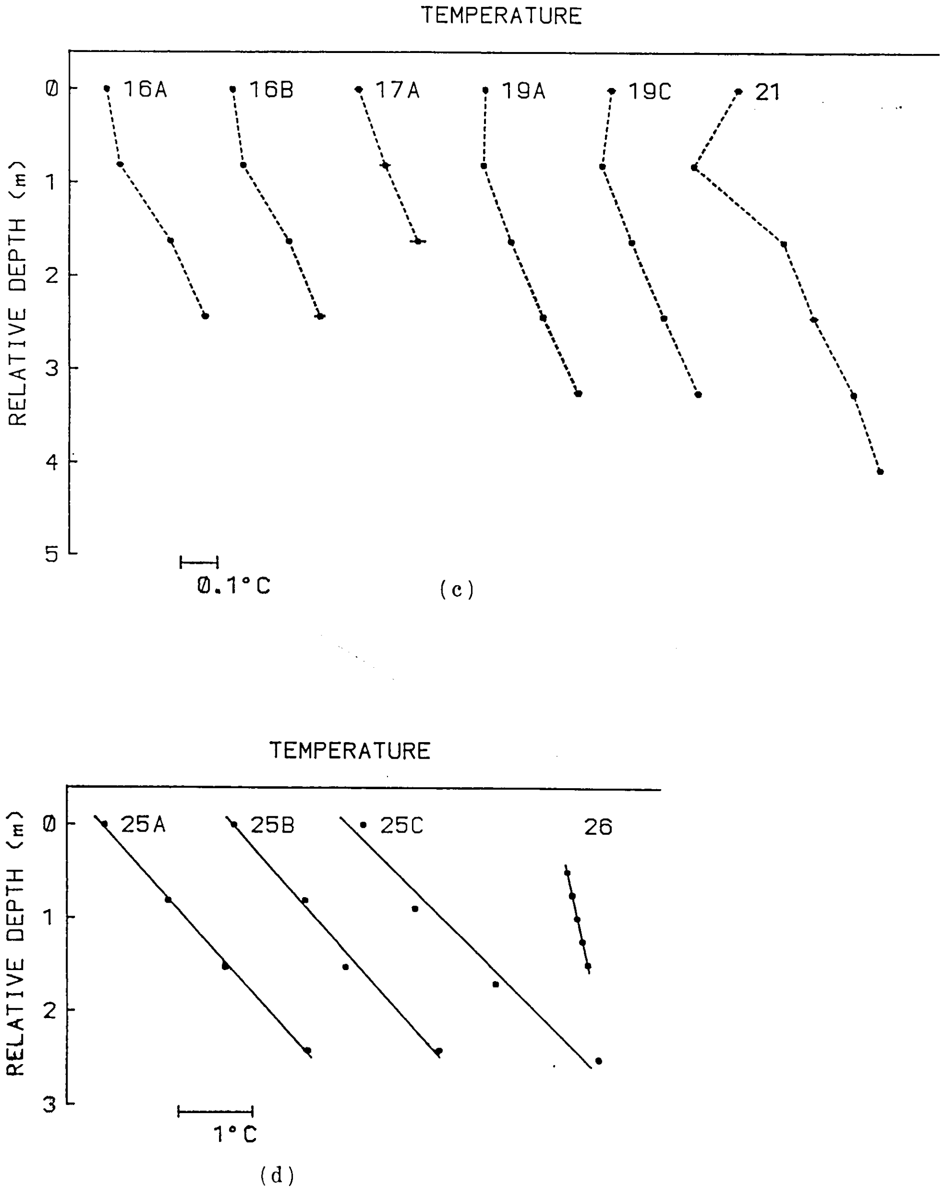

TEMPERATURE
RELATIVE DEPTH (m)
0
1
2
3
4
5
1A
1B
2A
2B
3B
4A
4B
5A
5B
0.1°C
(a)
TEMPERATURE
RELATIVE DEPTH (m)
0
1
2
3
4
5
8A
8B
9
10
11
12
13
0.1°C
(b)

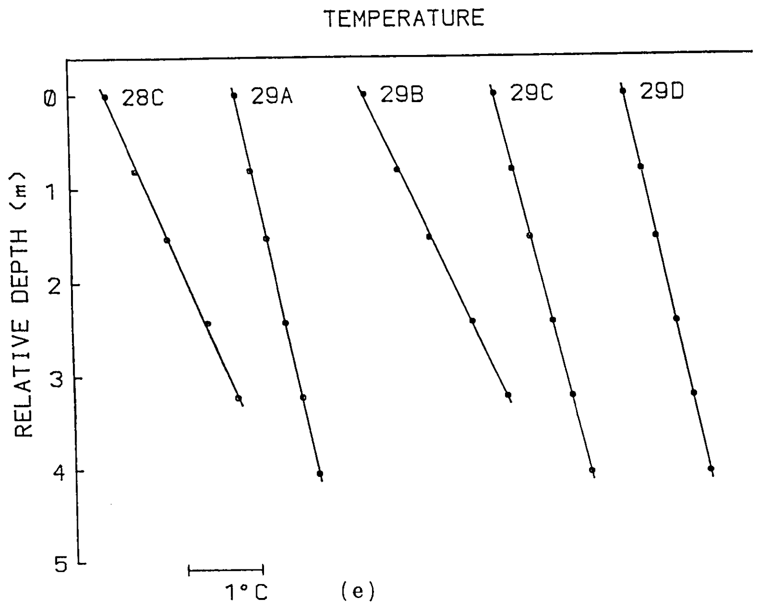
Fig. 2.


TEMPERATURE
RELATIVE DEPTH (m)
0
1
2
3
4
5
16A
16B
17A
19A
19C
21
0.1°C
TEMPERATURE
RELATIVE DEPTH (m)
0
1
2
3
25A
25B
25C
26
1°C

(c)

(d)

Fig. 2.



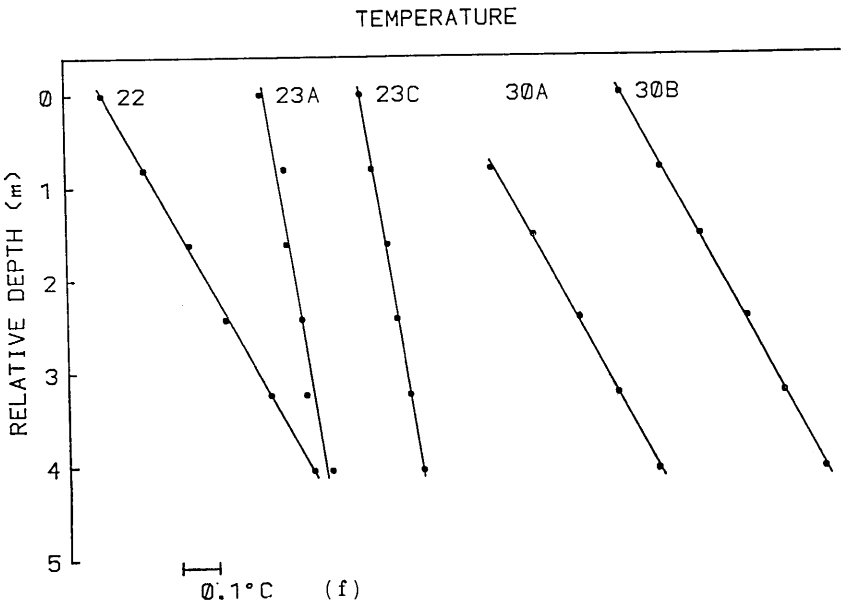


Fig. 2. Temperature versus depth profiles. Solid lines are the least squares fits by straight lines. (a) Ryukyu Trench area; (b) shallow sea area (I); (c) shallow sea area (II); (d) middle Okinawa Trough (Natsushima-84 Deep I); (e) middle Okinawa Trough (Natsushima-84 Deep II); (f) middle Okinawa Trough (outside the Natsushima-84 Deep).

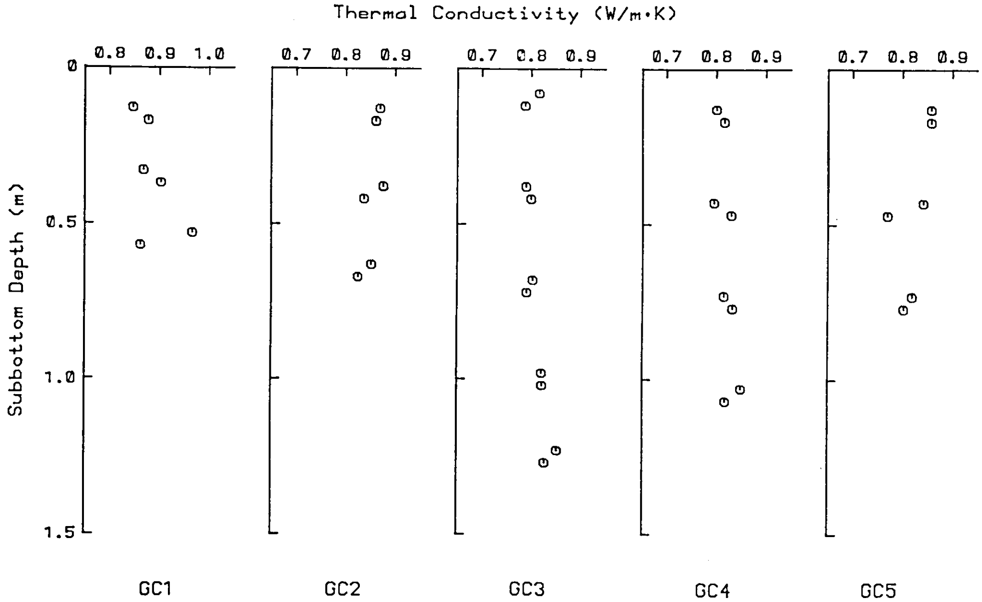


Fig. 3. Thermal conductivity versus depth measured on gravity core samples.

5. Non-linear Temperature Profiles

There are a number of possible mechanisms for observed non-linear temperature profiles. Three of them appear worth being considered here. They are; (1) vertical pore water flow through the sediments, (2) changes in the bottom water temperature, and (3) changes in thermal conductivity with depth.

Pore water advection is a plausible mechanism in the Okinawa Trough, as hydrothermal circulations have been observed in many young ocean basins. We follow the formulation by BREDEHOEFT and PAPADOPULOS (1965). Assuming that the flow of heat and fluid is vertical and steady, the tempeture variation with depth is expressed as

$$T(z)=(T_L-T_U)\frac{e^{\beta z/L}-1}{e^{\beta}-1}+T_U \qquad (1)$$

where $T(z)$ is measured relative to the bottom water temperature;

z=depth from the uppermost thermistor in the sediment;

T_L=temperature of the lowermost thermistor;

T_U=temperature of the uppermost thermistor in the sediment;

$\beta=v\rho CL/k$;

v=flow rate of the fluid (positive downward);

ρ=density of the fluid;

C=specific heat of the fluid;
k=thermal conductivity of the sediment;
L=vertical distance between the lowermost and uppermost thermistors in the sediment.

The sum of conductive heat flow and and advective heat flow gives the total heat flow

$$Q=k\frac{dT}{dz}-v\rho CT(z) \tag{2}$$

Substituting (1) into (2),

$$Q=\frac{k\beta}{L}\left(\frac{T_L-T_U}{e^{\beta}-1}-T_U\right) \tag{3}$$

We can also calculate the flow rate of pore water as

$$v=k\beta/(\rho CL) \tag{4}$$

The temperature profiles of SONNE 84-25A, 25C, 30A, and 38B were fitted to (1) by the method of the least squares. The best fit curves are shown in Fig. 4. The obtained total heal heat flow and flow rate are presented in Table 3.

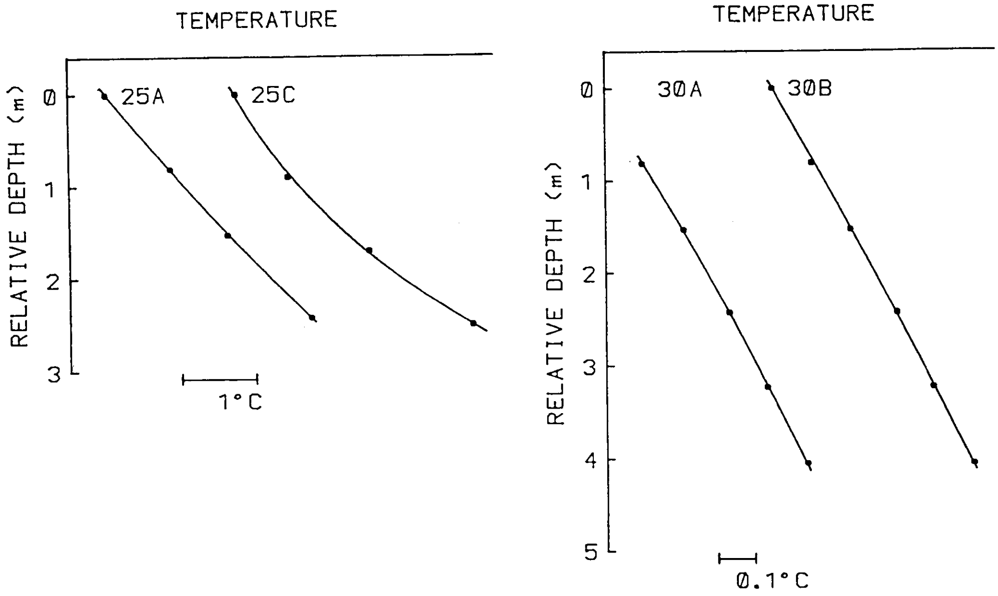


Fig. 4. Non-linear temperature profiles fitted to the pore water advection model.

Table 3. Heat flow estimated from non-linear temperature profiles.

Station	Pore Water Advection		Bottom Water Temperature Change				Conductivity Variation	
	Q mW/m^2	V 10^{-8}m/s	T mK	t days	G mK/m	Q mW/m^2	G mK/m	Q mW/m^2
SONNE84-4A	64	-8.8	-58	29	22	19		
4B	80	-14.0	-34	1	34	29		
25A	756	2.1						
25C	581	9.0						
30A	133	-1.3	-78	24	129	106	153	125
30B	118	-0.6	-71	201	121	99	131	107

Q is the heat flow calculated based on each model; V is the vertical water flux (positive downward); T is the amount of temperature change; t is the time since the change occurerd; G is the geothermal gradient.

The non-linear profiles at SONNE 84-4A and 4B can also be fitted to the pore water advection model (Table 3). The best fit values for flow rate are very high, but these high values may be possible as venting of pore water has been found on landward walls of several trenches (e.g. MOORE *et al.*, 1984). It is also likely, however, that these non-linear profiles are caused by changes in the bottom water temperature. A step change of T gives the temperature distribution (CARSLAW and JAEGER, 1959)

$$T(z)=Gz+\Delta T\operatorname{erfc}\left(\frac{z}{2(\kappa t)^{1/2}}\right) \qquad (5)$$

where z=depth from the sea floor;
G=undisturbed geothermal gradient;
κ=thermal diffusivity of the sediment;
t=time since the change occurred.

κ can be estimated from k using the relation derived by HYNDMAN *et al.* (1979). The results of the least squares fitting are shown in Fig. 5 and Table 3. The degrees of uncertainty of the parameters are high since they are determined from only four temperature-depth data points. The non-linearity of SONNE 84-30A and 30B might also be a result of changes in the bottom water temperature (Table 3). It is difficult to explain the profiles of 25A and 25C by this mechanism because the necessary amounts of temperature changes are too large (about 0.6°C and 1.7°C respectively) and linear temperature profiles are observed in the same depression.

We measured thermal conductivities of the sediments on gravity cores up to only 1 m length in the Ryukyu Trench and the Okinawa

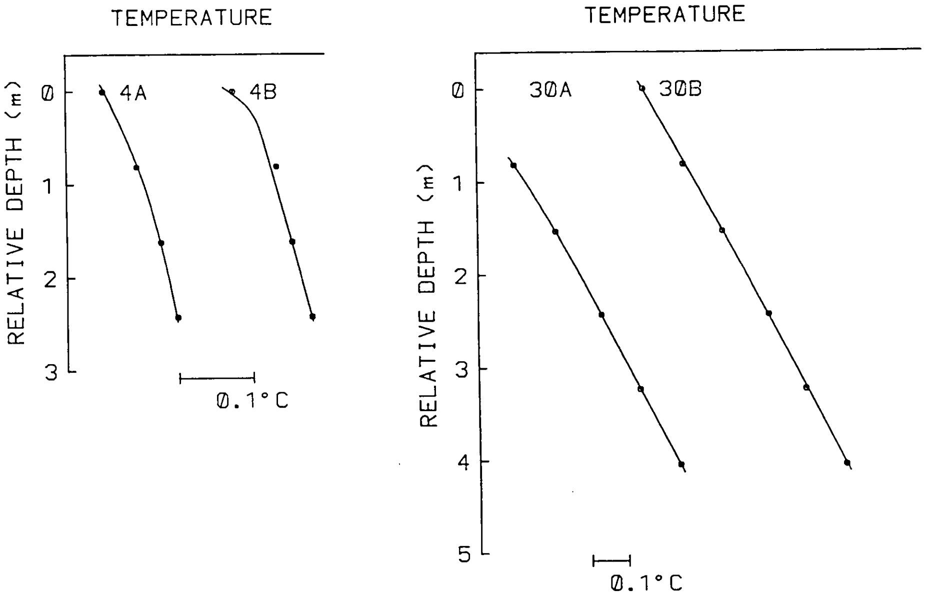


Fig. 5. Non-linear temperature profiles fitted to the bottom water temperature change model.

Trough areas. Therefore, there is a possibility that the conductivity may change in deeper layers. If this is the case, the uppermost temperature gradients should be used in heat flow calculations. Heat flow values calculated in this way are listed in Table 3 for SONNE 84-30A and 30B. The changes in temperature gradients of 4A and 4B are more than 100% and too large to be explained by conductivity variations. In the Natsushima-84 Deep, this mechanism does not seem to be preferable as linear profiles have also been observed.

The temperature profiles of SONNE 84-23A and 25C are anomalously bent. Similar profiles were observed in the Mariana Trough (HOBART *et al.*, 1979; ANDERSON *et al.*, 1986). It seems that heat transfer at these stations may be in a non-steady state or there might be lateral water flow.

6. Heat Flow Distributions

Fig. 6 shows the heat flow data around the studied area. The values obtained on this cruise and the DELP-84 WAKASHIO cruise are plotted together with the former results (YOSHII, 1979 (compilation); ANDERSON *et al.*, 1978; HERMAN *et al.*, 1978; EHARA, 1984; Y. MATSUBARA, unpublished; and K. SEKIGUCHI, unpublished). We used the heat flow values determined

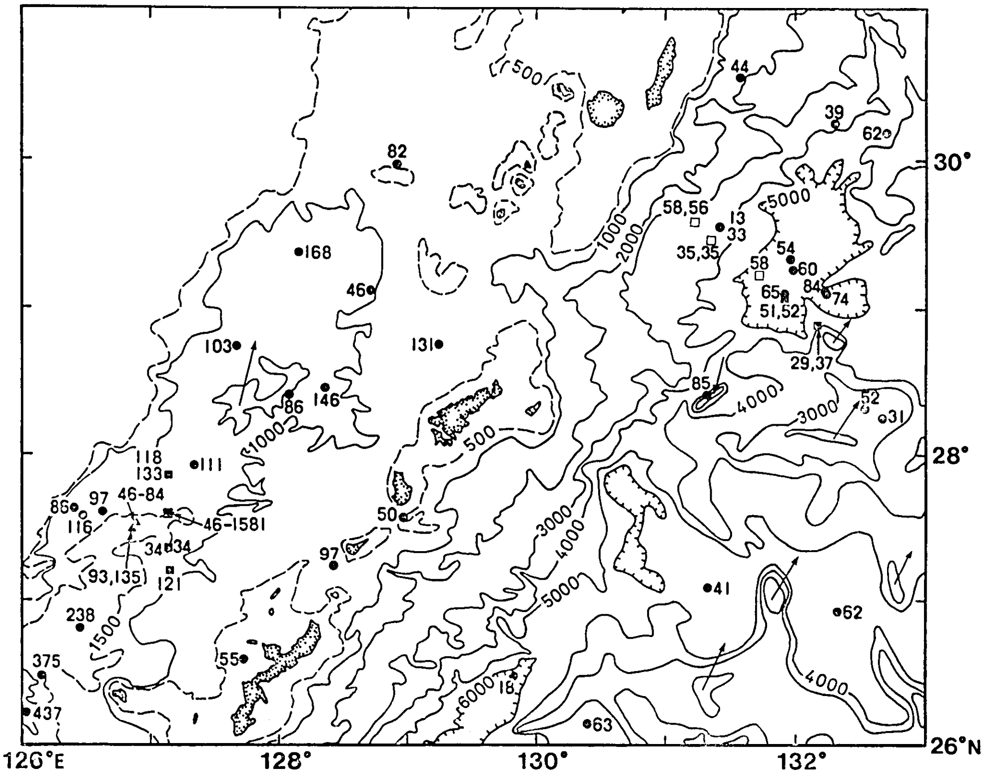


Fig. 6. Heat flow data around the studied area (in mW/m²). Circles represent previous results, squares the measurements on this cruise (open squares are values with low reliability), and triangles the measurements on the DELP-84 WAKASHIO cruise (YAMANO *et al.*, 1986). The sources of previous data are YOSHII (1979), ANDERSON *et al.* (1978), HERMAN *et al.* (1978), and EHARA (1984). Unpublished data by Y. MATSUBARA and K. SEKIGUCHI are also plotted. Depth in meters. Arrows mean topographic high.

by the pore water advection model for SONNE 84-25A, 25C, 30A, and 30B.

In the Ryukyu Trench area, the results of this cruise seem to be consistent with the former measurements. Heat flow is within a range of 50 to 65 mW/m² around the trench axis between the Kyushu-Palau Ridge and the Amami Plateau. On the lower part of the landward wall of the trench heat flow seems to be lower than 40 mW/m², though the values obtained in this study are not very reliable because of non-linear temperature profiles.

We cannot calculate heat flow values in the shallow sea area, probably due to large variations in the bottom water temperature. However, if heat flow in this area is very anomalously high (e.g. higher than 500 mW/m²), it should be reflected in the temperature profiles. Therefore, we may be able to conclude that very anomalously high heat flow in this area is unlikely.

The present results confirmed the extremely high heat flow in the central rift region of the middle Okinawa Trough, which had been found on the DELP-84 WAKASHIO cruise (YAMANO *et al.*, 1986). Sixteen heat flow values were obtained in the Natsushima-84 Deep during the two cruises. Fifteen of them exceeded 220 mW/m^2 and the mean of the sixteen values is 508±407 mW/m^2. High and variable heat flow values and non-linear temperature profiles indicate the existence of hydrothermal circulations. All the non-linear profiles obtained in the deep on the DELP-84 WAKASHIO cruise (YAMANO *et al.*, 1986) and this cruise indicate a downward flow of pore water. However, if upward flow exists, temperature gradients will be still higher and the non-linearity may not be detected as tempratures of the lower thermistors may exceed the upper limit of measurement.

Heat flow data along the profile P8-c except in the Natsushima-84 Deep range from 34 to 133 mW/m^2. They are comparable to those reported in other areas of the middle Okinawa Trough. Thus, it seems that the very high heat flow anomaly is concentrated in the central rift zone. It is unknown, however, whether the anomaly is confined to the inside of the depression or not, since we could not obtain heat flow data in the close vicinity of the Natsushima-84 Deep due to the hard bottom.

7. Summary

(1) The present results and the existing data show that heat flow is 50 to 65 mW/m^2 in the axial part of the Ryukyu Trench between the Kyushu-Palau Ridge and the Amami Plateau.

(2) The temperature profiles obtained in the northernmost part of the Okinawa Trough were severely affected propably by temporal changes in the bottom water temperature, so that heat flow values could not be determined. Further studies combined with the hydrographic data will be necessary.

(3) Heat flow is anomalously high and variable in the Natsushima-84 Deep, which lies on the axis of the middle Okinawa Trough. The mean and the standard deviation of 16 values measured on the DELP-84 WAKASHIO cruise and this cruise are about 500 and 400 mW/m^2 respectively. The observed non-linear temperature profiles can be interepreted as a result of hydrothermal circulation.

(4) Measurements were also made outside the Natsushima-84 Deep along a north-south line and the obtained values are about 100 mW/m^2 or lower. The high heat flow anomaly seems to be concentrated in

the central rift zone.

Acknowledgements

We are grateful for the efficient cooperation of the crew and the scientific party of R/V SONNE. The Japanese part of the operation was partially supported by Grants-in-Aid No. 5912708 and 60420013 of the Ministry of Education, Science and Culture, Japan, as a part of the Dynamics and Evolution of the Lithosphere Project (DELP).

References

ANDERSON, R. N., M. G. LANGSETH, D. E. HAYES, T. WATANABE and M. YASUI, 1978, Heat Flow, Thermal Conductivity, Thermal Gradient, in *Geophysical Atlas of the East and Southeast Asian Seas*, edited by HAYES, Map and Chart Ser. vol. MC-25, Geol. Soc. Amer.

ANDERSON, R. N., M. A. HOBART, N. FUJII and S. UYEDA, 1986, Heat flow and hydrothermal mounds in two million year old crust of the Mariana Trough, a back-arc basin (in preparation).

BREDEHOEFT, J. D. and I. S. PAPADOPULOS, 1965, Rates of vertical groundwater movement estimated from the earth's thermal profile, *Water Resour. Res.*, **2**, 325-328.

BULLARD, E. C., 1954, The flow of heat through the floor of the Atlantic Ocean, *Proc. R. Soc. London, Ser. A*, **222**, 408-429.

CARSLAW, H. S. and J. C. JAEGER, 1959, *Conduction of Heat in Solids*, Oxford University Press, Oxford, 510 pp.

EHARA, S., 1984, Terrestrial heat flow determinations in central Kyushu, Japan, *Bull. Volcanol. Soc. Japan*, **29**, 75-94, (in Japanese with English abstract).

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

HERMAN, B. M., R. N. ANDERSON and M. TRUCHAN, 1978, Extensional tectonics in the Okinawa Trough, in *Geological and Geophysical Investigations of Continental Margins*, edited by J. S. WATKINS, L. MONTADERT and P. DICKERSON, *Am. Assoc. Pet. Geol. Mem.*, **29**, 199-208.

HOBART, M. A., R. N. ANDERSON and S. UYEDA, 1979, Heat transfer in the Mariana Trough, *EOS*, **60**, 383.

HYNDMAN, R. D., E. E. DAVIS and J. A. WRIGHT, 1979, The measurement of marine geothermal heat flow by a multipenetration probe with digital acoustic telemetry and insitu thermal conductivity, *Marine Geophys. Res.*, **4**, 181-205.

MOORE, J. C., L. D. KULM, B. T. R. LEWIS and G. COCHRAN, 1984, Structural setting of subduction-driven fluid vents from the Oregon underthrust margin, *EOS*, **65**, 1089.

RATCLIFFE, E. H., 1960, The thermal conductivities of ocean sediments, *J. Geophys. Res.*, **65**, 1535-1541.

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

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

YOSHII T., 1979, Compilation of geophysical data around the Japanese Islands (I), *Bull. Earthq. Res. Inst., Univ. Tokyo* **54**, 75-117 (in Japanese with English abstract).

琉球弧北部及び中部における地殼熱流量測定
(1984 年 SONNE 号航海による観測)

東京大学地震研究所
山野　誠
上田誠也
古川善紹
Hamburg 大学　G. Ali DEHGHANI

1984 年に行われた SONNE 号の航海において，琉球弧北部地域での地殼熱流量測定を実施した．使用した測器は，Ewing 型及び violin bow 型の多重挿入可能なものである．九州―パラオ海嶺と奄美海台の間の琉球海溝では，新たに 5 地点で熱流量値が得られた．従来の測定値と合せてみると，海溝軸付近の熱流量は 50-65 mW/m^2 程度であり，陸側斜面ではそれより低くなるようである．沖縄トラフ最北部の水深 800 m 前後の地域では，堆積物中の温度プロファイルが著しい非線形性を示し，熱流量を求めることができなかった．これは，海底水温の時間的変動が大きいためと考えられる．沖縄トラフ中部では，東経 127 度付近の中軸部に存在する“なつしま-84 海凹”内で非常に高い熱流量が得られた．この凹地では，若潮丸による DELP-84 航海でも高熱流量が測定されており，計 16 点の測定値の平均は約 500±400 mW/m^2 となる．熱流量が非常に高くてばらつきが大きいこと，非線形の温度プロファイルが観測されたことからみて，熱水活動が起っている可能性が高いものと思われる．“なつしま-84 海凹”を通る南北の測線上でも測定を行ったが，高い値は得られなかった．高熱流量異常は，トラフ中軸部に限定されているようである．