HEAT FLOW AND HYDROTHERMAL CIRCULATION IN THE OKINAWA TROUGH

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The Okinawa Trough is an active backarc basin which is located behind the Ryukyu Arc. Recent geophysical and geological surveys revealed that the Okinawa Trough is in a stage of rifting of continental lithosphere, though there is a possibility that seafloor spreading has started in the very axial region of the southwestern part of the trough (Japanese DELP Research Group on Backarc Basins, 1986; Sibuet et al., 1987). Thus, the Okinawa Trough is thought to be thermally active and hydrothermal circulation may be taking place. The existence of hydrothermal circulation was suggested by the previous measurements showing that heat flow is relatively high and variable (e.g. Yasui et al., 1970; Lu et al., 1981), but no systematic and closely-spaced measurements were made before 1984.

In 1984, we carried out detailed heat flow measurements with multiple-penetration type probes in the Okinawa Trough on the DELP-84 Wakashio cruise (Yamano et al, 1986a) and a cruise of German R/V Sonne (Sonne-34, Yamano et al., 1986b). Heat flow surveys on the Pop 1 cruise of French R/V Jean Charcot were also made in 1984. The results of these measurements delineated some characteristics of heat flow distribution of the Okinawa Trough (Yamano et al., 1988). We made further measurements on the KH87-2 cruise of R/V Hakuho-maru in 1987, and the 88-04 cruise of R/V Chofu-maru and the Sonne-56 cruise in 1988. Geothermal studies have been also made using the Japanese submersible "SHINKAI 2000" since 1986. In 1988, heat flow measurements are scheduled in two more cruises.

Based on the results of the above studies, we will present the most up-to-date heat flow distribution in the Okinawa Trough and discuss hydrothermal circulation and the thermal structure of the trough inferred from the heat flow data.

Middle Okinawa Trough

Several thermal anomalies were detected in the middle Okinawa Trough during the recent heat flow surveys. Figures 1 and 2 show all the heat flow data in the middle Okinawa Trough area. As for the measurements on 1988 cruises, only the locations of the stations are presented since the data reduction is now in progress.

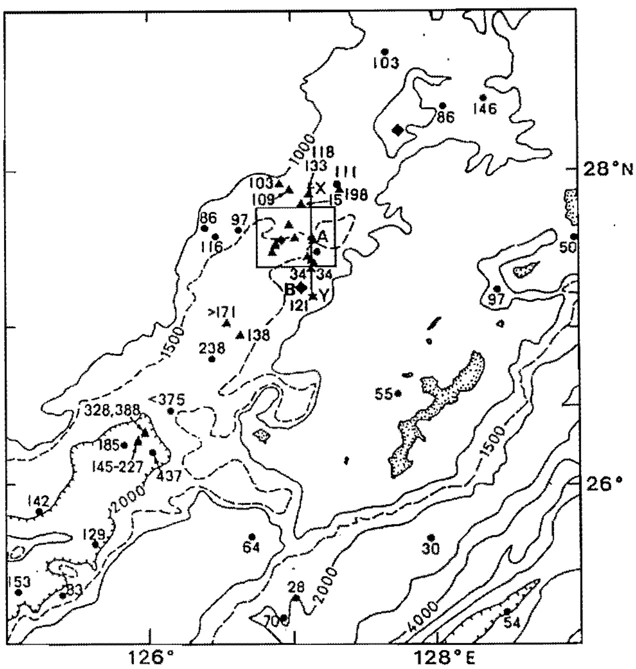

Figure 1
Heat flow data in the middle Okinawa Trough area. Points A and B are the Natsushima-84 Deep and the Izena Cauldron respectively. Triangles represent measurements in 1984 and thereafter and circles are the data before 1984. Rhombuses are stations on the Sonne-56 cruise.

The most well investigated area is an axial part of the trough at around 27.5°N, 127°E shown in Figure 2 (inside of the box in Figure 1). Topography is very complicated in this area and there are many small ridges, knolls, and basins lineated nearly in the east-west direction.

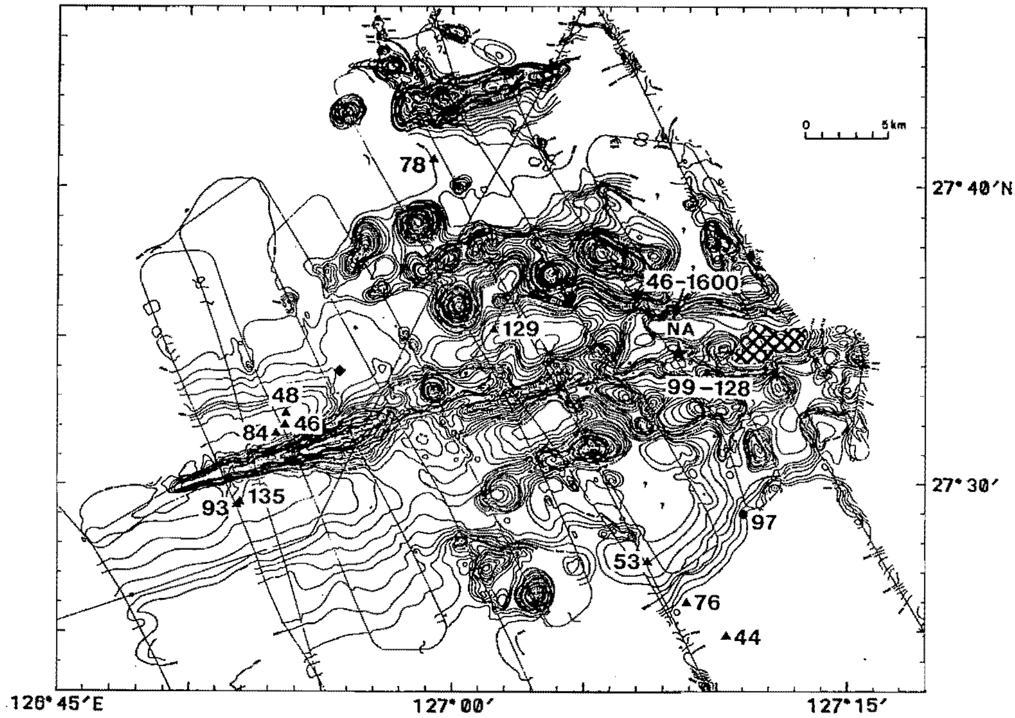

Figure 2
Heat flow values plotted in a Seabeam bathymetry map of the area in the box in Figure 1 (Sibuet et al., 1987). Contour interval is 20 m. Triangles represent measurements in 1984 and thereafter and a circle is the data before 1984. Rhombus is a station on the Sonne-56 cruise. NA is the Natsushima-84 Deep. Star represents the location of active hydrothermal mounds. A high heat flow anomaly was found in the shaded basin through measurements in 1988.

An extremely high heat flow anomaly was found in a small depression surrounded by small knolls at around 27°35'N, 127°09'E (NA in Figure 2 and termed "Natsushima-84 Deep" below). The average of 22 values obtained in this deep is about 600 $\pm$ 400 mW/m^2 and the maximum value reaches about 1600 mW/m^2. Anomalously high and variable heat flow suggests the existence of hydrothermal circulation. Some of the temperature versus depth profiles are concave, indicating downward porewater flow through the sediment. As upward flow tends to occur under the topographic highs and downward flow under valleys, it is expected that the Natsushima-84 Deep is a recharge area of hydrothermal fluid and the surrounding knolls are discharge areas. Discovery of active hydrothermal mounds on a small knoll just south of the Natsushima-84 Deep (star in Figure 2; Kimura et al., 1988) supports this inference.

To examine the extent of this high heat flow anomaly, measurements were conducted along a north-south line through the Natsushima-84 Deep (line X-Y in Figure 1). Figure 3 is heat flow and topography profiles along this line. Although the density of heat flow data is not enough for lack of soft sediment cover on the knolls and ridges, the high heat flow anomaly seems to be concentrated in the central rift region. New data obtained in 1988 showed that heat flow is also very high in a small basin east of the hydrothermal mounds (shaded in Figure 2). The average heat flow is comparable to that in the Natsushima-84 Deep and the maximum value is probably higher than 2000 mW/m^2. Thus, the high heat flow anomaly may extend in the east-west direction parallel to the trough axis.

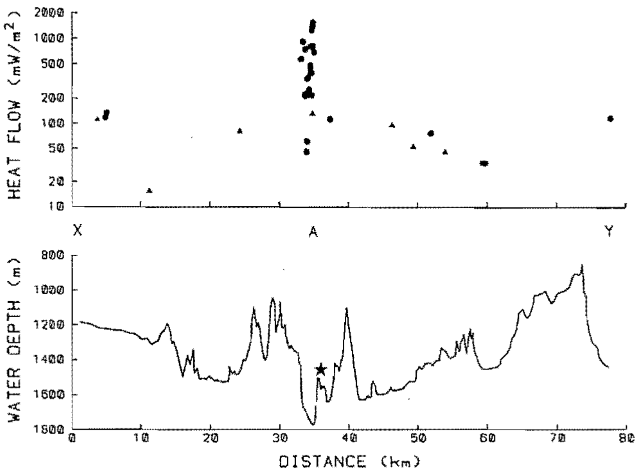

Figure 3
Heat flow and topography profiles along the line X-Y in Figure 1. Star indicates the small knoll with active hydrothermal mounds. Circles represent data in close proximity to the line and triangles are data in the vicinity of the line, projected onto it.

Such a high heat flow anomaly cannot be explained by a topographic effect or a result of stretching of continental lithosphere. The cause is probably present or recent volcanism associated with the rifting process (Yamano et al., 1988). Various geophysical data indicate present volcanic activities in this area and the ages of volcanic rock samples are only 0.2 to 0.3 m.y.

In the western part of Figure 2, heat flow measurements were made in basins north and south of the prominent central ridge. Heat flow is low in these basins, though the central ridge is thought to be a young volcanic feature with an age of less than 0.4 m.y. Some of the temperature profiles are concave. Measurements on the Sonne-56 cruise (rhombus in Figure 2) gave similar results. It is probable that the basins are recharge areas and discharge of hydrothermal water occurs at the ridge. Actually, communities of giant clams were discovered during the Sonne-56 cruise on the northern flank of the ridge, indicating the existence of some thermal activity.

Another high heat flow anomaly was found on the Sonne-56 cruise in a caldera-like structure with a diameter of about 5 km at around 27°15'N, 127°05'E (Izena Cauldron, point B in Figure 1). Preliminary data analyses give heat flow values ranging 100 to 1000 mW/m^2 on the floor of the cauldron. Heat flow seems to increase northward on the floor. Hydrothermal sulfide deposits were discovered on the northeastern inside slope of the cauldron, also indicating a high thermal activity in this area. The high heat flow anomaly might be confined in the cauldron as low heat flow was observed just west of the cauldron.

Heat flow surveys at around 28°15'N, 127°45'E during the Sonne-56 cruise produced somewhat anomalous results. The highest value probably exceeds 200 mW/m^2, while almost zero temperature gradients were obtained. The high variability may be due to hydrothermal circulation. Water depth is, however, relatively shallow (1000 to 1200 m) in this area, so that the temperature profiles might be affected by temporal variation in the bottom water temperature.

Southwestern Okinawa Trough

All the available heat flow data in the southwestern Okinawa Trough are shown in Figure 4. Heat flow values previously reported are rather variable, from 9 to 183 mW/m^2. This is possibly caused by advective heat transfer. Since this area is covered by very thick sediment layers, water flow may be concentrated in outcrops and/or along faults.

New heat flow values were obtained along a north-south line across the Okinawa Trough on the Pop 1 cruise (squares in Figure 4). They show a tendency that heat flow increases northward from about 30 mW/m^2 near the central rift to over 200 mW/m^2. Genthon et al. (1987) attributed this variation to structurally controlled large scale hydrothermal circulation. This line is, however, located in a transition zone between two central grabens, thus the heat flow profile may not be a typical one across the trough.

On the Sonne-56 cruise, heat flow surveys were carried out in the vicinity of a small knoll, the Yaeyama Central Knoll, which is elongated parallel to the trough axis (star in Figure 4). The ridge exists inside of a prominent axial graben (Yaeyama Graben) and thought to be a new intrusion at the axis of the Okinawa Trough (Katsura et al., 1986). Measurements were made both inside and

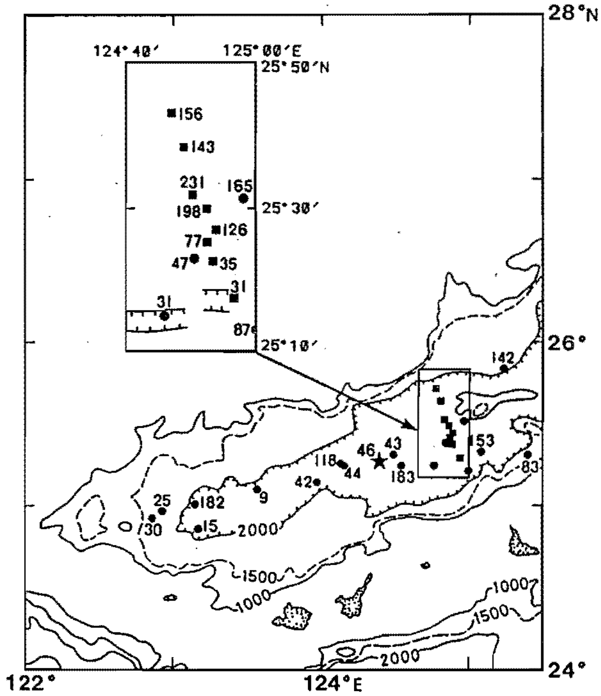

Figure 4
Heat flow data in the southwestern Okinawa Trough. Squares represent the values obtained on the Pop 1 cruise and circles are the other data. Star is the Yaeyama Central Knoll.

outside of the Yaeyama Graben. Heat flow is lower than 100 mW/m^2 at all of seven stations (13 penetrations). The low heat flow near the trough axis seems to be consistent with the results of the Pop 1 cruise. At one station just west of the Yaeyama Central Knoll, heat flow variation among three penetrations is very large and a concave temperature profile was observed. It suggests that the surroundings of the knoll are recharge areas, and discharge may be concentrated on the knoll.

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