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Comparison of Regional Thermal Model with Seismogenic Layer of the Japanese Islands

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ABSTRACT

With compilation of thermal gradient and heat flow density data, new geothermal databases of the Japanese Islands have been established. However, owing to local hydrodynamic perturbation and heterogeneity of thermal conductivity, measurements of thermal gradient and heat flow are often scattered and sometimes insufficient to understand a regional thermal regime. Thus we obtain the average model of the Japanese Islands. These values reveal regional thermal structure from the geothermal database compiled.

Seismic structure should be related with the regional thermal structure. Earthquakes mainly occur within the upper crust and there is a lower boundary of the seismogenic layer, called cut-off depth. It is interpreted that the cut-off depth is related to the brittle-ductile transition in the crust. Many studies suggested that the cut-off depth varies over a depth range of 5 – 25 km and that the thermal structure is the major factor governing the cut-off depth. Recent study at the geothermal field in the Japanese Islands expects that the cut-off depth lies at 300 - 350 □.

We here obtain the average thermal model of the Japanese Islands and compare it with the cut-off depth by the observed seismicity. Then we discuss the relationship between seismogenic layer and thermal structure.

1. GEOTHERMAL DATABASE

The geothermal database of thermal gradient and heat flow density data of the Japanese Islands has been established (Fig. 1) (Matsubayashi et al., 1992; Okubo, 1993; Yamano et al., 1997; Yano et al., 1999a; 1999b). However, owing to local hydrodynamic perturbation and heterogeneity of thermal conductivity, measurements of thermal gradient and heat flow are often scattered and sometimes insufficient to understand a regional thermal regime.

The thermal structure forms a high thermal gradient over a volcanic area and a low over a non-volcanic forearc area. The values in the volcanic areas indicate over 40 K km^{-1}. Besides, there are local high anomalies of active volcanoes over 100 K km^{-1} (Yano et al., 1999a; 1999b). The thermal gradients in the forarc area indicate commonly under 40 K km^{-1}.

Terrestrial heat flows in and around the Japanese Islands are compiled by Matsubayashi et al. (1992), Yamano et al. (1997) and GSJ and CCOP (1997). The number of data is more than 500. The compiled map reveals thermal structures across volcanic chain – forearc area – trench – oceanic plate (Fig. 1).

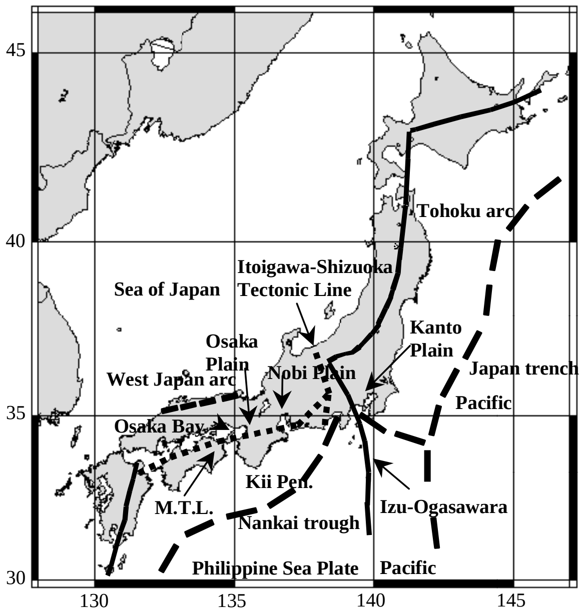

Figure 1a: Outline of tectonic and geological structure. "M.T.L." in the figure represents "Median tectonic line".

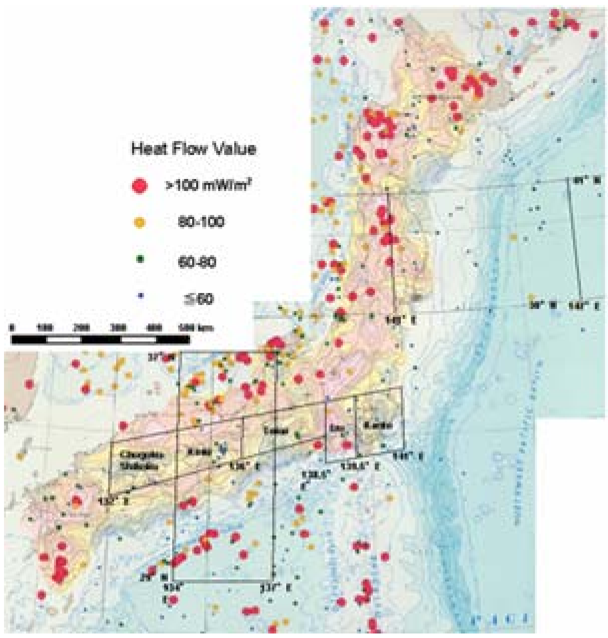

Figure 1b: Heat flow map of Japan and its surroundings (Matsubayashi et al. 1992). Color contours show Curie point depths estimated by the magnetic spectral analysis (Okubo et al., 1989).

The west to east cross section of the Tohoku arc shows a high heat flow of over 150 mW m^{-2} at the volcanic chain, a very low value under 50 mW m^{-2} from the forearc area and the trench, and a low value ranging around 50 mW m^{-2} over the Pacific plate (Fig. 3).

The north to south cross section of the southwest Japan arc indicates a heat flow pattern as it requires a reasonable interpretation (Fig. 4). The heat flow values over the Nankai accretionary prism, the margin of forearc area, are lower than 100 mW m^{-2}. The values at the Nankai Trough are genrally higher than 130 mW m^{-2} with a maximum of 230 mW m^{-2} (Yamano et al., 1992). The profile of heat flow (Fig. 4) demonstrates the high anomaly at the Nankai Trough and a lower heat flow over the Philippine Sea plate.

Geothermal gradients of the Japanese islands were calculated from bottom hole temperatures of 1828 deep drillhole and 108 terrestrial heat flow measurements. The results were compiled in the database (Tanaka et al., 1999; Yano et al., 1999a; 1999b; GSJ and KIGAM, 2002). The minimum depth of drillhole in the database is 300 m and the maximum depth reaches 6000 m. 60 % of the data were obtained from drillholes for hot spring resources. These data usually indicate only a bottom hole temperature instead a temperature – depth curve. The geothermal gradient calculated from the bottom hole temperature and the average meteorological surface temperature is a way to express the data on a map. The thermal regime of homogeneous media represents a uniform geothermal regime at the steady state. However, since natural thermal regime at shallow depth is always affected by disturbances such as the hydrodynamic perturbation, the thermal gradient is not always uniform. The calculated geothermal gradient in the database should include errors. Thus we obtain the average values of the Japanese Islands. These values indicate regional thermal structure (Fig. 4).

The Curie depth (Fig. 1b) is indirect evidence about thermal structure. The Curie depth is the depth at which crustal temperatures reach the Curie point of the dominant magnetic mineral, such as titanomagnetite, which is the most common magnetic mineral in the crust. Providing valuable information about deep magnetic discontinuities associated with the regional temperature distribution not easily examined using other methods, the spectral analysis of magnetic anomalies is often applied to estimation of the Curie point depth. The results are approximate but are unique and indicate a good agreement with the temperature measurements (Okubo et al., 1991).

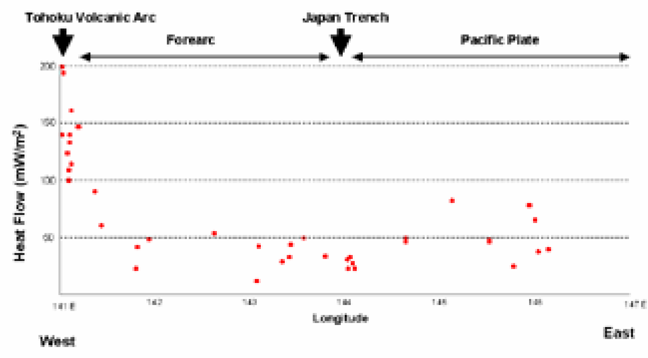

Figure 2: Cross-section of heat flow across the Tohoku volcanic arc, Japan trench and the Pacific plate. Locality is shown in Figure 1b.

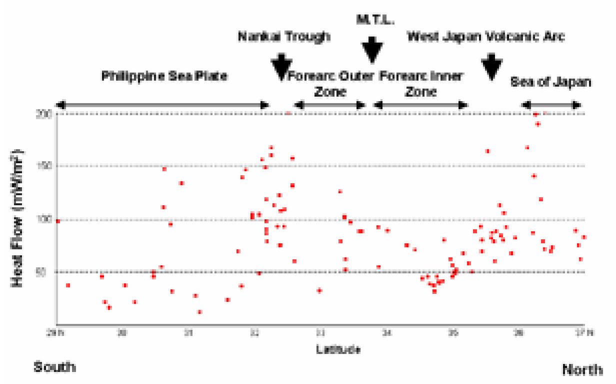

Figure 3: Cross-section of heat flow across The Philippine Sea plate, Nankai trough and the West Japan volcanic arc. Locality is shown in Figure 1b. "M.T.L." in the figure represents "Median tectonic line".

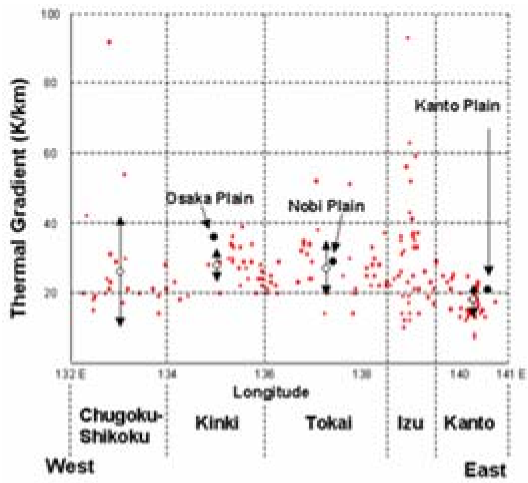

Figure 4: Cross-section of thermal gradient and their statistics of respective zones. Locality is shown in Figure 1b.

2. CUT-OFF DEPTH OF SEISMICITY

Seismic structure should be related with the regional thermal structure (Kobayashi, 1977; Ito, 1990; Ito, 1993; Bodri and Iizuka, 1993). Earthquakes mainly occur within the upper crust and there is a lower boundary of the seismogenic layer, called cut-off depth (Ito, 1999). It is interpreted that the cut-off depth is related to the brittle-ductile transition in the crust. Many studies suggested that the cut-off depth varies over a depth range of 5 – 25 km and that the thermal structure is the major factor governing the cut-off depth. Recent study at the geothermal field in the Japanese Islands expects that the cut-off depth lies at 300 - 350 □.

3. DISCUSSION

The NWN-SES profile of Kinki shows the cut-off depth of 20 km over the Osaka Bay and 15 km over the west of Kii Peninsula (Fig.5). The profile of thermal gradient at the same location shows 20 K km^{-1} over the Osaka Bay and 30 K km^{-1} over the west of Kii Peninsula. The Curie depths are about 12 km over the Osaka Bay and about 10 km over the Kii Peninsula. Conclusively, the west of Kii Penisula marks a shallow cut-off depth and the thermal data suggest that thermal structure is higher in temperature than the northwest area.

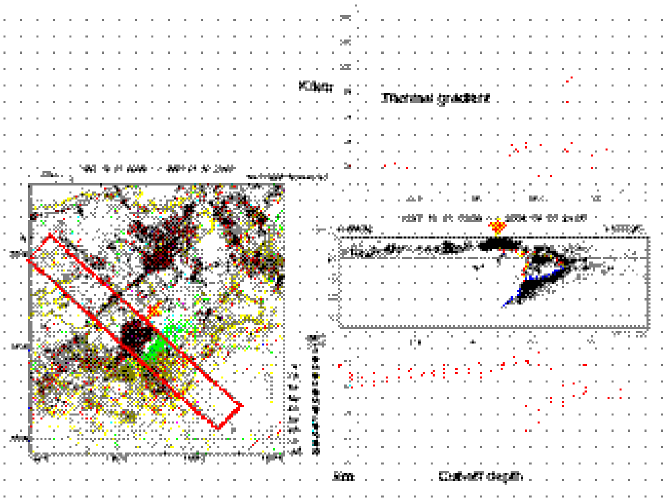

Figure 5 Cross-section of heat flow and their statistics of respective zones. Locality is shown in Figure 1b.

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