EVIDENCES OF ASIAN GEOTHERMAL STRUCTURE

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ABSTRACT

The development of geothermal resources requites assessment based on reliable data. The measured temperatures from geothermal and hot spring explorations as well as heat flows are good parameters to delineate anomalous geothermal zones. Although the Curie point depth map is always sketchy, a wide compilation and analysis of magnetic data could provide a good reference of geothermal structure of Asia. The lower limit of seismicity expresses an isotherm of about 350°C and the map of seismicity itself could simply give indirect information related with geothermal potential. I propose an international cooperative study to compile measured temperatures, magnetic data and seismicity in Asia with the purpose of contributing to discussions on the Asian regional geothermal potential.

1.0 INTRODUCTION

Geothermal energy has been booming in Asia. The Asian economic policy of the last decade is to open their market to the world. The policy has contributed to a rapid development of geothermal energy in the Philippines and Indonesia. The geothermal resource, one of the promising oil-alternative energy, has an advantage of giving a low impact to environment. Other Asian countries have started to promote the geothermal energy development since the new policy commenced.

The geothermal structure of the crust has been characterized on the basis of available geothermal data. High heat flows are observed in island arcs and ridges. Heat flow values in stable continental crust are usually low. The geothermal structure reflects such dynamic interior of the earth and often poses a complexity. The geothermal energy we use derives from the dynamism and complexity.

To understand the geothermal structure could lead us to effective exploration. To evaluate the potential, assessment of geothermal resources based on reliable data is required. The compilation of direct geothermal evidences, such as measured temperatures from drillholes, is the most important. But the data is limited. Then, other indirect evidences, such as the Curie point depth map and mapping of seismicity, deserve our attentions.

2.0 GEOTHERMAL DATA

Geological Survey of Japan (GSJ) and CCOP have published the heat flow map of East and Southeast Asia (GSJ and CCOP, 1997). The data are from the latest public-domain data set supplied by the International Heat Flow Commission of IASPEI and combination of estimated temperature gradient and compiled thermal conductivity data set of each sedimentary basin, which were collected from oil/gas exploration wells in those basins.

The map shows well-known high heat flow zones of the Japanese Islands, Taiwan, The Philippines and Indonesia. Moreover, the map indicates several high heat flow zones in Korea, the main land of China and Thailand.

Adding to the data set, Yano et al., (1999) compiled all available measured temperature data in the Japanese islands. The database includes many data from hot spring explorations, which usually indicate only the bottom hole temperature. Therefore, they compiled all data as geothermal gradients calculated from the surface and the bottom hole temperatures. Consequently, about 1800 temperature data were compiled in the Japanese Islands (Fig. 1).

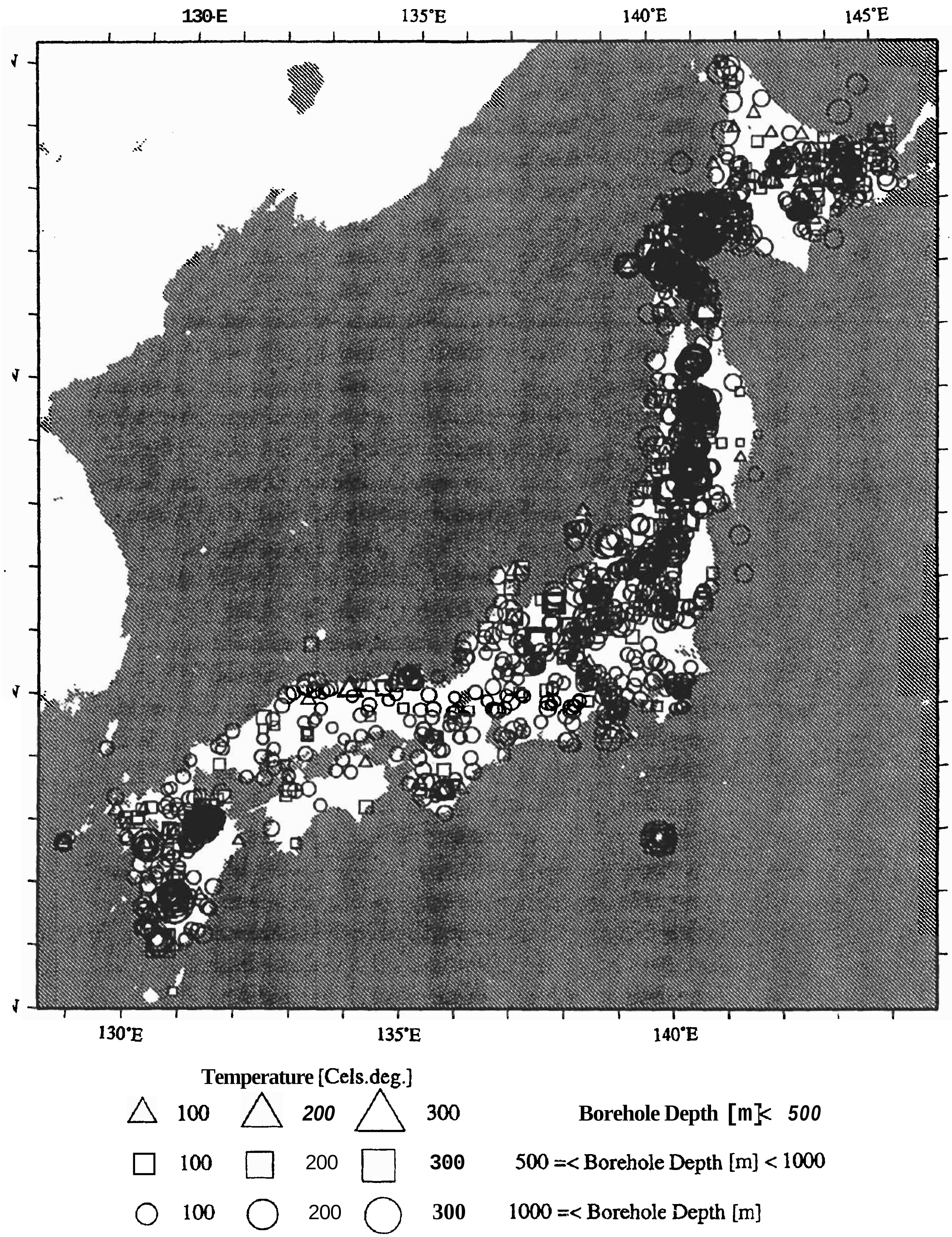

Figure 1. Temperature distribution of the Japanese Islands (Tanaka et ai., 1999). The data are from bottom hole temperatures of drillholes.

3.0 CURIE POINT DEPTHS

The spectral properties of aeromagnetic data have often been applied to estimate Curie point depths (e.g., Qkubo et al., 1985; Qkubo et al., 1989; Qkubo et al., 1991). This is the depth at which crustal temperatures reach the Curie point of the dominant magnetic minerals.

The Curie point depends on the chemical composition of magnetic minerals. According to the experiments of Nagata (1961), as the amount of titanium increases both the magnetization intensity and the Curie point decrease. The Curie point of magnetite is 580°C, and decreases with increasing TiO_2 content to less than 100°C. This suggests that the Curie point at depth cannot be easily defined. The temperature at the depth of magnetic bottom was estimated by comparing the Curie depth map of the Japanese Islands and the geothermal gradients obtained from drillholes (Qkubo et al., 1989). The comparison resulted to the Curie temperature of 450°C.

Tanaka et al., (1999) applied the Curie depth analysis to the magnetic anomalies of East and Southeast Asia (GSJ and CCOP, 1994). Although the geologic and physiographic complexities of this area constrain the method, the Curie point depths correlate remarkably with heat flows and are consistent with the tectonic settings. Shallow basal depths of magnetic sources that extend in back-arc regions correspond to high heat flow values. The correspondence of deep basal depths with low heat flow values along the trench axis suggests that they are both related to the subducting plate. Good agreement between the Curie point depths and other data suggest that the Curie point depth analysis is useful in estimating the regional geothermal structure (Fig. 2).

4.0 SEISMICITY

The geothermal structure correlates well with seismicity, implying that rock properties vary with temperature, as predicted by laboratory observation (e.g., Stesky et al., 1974; Brace, 1977). This correlation suggests a causal connection between the geothermal structure and seismicity. In the land area of Japan, shallow crustal seismicity is confined to the upper 25 km of the crust, and even shallower around the volcanoes (e.g. Hasegawa et al., 1991; Ito, 1993), suggesting that the brittle-ductile transition controls the lower limit of seismicity (Fig. 3).

The temperature of the brittle-ductile transition is controversial. The comparison between seismicity and geothermal structure deduced from drillholes suggest that the temperature is about 350°C.

Regional variations in the lower limit of seismicity in southwest Japan are derived from more than 60,000 well-determined earthquakes (Ito, 1999). The thickness of the seismogenic layer is closely related to strength of the crust and accordingly to the occurrence of large inland earthquakes, since the seismic-aseismic boundary is thought to be related to the brittle-ductile boundary in the crust. Large inland earthquakes are likely to occur in the area where the lower limit of seismicity changes abruptly.

5.0 DISCUSSION AND CONCLUSIONS

The direct evidence of geothermal structure is the reliable measured temperature. Although the heat flow is a good direct evidence for geothermal assessment, the parameter requires the thermal conductivity as well as the geothermal gradient. Thermal conductivity is not commonly measured in the exploration of hot spring and geothermal resource. Sometimes only the bottom hole temperature is measured without any standing time. Moreover, the hydrothermal convection, which always occurs in the geothermal field, is inadequate for observation of heat flow. These leave many measured temperature data from the exploration not be compiled.

The map of geothermal gradient could be useful for geothermal assessment even if the quality of the measured temperature is low. Since the main objective for such surveys is to find an anomalous geothermal zone at the depth, geothermal gradient map provided by the compilation of all measured temperatures is one of good parameters for assessment of geothermal energy.

We should note it that the Curie point depth expresses a statistical average of magnetic lower boundary. The algorithm requires an extensive 2-dimensional data set. A deep geological structure produces an anomaly long

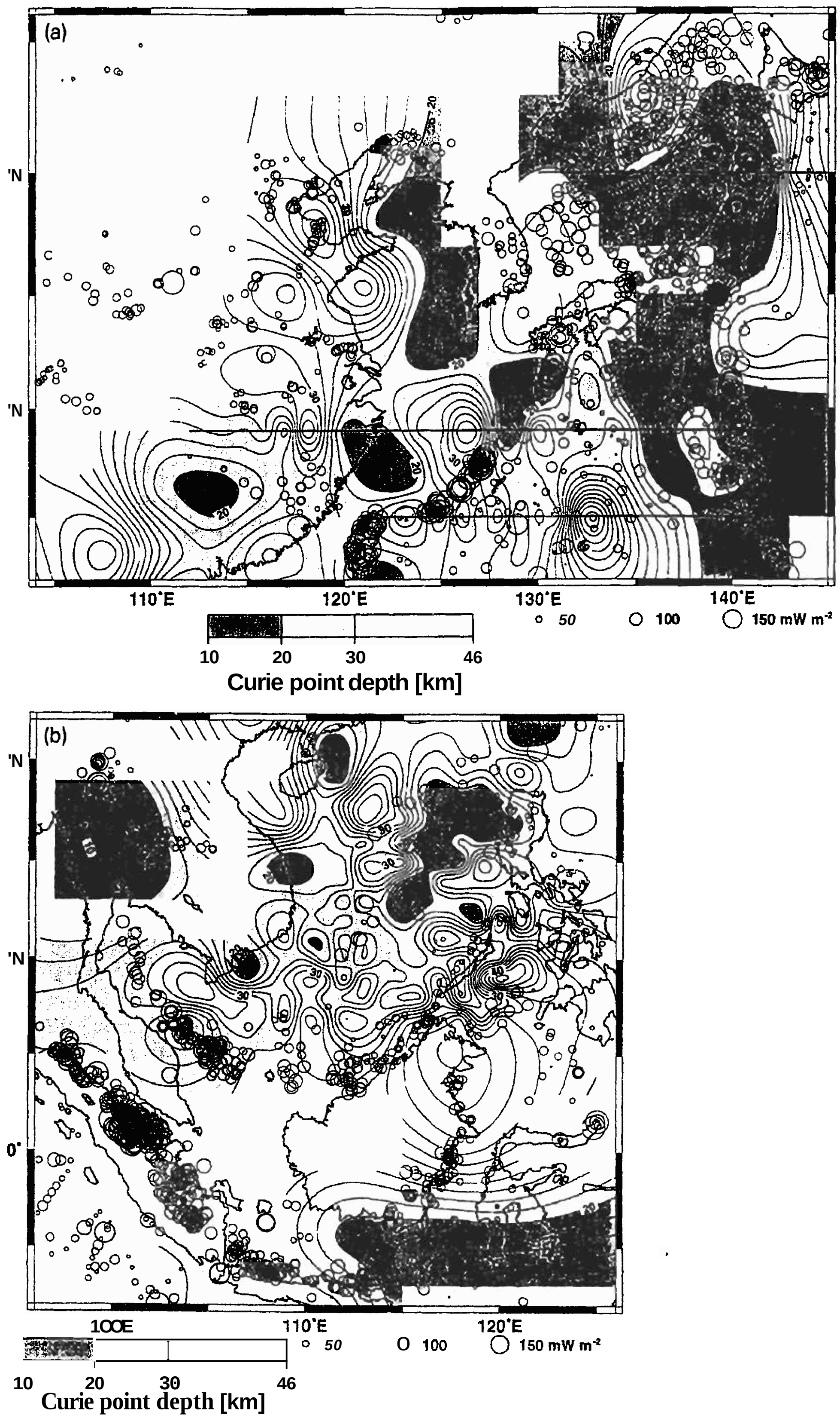

Figure 2. Contour map of the depth to Curie point in km (Tanaka et al., 1999) and heat flow data (Pollack et al., 1993)

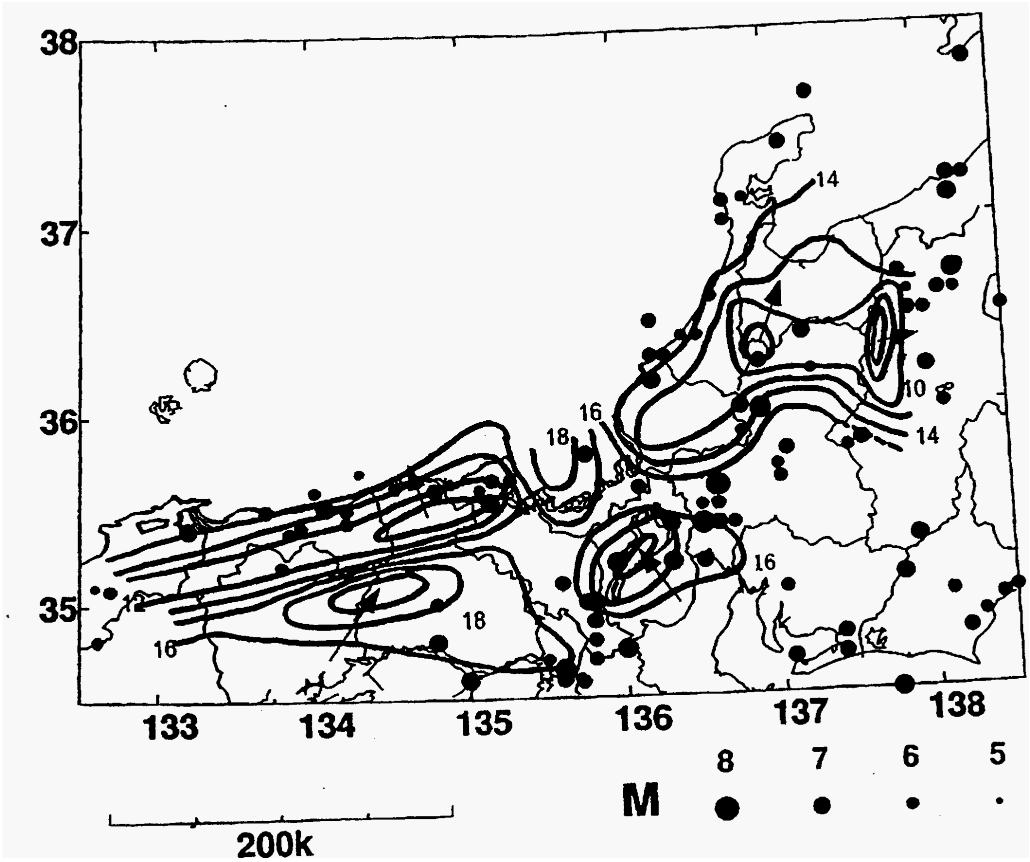

Figure 3. **Contours of cut-off depth of seismicity in southwest Japan (Ito, 1999). Contour interval is 2 km. Numerals show cut-off depth. Dots indicate large earthquakes with M6 or greater from 715 to 1995.**

in wavelength. Thus, the wavelength of interest in the estimation is rather long. Model simulation suggests that the method is valid as long as the dimension of square area is about ten times the actual target depth (Okubo et al., **1985).** The implication **is** that a minimum square area size **of** about several hundreds km is often necessary for resolving the basal depths. Consequently, the Curie analysis show statistical average of a wide area and the map is always sketchy. Local and small high heat flow zones could be invisible for the Curie depth analysis.

The Curie point depth map presented by Tanaka et al. **(1999)** covets a wide area of East and Southeast Asia. Although the map is useful to estimate the regional geothermal structure, the mapped area is unfortunately only in offshore and coastal area. The reason is that the magnetic data coverage is limited. A wide compilation of magnetic data could provide the Curie depth map of land area.

The lower limit of seismicity expresses an isotherm of about 350°C. The problem is accuracy of epicenter determination, especially depth determination. The epicenter is determined by data observed at several stations. Since the stations are usually located on the ground, the vertical accuracy is rather poorer than the horizontal location. This suggests that it will be difficult to determine the lower limit of earthquake in Asia.

Another aspect is that the seismic zone and the volcanic zone are almost on the same place forming the circum-Pacific belt. Correspondence between the earthquake zone and the volcanic zone implies that a high seismicity zone shows an active zone. Therefore, to map seismicity could simply give indirect information related with geothermal potential.

Finally, I propose to compile measured temperatures, magnetic data and seismicity of the Asian area in the international cooperative study. This could contribute to discussion on the regional Asian geothermal potential.

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