CURIE POINT DEPTHS OF JAPAN

Yasukuni Okubo Hiroji Tsu and Katsuro Ogawa

Geological Survey of Japan, 1-1-3 Higashi, Yatabe, Ibaraki, 305 Japan

ABSTRACT

Curie point survey was performed to evaluate the deep heat source distributions, and the nationwide Curie point depth map was made as the final product. Comparison between the Curie point depth map and the existing geological and geophysical data supports the validity of the estimated Curie point depths.

The Curie point depths were utilized for the mapping of the geothermal high potential areas together with the depths to the gravity basement, the lineament density map derived from SAR images and other data such as geology, hot springs.

1. Introduction

The Curie Point Survey of the Japanese Islands started in 1981 and was completed in 1984 as a part of the project named "Nationwide Geothermal Resources Survey" conducted by the New Energy Development Organization(NEDO) under the cooperation with the Geological Survey of Japan(GSJ). Fig.1 shows the concept of the project. By three types of data, i.e., Curie point depth, gravity and Synthetic Aperture Radar(SAR), the Japanese Islands were covered to explore and evaluate the nation's geothermal resources.

This paper deals with the acquisition and compilation of aeromagnetic data, and analysis, interpretation and utilization of Curie point depths.

2. Aeromagnetic data

A total of 153,120 line km(mainly onshore areas) were flown by magnetometer-installed aircrafts at 4,500 feet constant barometric altitude, with a line spacing of 3-4km. An additional coverage of 350,000 square km(mainly offshore areas) flown by GSJ were also included for the compilation, analysis and interpretation. After the data compilation, gridded aeromagnetic data were obtained in six subareas. In each subarea, the datum is constant above sea level, which enables the Curie point depth analysis.

3. Curie point depths

The high filter with the cut-off wavelength of 40-50km was applied to the gridded aeromagnetic data to remove the long wavelength components which would interfere with the Curie point (depth) analysis. The high-pass filtered aeromagnetic data were used as input to the centroid depth estimation procedure of the Curie point analysis(Okubo, et al.,1985). A Curie point depth was calculated using a 81x81 or 48x48 square km subblock(a square area of gridded aeromagnetic data). Fig.2 shows the contour map of the calculated Curie point depths of the Japanese Islands. This map may represent the temperature distribution in the earth crust because the Curie point depth is the depth at which the earth temperature reaches the Curie temperature(580°C for pure magnetite).

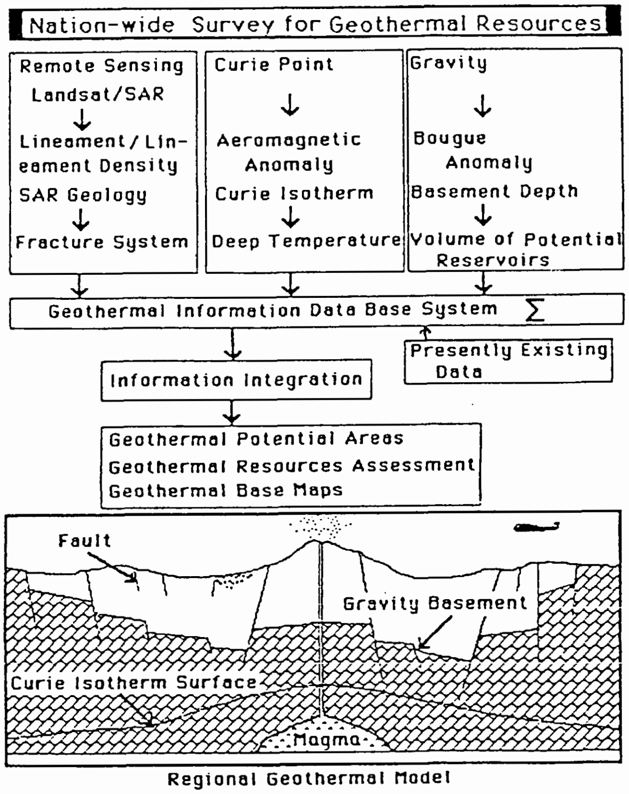


Fig.1 Concept of the Nationwide Geothermal Resources Survey.

The shallow Curie point depths(less than 8 km below sea level: painted in black color in Fig.2),

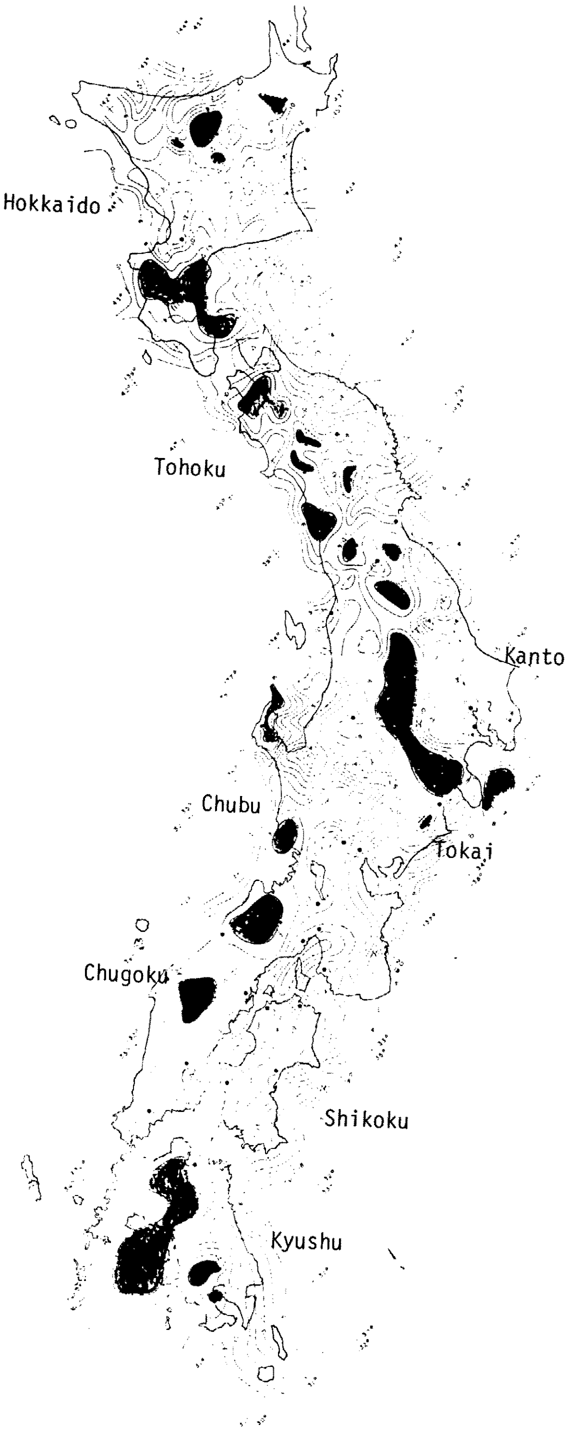


Fig.2. Curie point depth contour map of Japan(courtesy, NEDO). (Depth in kilometers below sea level)

● areas where Curie depths are shallower than 8km.

which correspond to high temperature gradient(more than 70°C/km), lie within the Quaternary volcanic provinces and geothermal areas from Hokkaido to Kyushu. On the other hand, the deep Curie point depths(more than 15km) lie over the pre-Neogene structural belts and the forarc basins in the Pacific Ocean side. The intermediate Curie point depths are located in the backarc basins which had high volvanic activity called "Green Tuff activity" during the Miocene. The average Curie point depth of the onshore areas is approximately 10km below sea level.

4. Validity of the Curie point depth map

The heat flow contour map of the Japanese Islands and surrounding area(Fig.3) shows typical of an active island arc system, that is low(less than 1 HFU) on the forarc side and high(greater than 2 HFU) on the volcanic belts and backarc side. Fig.4 shows heat flow across Tohoku(northern Honsyu). Fujii & Kurita(1978) show a schematic geothermal structure under the arc of Japan(Fig.5). The estimated Curie point depths from the Curie point depth map along latitude 40°N shown in Fig.6 indicate the same features. Curie point analysis by a model simulation method using high-cut filtered magnetic profile of Tohoku was done and reported by Tsu & Ogawa(1932), which resulted in roughly the same as Fig.6(see Fig.7). In brief, high temperature zones exist in shallow layers below the volcanic belts and become deeper toward the subduction zone, and these features are also shown in the Curie point depth map.

Available measured temperature gradients were compared with the gradients calculated from the

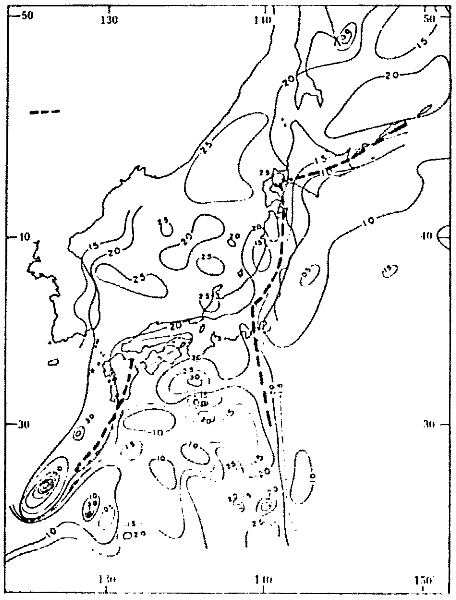


Fig.3 Heat flow map around Japan(after Uyeda,1972). (Contour interval;0.5HFU)

╌╌ volcanic fronts

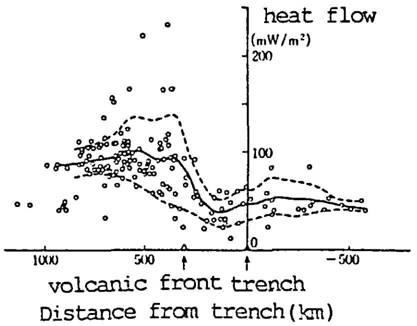


Fig.4 Heat flow distibution across Tohoku district(after Uyeda & Mizutani,1978).

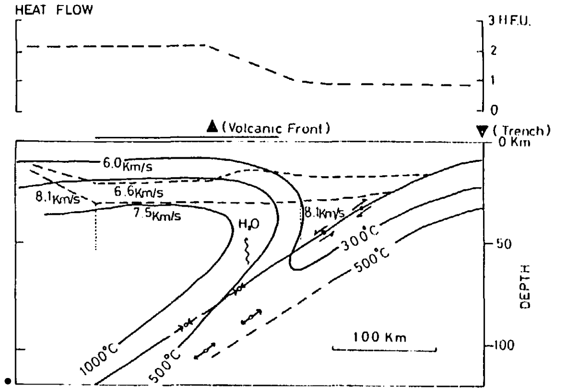


Fig.5 Characteristic profile of heat flow and geothermal structure across the north Japan(after Fujii & Kurita,1978)

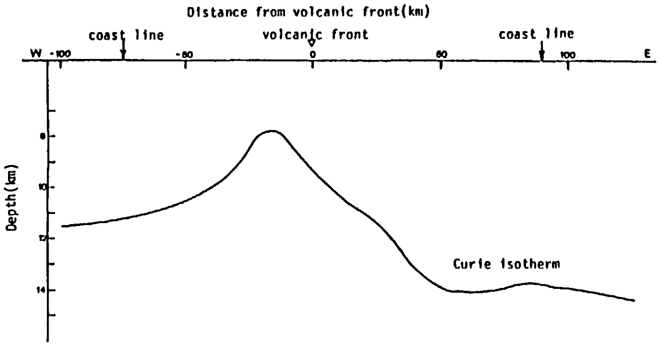


Fig.6 Curie point depths along latitude 40°N.

estimated Curie point depths at the same locations. The calculated gradients assume, thermal conductivities of the rocks are homogeneous; heat is transfered only by conduction; surface temperature is 0°C; elevations are given as the average of 65km x 65km subblocks; and no heat sources exist between the surface and the Curie point depths.

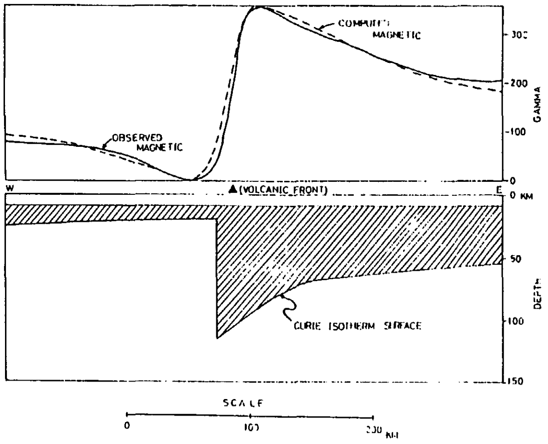


Fig.7 Interpreted Curie isothem surface for the smoothed magnetic data across the northeastern Japanese arc(near the Tsugaru strait) (after Tsu & Ogawa,1982).

The comparison of the measured vs. calculated temperature gradients are shown in Fig.8.

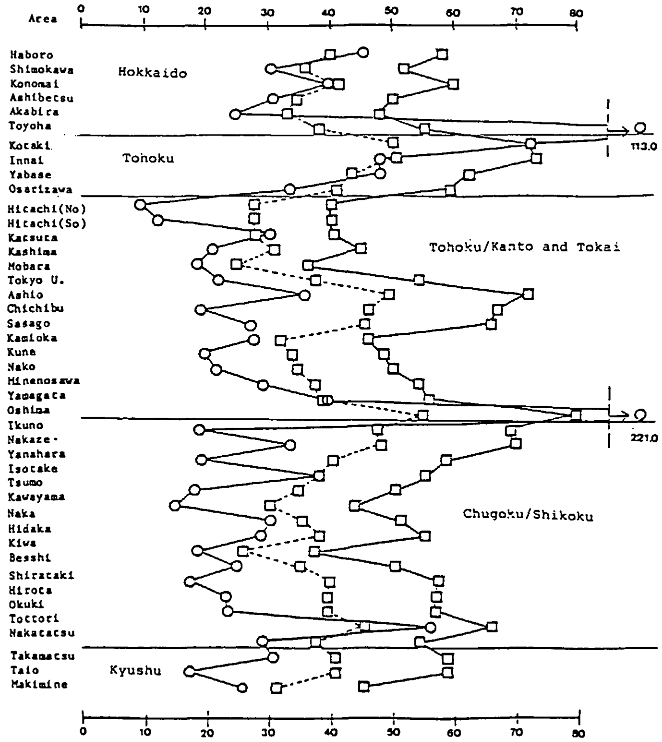


Fig.8 Comparison of measured vs. calculated temperature gradients.

—□— Calculated gradients assuming Curie temperature to be 580°C

---□--- Calculated gradients assuming Curie temperature to be 400°C

—○— Measured gradients(Horai,'63, Uyeda, et al.,'58, Uyeda & Horai,'63a,b and Honda, et al.,'79)

Significant result in the comparison is the constant difference between the measured and the calculated gradients assuming the Curie temperature to be 580°C. There are some reasons for this difference. Among those is related to the assumption of the Curie temperature of the rocks in the crust.

Curie temperatures of rocks basically depend on the content of most general ferromagnetic mineral, or magnetite in rocks. The Curie temperature of pure magnetite is 580 °C(see Fig.9). However, the Curie temperature tends to be lower with increase of titanium. Nagata reported, on the basis of fairy extensive observations, that the titanium content of the ferromagnetic minerals increased with increasing temperature and pressure. The relation between a depth vs. the Curie temperature is shown by Nagata(Fig.10). Therefore, the actual Curie temperature will presumably be below 580°C. Fig.10 indicates that the Curie temperature can be estimated to be approximately 400 °C. The calculated gradients assuming the Curie temperature to be 400°C are shown by the broken line in Fig.7. The difference between the calculated and the measured gradients will be reduced by this adjustment.

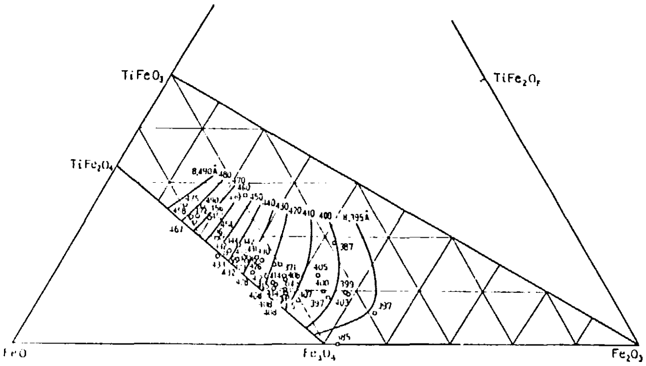


Fig.9 Relation between Curie temperature and chemical composition of titaniferous magnetites in volcanic rocks(after Nagata,1961).

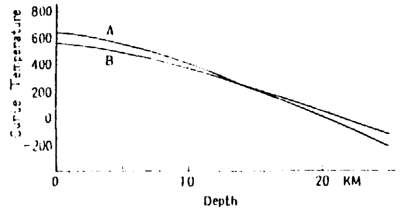
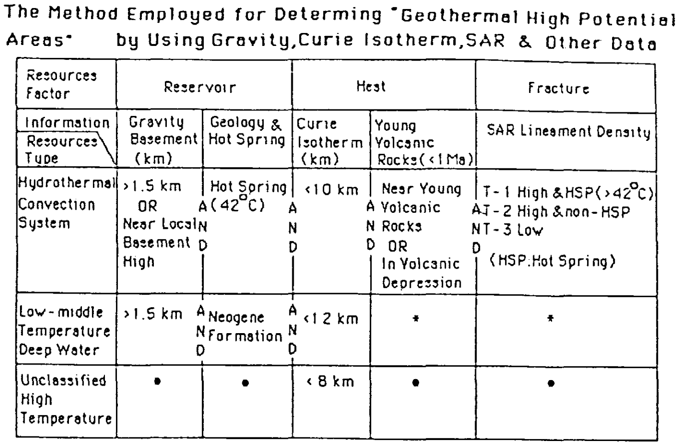


Fig.10 Variation of Curie temperature of ferromagnetic minerals with depth.
(A) for the ilmenite-hematite solid solution series
(B) for the ulvöspinel-magnetite solid solution series(after Nagata,1961).

5. Mapping of geothermal high potential areas using Curie point depths

The Curie point depths were utilized for the mapping of the geothermal high potential areas together with the depths to the gravity basement, the lineament density map derived from SAR images and other data such as geology, hot springs. Fig.11 shows the criterion employed for the mapping. Three factors, i.e., 'reservoir', 'heat' and 'fracture', were defined to classify the Japanese Islands into the areas of 'hydrothermal convection', 'low to intermediate temperature deep water', 'unclassified high temperature' and 'non-geothermal'. The Curie point depths were used for the evaluation of 'heat'. The map showing the geothermal high potential areas was made based on this criterion.

This map gives us the better understanding of the geothermal potential of the Japanese Islands. Most of the high geothermal potential areas in the map are known geothermal fields. However, several unknown areas were pointed out by the map. The second phase of the Nationwide Geothermal Resources Survey started in 1984 to confirm the geothermal potential of those unknown areas. The detailed geological, geophysical and geochemical surveys including heat holes are now underway in the four experimental areas selected from the unknown areas mentioned above.



The Method Employed for Determing "Geothermal High Potential Areas" by Using Gravity,Curie Isotherm,SAR & Other Data

Resources Factor	Reservoir		Heat		Fracture
Information / Resources Type	Gravity Basement (km)	Geology & Hot Spring	Curie Isotherm (km)	Young Volcanic Rocks(<1 Ma)	SAR Lineament Density
Hydrothermal Convection System	>1.5 km OR Near Local Basement High AND	Hot Spring (42°C) AND	<10 km AND	Near Young Volcanic Rocks OR In Volcanic Depression AND	T-1 High & HSP(>42°C) T-2 High & non-HSP T-3 Low (HSP:Hot Spring)
Low-middle Temperature Deep Water	>1.5 km AND	Neogene Formation AND	<12 km	*	*
Unclassified High Temperature	●	●	<8 km	●	●

(* : not defined)

Fig.11 Criterion for determining the geothermal high potential areas by using the data obtained by the Nationwide Geothermal Resources Survey.

6. Conclusion

The geological and geophysical data positively support the validity of the estimated Curie point depths. Further knowledge of the Curie temperatures in the earth crust will improve the results obtained by the Curie point depth analysis, and thus make it an effective tool for estimating heat sources.

Acknowledgement

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References

Fujii, N. and Kurita, K., 1978. Sesmic activity and pore pressures in island area, GDP conference abstract, p.30-31.

Honda, S., Matsubara, Y., Watanabe, T., Uyeda, S., and Shimazaki, K., 1979. Compilation of eleven new heat flow measurements on the Japanese Islands. Bull. Earthquake Res. Inst., v.41, p.45-73.

Horai, K., 1963. Studies of the thermal state of the earth - the tenth paper: terrestrial heat flow measurements in Tohoku district, Japan. Bull. Earthquake Res. Inst., v.41, p.137-147

Nagata, T., 1961. Rock magnetism. Maruzen, Tokyo.

Okubo, Y., Graf, R.J., Hansen, R.O., Ogawa, K., and Tsu, H., Curie point depths of the island of Kyushu and Surrounding areas, Japan. Geophys., in the press.

Tsu, H. and Ogawa, K., 1982. Analysis of Curie isotherm surface(I) - model experiments and the trial to estimate the geothermal structure under the island arc. J. Geothermal Res. Soc. of Japan, v.4, no.1, p.1-30.

Uyeda, S., 1972. Heat flow, in the crust and upper mantle of Japanese area, part 1. Geophysics, Earthquake Res. Inst., Chapter 5, 97-105.

Uyeda, S. and Horai, K., 1963a. Terrestrial heat flow measurements in Kinki, Chugoku, and Shikoku districts, Japan. Bull. Earthquake Res. Inst., Tokyo Univ., v.41, p.109-135.

Uyeda, S. and Horai, K., 1963b. Terrestrial heat flow measurements in Kanto and Chubu districts, Japan. Bull. Earthquake Res. Inst., Tokyo Univ., v.41, p.83-107.

Uyeda, S. and Horai, K., 1964. Terrestrial heat flow in Japan. J. Geophys Res., v.69, p.2121-2141.

Uyeda, S., Yukutake, T., and Tanaoka, I., 1958. Studies of the thermal state of earth - the first paper: preliminary peport of terestrial heat flow in Japan. Bull. Earthquake Res. Inst., v.36, p.251-273.

New Energy Development Organization, 1982. Prospective Geothermal Fields Report(Kyushu Area).

New Energy Development Organization, 1982. Kyushu Curie Point Survey Final Report.

New Energy Development Organization, 1982. Tohoku Curie Point Survey Final Report.

New Energy Development Organization, 1982. Hokkaido Curie Point Survey Final Report.

New Energy Development Organization, 1983. Chubu Curie Point Survey Final Report.

New Energy Development Organization, 1983. Tohoku-Naubu, Kanto & Tokai Curie Point Survey Final Report.

New Energy Development Organization, 1983. Chugoku Curie Point Survey Final Report.

New Energy Development Organization, 1984. Japan Curie Point Survey Final Report.