Proc 12th New Zealand Geothermal Workshop 1990

CHARACTERIZATION AND EVALUATION OF THE SENGAN GEOTHERMAL FIELD, JAPAN USING A LARGE SET OF PHYSICAL PROPERTY DATA OBTAINED FOR CORE HOLES

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ABSTRACT

Using a large number of bulk density and thermal conductivity data carefully obtained on core samples from deep holes together with temperature log data and other geophysical information and studying their relation to geology in the area, it has become possible to evaluate the energy and fluid transport phenomena in the upper crust of a representative high-heat-flow spot, Sengan-Hachimantai geothermal area, Japan. The primary factor which controls the density and thermal conductivity values in a geological environment of volcanic rocks has been found to be porosity, based on very closely spaced measurements of the two properties of those core samples. It is shown that hydrothermal convection cells are localized within narrow fractured zones, for example in the Yakeyama sub-area, and that temperatures in the poorly fractured zones are controlled by thermal conduction. Estimation of the resource potentiality of the area is made using the temperature and physical property data obtained in this work.

INTRODUCTION

Drillholes provide crucial information, which is otherwise unavailable. Data from drillholes are concerned, the most intensive data collection in Japan may be those provided by the new energy research programs in the Sengan-Hachimantai area in northeast Japan. It has included geological, geophysical, and geochemical studies (hereafter called Sengan Area: see G.S.J.,1987). A large heat source below the voluminous accumulation of silicic pyroclastic rocks was anticipated in the area. Based on this working hypothesis more than one hundred shallow holes and afterwards more than 20 wells deeper than 1500 m have been drilled in the area and provided an excellent opportunity to study the relationship between shallow and deep temperature regimes for the same site (Matsubayashi,1989). This paper describes the major findings obtained from the drillholes with special reference to heat transport processes and geophysical structure of a large-scale geothermal field in an island-arc environment.

THERMAL CONDUCTIVITY

Results of thermal conductivity measurements on core samples from seven deep wells with depths ranging from 1500 to 2486 m in the Sengan Area are summarized. Locations of those wells are shown in Fig.1. We are interested in examining the relationship between thermal conductivity and bulk density for ensemble of each rock type. The stratigraphy of the area has already been established by Suto et al.(1989) using the core samples from these wells. Fig.2 shows, as a typical data set, detailed changes of density and thermal conductivity as function of depth for well SN-4. It is

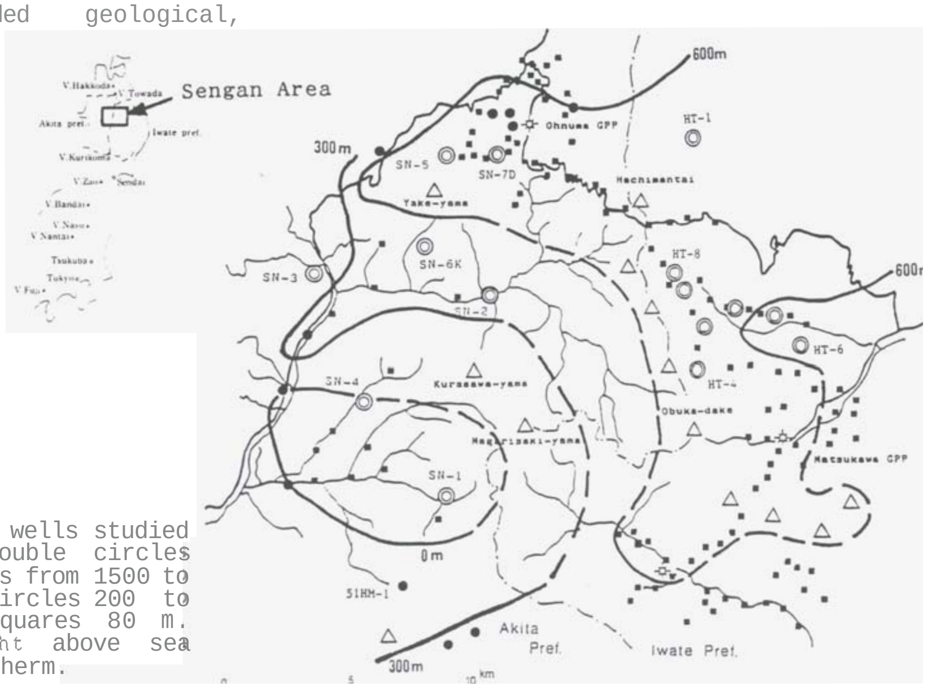

Fig.1 Location map of wells studied in this work. Large double circles are holes having depths from 1500 to 2486 m, small silid circles 200 to 500 m, and solid squares 80 m. Contours show the hight above sea level of the 50℃ isotherm.

noted that thermal conductivity and bulk density correlate to each other very well, suggesting that porosity, rather than lithology change, is the main controlling factor for the changes of both properties.

Using the empirical relationship between thermal conductivity and bulk density for representative rock types, it has become possible to estimate thermal conductivty value from existing data of density, which is more frequently measured and reported. Thermal conductivity distribution in the Sengan area may be represented by a schematic cross-section shown in Fig.3, where temperature dependence of thermal conductivity is corrected by the empirical formula of Sekiguchi (1984).

TEMPERATURE DISTRIBUTION

Even after deep drillhole temperature data can be measured, it is not easy generally to know the subsurface temperature distribution with high accuracy , which is in a complicated 3-dimensional geometry in areas covered with volcanic rocks, mainly due to the heterogeneity of physical properties discussed above. Heat flux from depth itself may have large variation in such areas and also topographic releaf is large, inspite of the fact that thermal effect of hydrothermal circulation may happen to be negligibly small. One presentation of geo-temperature distribution in the Sengan Area is included in Fig.1, on which superimposed is a map of iso-height contours of 50℃ isotherm above the sea level. The contour lines indicate that geothermal gradient roughly coincides with the youngness of volcanic cluster: the area of high geothermal gradient corresponds to the cluster of younger volcanoes in this area, of Pliocene and Pleistocene. On the other hand, lower geothermal gradient corresponds to the southern area where two large caldera collapse events occurred in Pliocene. The caldera is named Old Tamagawa caldera by Suto (1987), and any later magmatic events have not occurred there.

Based on the characteristics of subsurface heat transport in other words that of temperature distribution pattern, five sub-areas have been defined (Matsubayashi, 1989) and estimated heat flow values are listed in Table 1. For the temperature-depth relation in the Hachimantai sub-area of the Sengan field (Matsubayashi. 1989), heat flow value has a large variational range between **250** and **420** mW/m**2. It may indicate enhancement of upward heat transport by convection below the impermeable Tertiary formations that have been reached by drillholes. It is inferred that such convective heat transport is driven by dyke-shaped hot materials intruded in the basement rocks.

Looking at the temperature data in the Yakeyama sub-area, including two drillholes at northern and southern slopes of the Yakeyama volcano, it is remarked that there is an asymmetry of geothermal gradient between the northern (well SN-5) and southern slopes (well SN-6K). The fact that both holes (SN-5 and SN-6K) show conduction-dominated temperature-depth curves indicates that the major cause of the different geothermal gradient has to be at a level below the drillhole penetration depth, 1500m to 1600m. Particularly, upward fluid movement in deeper horizon is inferred for the northern slope. There are other pieces of evidence supporting this inference: surface self-potential survey detected a broad positive anomaly at the northern slope of Yakeyama. Hydrothermal alteration study for the near-bottom core samples from the drillholes has also shown that the degree of fluid infiltration has been higher at the northern slope than that at the southern slope.

In both above mentioned sub-areas. hydrothermal convection cells are localized within narrow fractured zones, for example at Sumikawa and Ohnuma in the Yakeyama sub-area, and that temperatures in the poorly fractured surrounding areas are controlled essentially by thermal conduction.

REMARKS ON RESOURCE POTENTIAL

For the purpose of comparing geothermal resource potentials quantitatively for various types of temperature-depth ralations. an index was proposed which is very simply

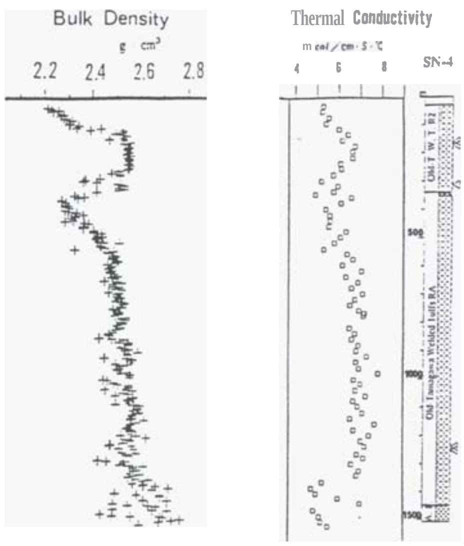

Fig.2 Detailed depthwise change of density and thermal conductivity of well **SN-4** (taken from Suto et al., 1989).

defined as the integral of temperature along depth:

$$I_{he} = \int_{0}^{Z_B} \{ T(z) - T_{ref} \} dz$$

It can be shown that the output thermal energy increases linearly with the increase of Heat Extractivity Index (I he), using the heat extraction scheme proposed by Morita and Matsubayashi(1988), Downhole Coaxial Heat Extraction System, and that the temperature-depth curve of upward convex type has a larger heat extractivity than that of linear type. I he is a good measure to evaluate the accessible" resource base as defined by Muffler and Guffanti(1979), which represents the total thermal energy stored in rocks and fluid in the formations within a predefined depth range.

Heat capacity of the bulk formation depends on porosity but the dependence is very week, so that the determining factor of accessible resource base may be the index I he. Observed temperature data presented above are used for calculating the index. Estimation of accessible resource base [depth limit = 1.5 km from surface] was made and values ranging from (1 to 4.4) X 10 E+18 cal for 5 km X 5 km blocks were obtained. These values are equivalent to the values of I he [1.5 km] which ranges from 64 to 282 [km·°C]. Fig.4 shows the distribution of I he [1.5 km] values. Because of the large areal extent of anomalously high heat flow region in the Sengan ares, the area may be one of the promising target fields for a future research program aiming at using geothermal energy by some "heat extraction type technology", although conventional uses of geothermal fluids also are now and will remain very active within this area.

Table 1. Summary of heat flow data in individual sub-areas in the Sengan-Hachimantai geothermal area.

Sub-area	Range of Conductive Heat FLow
Hachimantai	250 - 420 mW/m**2
Yakeyama	300 - ?
Kowase-gawa	145 - 190
Kakkonda	? (convection dominated)

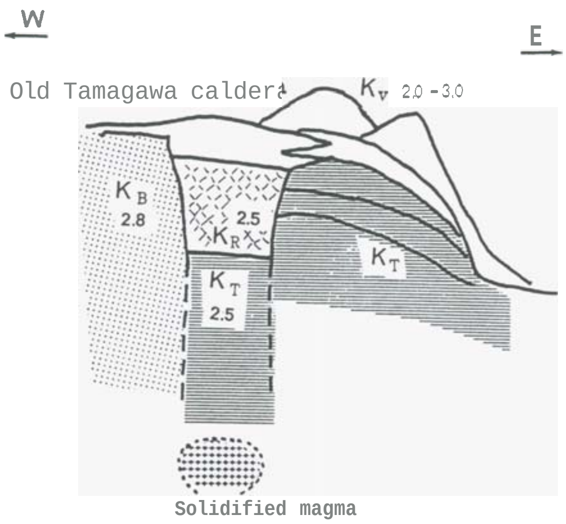

Fig.3 Schematic E-W cross-section through the Old Tamagawa caldera and Hachimantai volcano clusters, showing the subsurface thermal conductivity distribution. Representative values corrected for in-situ temperature condition are as follows (in W/mK): Sedimentary basement, K = 2.8; Rhyolite welded tuff, K = 2.5 ± 0.2: Tertiary rocks, K = 2.5 ± 0.3. For surface volcanics of different compositions (white part in this cross-section), K has a wide range between 2.0 and 3.0, depending on porosity and rock type.

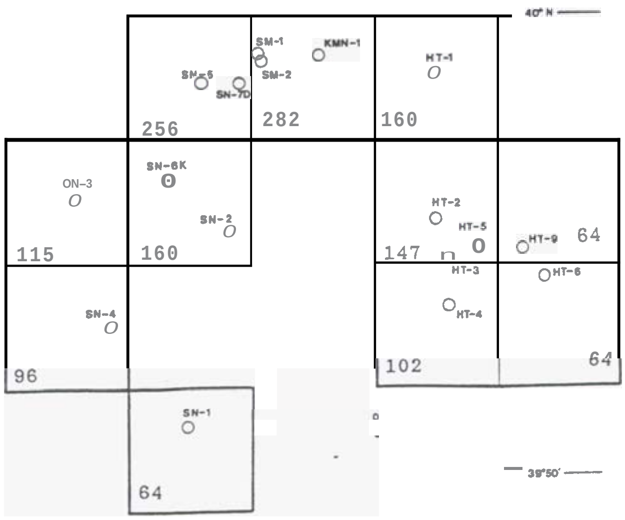

Fig.4 Distribution of I he [1.5 km] values for 5 km x 5 km grid blocks in the Sengan Area.

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