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CONDUCTION DOMINATED GEOTHERMAL REGIME IN THE SENGAN REGION, NORTHEASTERN HONSHU, JAPAN

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ABSTRACT

The Sengan Region, one segment of the backbone range of Northeastern Honshu, has a very unique thermal structure. Heat flow determined in holes with depths 200 to 500 m is higher than 120 mWm^{-2} anywhere within the region of approximately 40 km (E-W) x 50 km (N-S) mostly covered with young volcanic rocks thicker than 500 m. In contrast to other Japanese geothermal target areas such as Hohi, Kyushu, the Sengan Region is characterized by the absence of shallow temperature inversions indicating transient horizontal water flow or thermal convection, except for the immediate vicinity of the known reservoirs under exploitation. This pattern may be related to the characteristic mode of volcanic history of the region.

INTRODUCTION

In many geothermal fields in the world we encounter temperature logs in shallow holes (depths less than 500 m) that have a portion of negative temperature gradient. If the portion shows error function behavior, the transient effect of lateral water flow of a thin aquifer may be the explanation (Ziagos and Blackwell, 1980). Free convection driven by regional forced convection as considered by Morgan et al. (1981) for the Las Alturas geothermal anomaly, Rio Grande Rift, may be applicable to homogeneously permeable and constricted basins. These kinds of phenomena are also observed in most of the Japanese geothermal areas. However, the Sengan Region, Northeastern Honshu, which includes three geothermal power plants (one vapor-dominated and two hot-water ones) and is described as the "Hachimantai Volcanic Region" by Nakamura and Sumi (1981), does not have conspicuous temperature inversions in holes with depths ranging from 200 to 500 m. In the present work we consider the Sengan Region as a conduction dominated (shallow) geothermal regime, on the basis of temperature log data in approximately 30 holes. The set of data contrasts to that collected in areas such as the Hohi Region, Kyushu, where very complicated shallow hydrological effects have been observed.

TEMPERATURE MEASUREMENTS

Temperature data in drill holes used in the present work are obtained in two different ways. Static, high accuracy measurements were made by the author for five holes 250 m deep employing a portable type high resolution thermometer. For the other holes, consecutive logs up to 5 days after stopping mud circulation were made by a logging company. Time extrapolated temperatures were obtained using the formula of Lachenbruch and Brewer (1959). The former has proved to be useful for demonstrating the effect of surface topography on geothermal gradient measurement. A numerical technique was used to solve the steady state thermal conduction equation to obtain a topographic correction (Matsubayshi, 1983). The latter, which as a limitation in its accuracy, is regarded as reliable when used for discussions such as whether or not transient horizontal water flow effect is present, or whether vertical water flow velocity is high enough to push up or down the isothermsl relative to the purely conductive temperature field.

Thermal conductivity of core samples in water-saturated states were measured for five holes where static temperature gradients were actually measured.

RESULTS AND DISCUSSIONS

In the first place, we look at one study area with seven holes in a circle of 11 km in diameter and mostly covered with high density, impermeable rhyolitic rocks called the Tamagawa Welded Tuff. The presence of a high level young magma chamber below this large volume of acidic tuffs is suspected (Tamanyu and Suto, 1979). Figure 1 shows the location of the holes, temperatures of which are plotted against height above sea level in Figure 2.

It is apparent from Figure 2 that the thermal regime in this area is essentially conductive so far as the depth range of about 300 m below the surface is concerned. But the values of heat flow in this small area fall in a broad range; 150 mWm^{-2} for H-3 hole (topographic effect corrected, Matsubayshi, 1983) to about 350 mWm^{-2} for HM-1 hole (no thermal conductivity was measured). The scatter of heat flow values within an area as

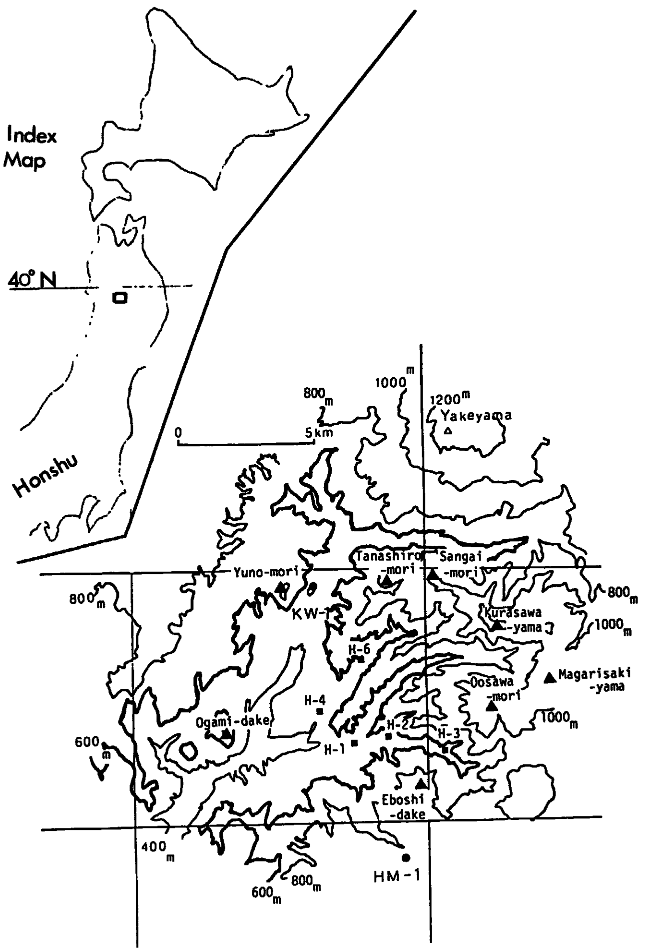

Figure 1. Location map of the area for detailed heat flow study in the northwestern part of the Sengan Region. Squares and solid circles indicate 250 m deep holes and 500 m deep holes, respectively.

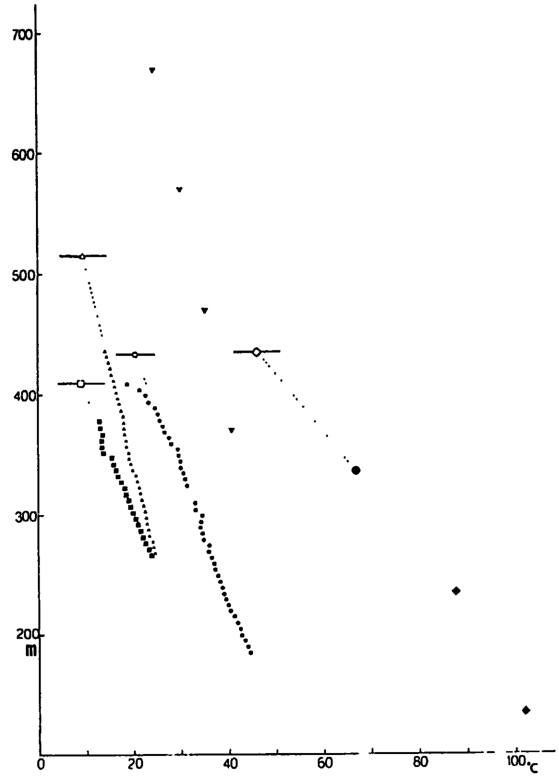

Figure 2. Temperatures plotted against height above sea level for holes shown in Fig. 1.

small as 100 km^2 may be caused by a hydrothermal system which exists beneath the Tamagawa Welded Tuff. The physical mechanisms by which the hydrothermal system is driven will remain unknown until deep drilling reaches the permeable sedimentary rocks which underlie the cap rock. The geological structure in this region is too complicated to rely on geophysical data such as resistivity or seismic reflection, etc.

Secondly, temperature log data of other parts of the region is also investigated. All these data belong to the second data category mentioned above (time extrapolated temperatures) and are taken from the reports of the drilling projects financed by the Government. Figures 3 and 4 show the examples. The data in Fig. 4 come from the deep holes in an area of 10 km (E-W) x 20 km (N-S) located to the north of the Matsukawa vapor dominated geothermal reservoir. Although the depths of the holes in this area are more than twice as large as those of the first study area, the general pattern of the temperature-depth curves is very similar to that of Fig. 2. It seems only below the thick young volcanic that there exists a hydrothermal system which causes a large scatter in heat flow values within the small area.

It should be remarked that the descriptions given above have not been referring to the temperature structure in the known reservoirts. In fact, in the immediate vicinity of the Kakkonda geothermal power plant, surface exposure of the Tertiary sedimentary rocks is known to be the site of discharge from the convecting reservoir, which is represented by hydrothermal alteration zones (Nakamura and Sumi, 1981). But the discontinuity of formations in this area seems to prevent the hot water reservoir from extending over a large horizontal scale. This probably makes one of the differences in this region from such a type of large geothermal reservoir as Wairakei, New Zealand.

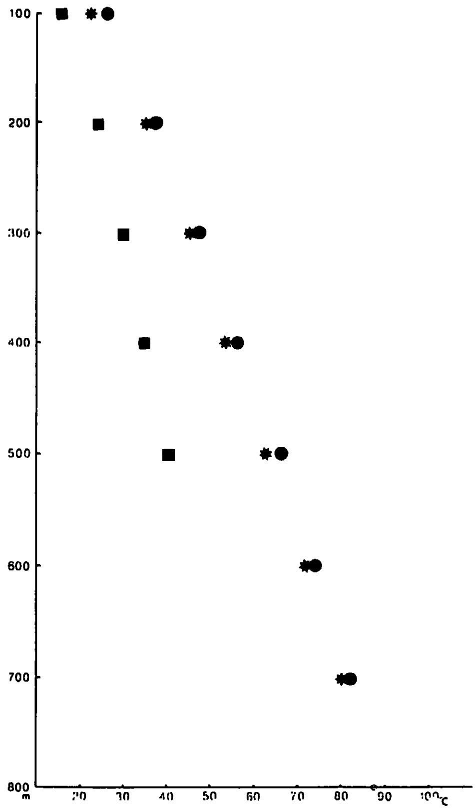

Figure 3. Temperatures plotted against depth from the surface for the holes in the northern part of the Sengan Region. Different symbols indicate different holes.

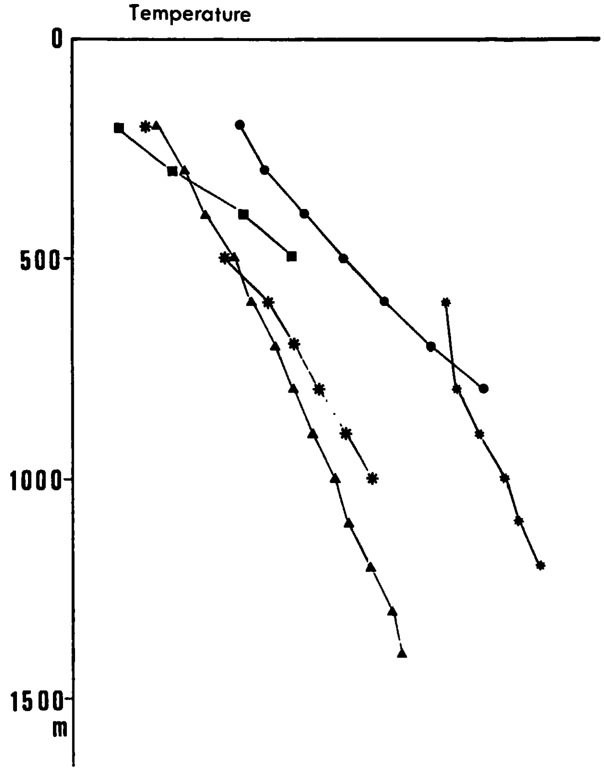

Figure 4. Temperatures plotted against depth for the deep holes in the eastern part of the Sengan Region.

Generally, low permeability of the young volcanics in the Sengan Region may be due to the characteristic mode of volcanism in the region. Although we do not have sufficient data of radiometric ages of these volcanics, a large volume of lavas might have been brought to the surface in a short period of time, instead of repeated intermittent activities. Voluminous ascent of acidic magma may have deformed the pre-existing formations and the fractures thus formed may have provided the channels for the geothermal fluids with the result of self-sealing of the fractures. We actually observe well sealed fractures by alteration minerals in many parts of the cores from the holes shown in Figure 1.

There are other areas in the Sengan Region which have basically the same thermal characteristics as those shown above. The important question to be answered is what physical meaning we can find for the minimum heat flow of the Sengan Region (150 mWm^{-2}). One possibility is the effect of a very large scale hydrothermal system beneath the thick volcanic rocks and the scatter of the observed heat flow values might be due to the smaller tributary systems which exist on shallower levels. Another is that we are looking at steady-state or transient thermal conduction from the magma with shallow redistribution of heat flow by hydrothermal heat transport below the volcanic rocks. Before we get a definitive interpretation of the available heat flow data, there are also many unanswered problems concerning the geothermal structure of this region. They are the history of the magma emplacements or volcanism (since the time of Green Tuff activity), the crustal deformation history associated with it, and the deep subsurface hydrology which most directly controls the present-day thermal structure. Continued research efforts including deep drilling are now in progress as one of the national research programs by the Geological Survey of Japan in cooperation with the New Energy Development Organization.

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