EVALUATION OF GEOTHERMAL HEAT SOURCE

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(1)INTRODUCTION

Geothermal heat potential is usually evaluated by the activities of Quaternary volcanism. The igneous-related geothermal systems proposed by Smith and Shaw(1975) is famous idea for quasi-quantitative evaluation of heat contents based on the diagram of conductive cooling model of magma chamber. This method rests on estimates of the probable volumes(VB) of high-level magma chambers and determinations of the radiometric ages(TY) of the youngest volcanism.

This method is adopted to the Quaternary volcanoes in Japanese geothermal fields, such as Hohi, Sengan, Kurikoma areas (Fig. 1, 2, Table 1). These results suggest that heat potentialities inferred from Smith and Shaw diagram seem to be underestimated for the middle Pleistocene volcanoes (TY:around 0.3 Ma) of which magma chambers have been proved to play important roles in heat sources by deep drillings. Author tried to examine the two major assumptions of Smith and Shaw diagrams, which are (1)heat transfer in rocks surrounding the magma chamber is by solid-state conduction and (2)effects of magmatic preheating and gains of magma after the time TY are ignored. Assumption(1) is ignored because it works on the heat evaluation as the cause of overestimation. Whereas, assumtion (2) conversely affects as the cause of underestimation. Therefore, assumption(2) and other parameters, for example time lag for ascending propagation of heat anomaly which affect as the cause of underestimation should be examined. It is difficult to evaluate the amount of heat supply to magma chamber after TY. But, the longevity of post volcanism which commonly continues over several hundred thousands years in many geothermal fields, strongly suggest the intense heat supply to magma chamber after magma injection.

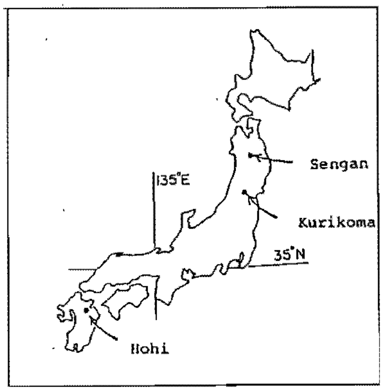

Figure 1. Index map

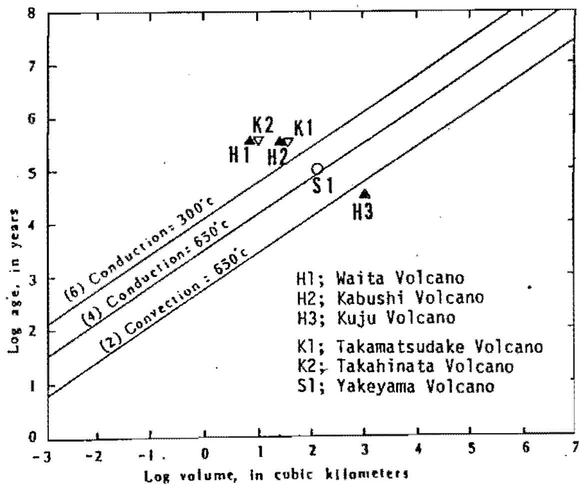

FIG. 2. Graph of theoretical cooling times versus volume for magma bodies (Smith and Shaw, 1975). Line (2): Assume that cooling takes place by internal convection of the magma chamber until solidification is nearly complete. (Points below line (2) show that magma chamber are almost molten). Line (4): Assume that cooling is entirely by condition, both inside and outside the magmatic chamber, until solidification is complete (≈ postmagmatic stage). Line (6) Assume that central temperature of the solidified pluton has fallen to about 300°C (≈ ambient temperature).

Table 1. Magnitudes of identified volcanic systems

Name of volcanic system	Composition last eruption	Age dated (TY)	Magma chamber Volume (VB)
[HOHI]			
Waita Volcano	Dacite	0.35 Ma	8 Km^3
Kabushi Volcano	Dacite	0.32 Ma	23 Km^3
Kuju Volcano	Dacite	0.03 Ma	940 Km^3
[KURIKOMA]			
Takamatsudake Volcano	Dacite	0.32 Ma	32 Km^3
Takahinata Volcano	Dacite	0.35 Ma	11 Km^3
[SENGAN]			
Yakeyama Volcano	Dacite	0.1 MA	125 Km^3

(2)HEAT POTENTIAL OF THE MAGMA CHAMBER INJECTED AROUND 0.3 MA

According to the analytical report on Nationwide Geothermal Exploration Survey Project by NEDO, the rate of heat propagation and conductive cooling of magma reservoir and its environs were calculated and drawn as Fig. 3 for the example of the Hachimantai Young Volcanics. This figure indicates that the time lag of heat propagation from magma seated at 7 Km in depth to upper shallow crust of 2-4 Km in depth takes several ten thousands years. Therefore, very young volcanoes less than 0.02 Ma can not afford to produce the active geothermal system at shallow crust around 2-4 Km in depth. Mt. Iwate in Sengan area and Mt. Kurikoma in Kurikoma area are the examples of this case. Fig. 3 also shows that 0.3 Ma magma is impossible to supply the heat source to present geothermal systems because the magma have already conductively cooled down. But, the actual geothermal explorations at Hohi, Kurikoma and Sengan areas suggest that the magma reservoirs of which TY is around 0.3Ma, have still supply the plenty of geothermal heat energy to present geothermal systems. Then, we have to introduce the concept of the long term heat supply after magma injection. For the purpose of reexamination of heat potential of magma reservoir with due consideration of heat supply after magma injection, three Japanese representative geothermal fields, Hohi, Kurikoma and sengan areas are investigated as follows.

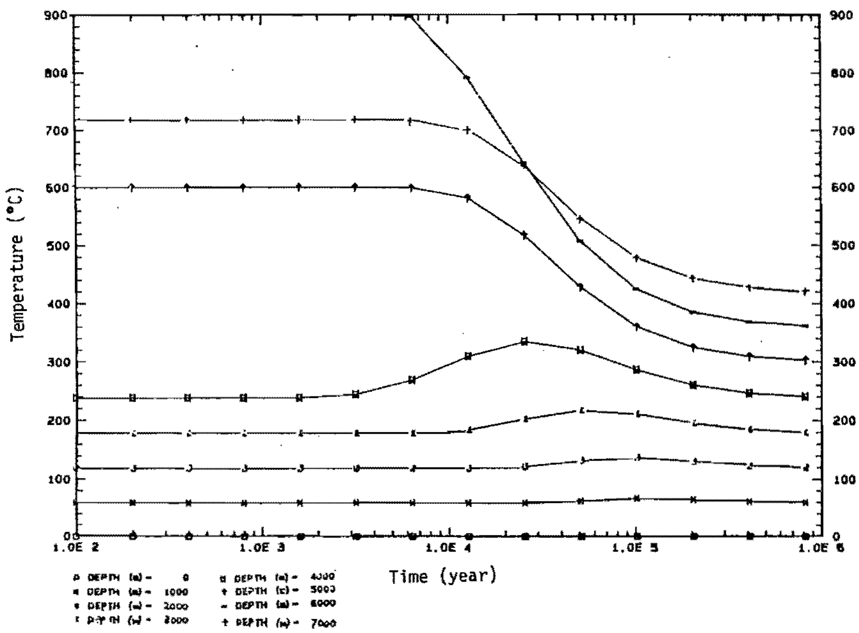

Fig. 3. Conductive cooling curve at subsurface each depth to magma chamber

(3)HOHI AREA

Geological and geothermal informations about the Hohi geothermal area and its environs were compiled as a map sheet (Research group for the geological map of Hohi Geothermal Area, 1982). Many drillings have been carried out for deep geothermal energy exploration project in this area. Based on these drilling, temperature contour map under the ground was drawn. And also, many young volcanics were age-determined. It becomes to be made clear that the distribution areas of the Young volcanics of which TY is around 0.3-0.4 Ma are corresponded to the areas of subsurface high temperature (Fig. 4). This result means that the magma reservoir of 0.3-0.4 Ma volcanism (the Early Kuju Volcanics) such as the Waita Volcano and the Kabushi Volcano, has not yet cooled down due to sufficient thermal supply to magma after the latest volcanism. Whereas, the volcanism of the Kuju Volcano started around 0.3 Ma and continued to 0.03 Ma at least. Therefore, the magma chamber of the Kuju Volcano has maintained high heat potential by continuous heat supply or intermittent mgma injections. In general, acidic volcanism followed by remarkable mineralization, is more expected than basic volcanism, that high heat potential continues for a long time.

(4)KURIKOMA AREA

Geological and geothermal informations about the Kurikoma geothermal area and its environs were compiled as a map sheet (Research group for the geological map of Kurikoma Geothermal Area, 1986). 6 drill holes of 1500m class in depth were completed at the Onikobe Caldera for the geothermal research program named "Confirmation study of the effectiveness of prospecting techniques for deep geothermal resources", and 8 drill holes of 1000-1500m class in depth were excavated at the Ogachi Caldera for the geothermal exploration program named "Survey to identify and promote geothermal development". According to the results of these projects, subsurface temperature contour map was drawn, and also, young volcanics were dated. These data made clear that the distribution areas of the Young Volcanics of which TY is around 0.3-0.4 Ma are corresponded to the area of subsurface high temperature (Fig. 5). This fact indicates that the magma reservoirs of 0.3-0.4 Ma volcanism, the Takahinata Dacite in the Onikobe Caldera, and the Takamatsudake Dacite in the Ogachi Caldera, have not yet cooled down by intense thermal supply through assumed deep seated fracture zones. Whereas, the magma reservoir of the Kurikoma Volcano is too young or too deep to produce shallow geothermal system.

(5)SENGAN AREA

Geological and geothermal informations about the Sengan geothermal area and its environs were compiled as a map sheet (Research group for the geological map of Sengan Geothermal Area, 1984). 8 drill holes of 1500m in depth were excavated for the geothermal research program named "Confirmation study on the effectiveness of prospecting techniques for deep geothermal resources". Based on these drilling, subsurface temperature contour map was drawn (Fig. 6). This map shows that the distribution areas of the Young Volcanics around the Tamagawa Caldera except western part are corresponded to subsurface high temperature ares. The ages(TY) of these volcanics, such as Oobuka, Oomatsukura, Nyuuto Volcanoes, approximately range from 1.0 to 0.5Ma. Therefore, intense thermal supply after TY should be taken account. Especially, subsurface intrusive rocks confirmed by drillings at Kakkonda, Matsukawa and Sumikawa geothermal developing areas, must make important roles to supply heat energy upward through deep seated fracture zone. But, the Yakeyama volcano is an example that extra heat supply do not need because of contineous volcanism. Whereas, Iwate Volcano is too young to make geothermal system.

(6) EVIDENCE OF ACTIVE THERMAL SUPPLY AFTER MAGMA INJECTION

As above mentioned, it is made clear that active thermal supply to magma after latest volcanism should be considered from the results of case studies at Hohi, Kurikoma and Sengan. Here, the author try to present the evidences of this thermal supply as follows.

a) subsurface thermal gradients are calculated by lower part of deep drill holes exceeding 1000 m in depth, as 90°C/Km at Hohi area, 140°C/Km at Kurikoma area and 100°C/Km at Sengan area respectively. Given these facts, magma chambers are possible to be now molton around 5-8 Km in depth by active thermal supply to magma.

b) The ages of geothermal alteration or ore mineralization are estimated by K-Ar and Fission track methods using the concept of closure temperature. These results indicate the life time of post-volcanism is generally around 0.5-1.0 Ma. Therefore, active thermal supply after magma injection is fairly possible to occurr commonly.

c) In general, Magmatic pressures increase at active volcanoes, and are fallen down by eruptions. If magmatic pressure is constant for a long time, it will be interpreted as balancing of heat supply to magma and heat discharge to surface of earth. These heat balance might be occurred at extinct or dormant volcanoes of which almost part are age-determined around 1-0.1 Ma.

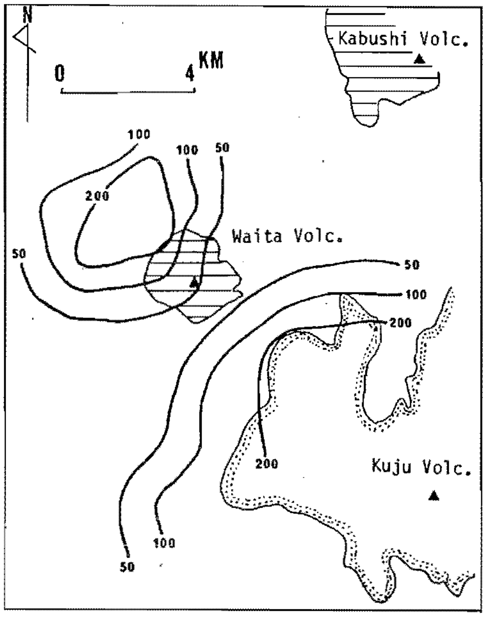

Fig. 4. Comparison between distribution areas of young volcanics and subsurface temperature contour map at sea level in Hohi area.

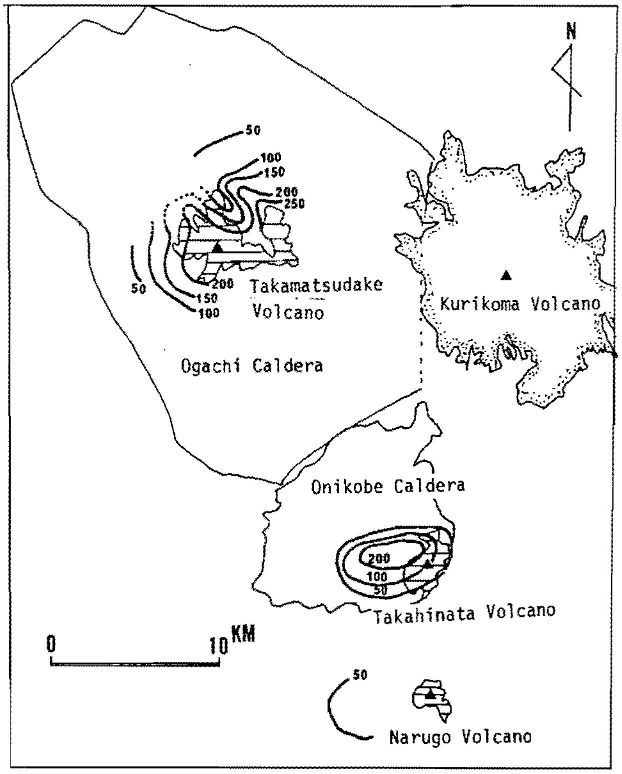

Fig. 5. Comparison between distribution areas of young volcanics and subsurface temperature contour map at sea level in Kurikoma area.

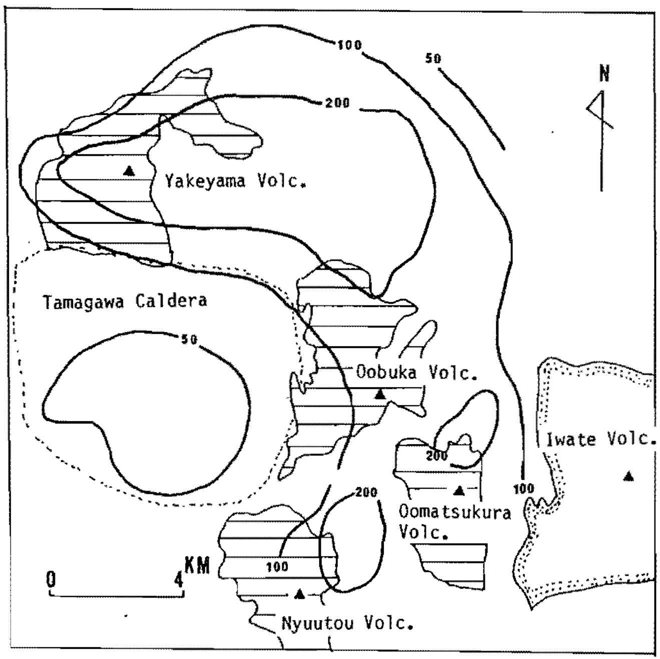

Fig. 6. Comparison between distribution areas of young volcanics and subsurface temperature contour map at sea level in Sengan area.