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ALTERATION AGE AND HEAT SOURCE ROCK IN THE HOHI GEOTHERMAL AREA, JAPAN, IN RELATION TO “GEOTHERMAL INDEX”

Masao HAYASHI[1]
[1]Kyushu Sangyo University, 2-3-1 Matsugadai, Fukuoka 813, Japan

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ABSTRACT

In order to relate underground temperature to age of altered and volcanic rocks at the surface, TL and FT datings have been carried out on zircon from the Hohi geothermal area. Depth-temperature curves of wells drilled in the area were evaluated using “Geothermal Index (GI)”, which ranges from 0 to 100 and is higher than 35 for steam-productive wells. In most cases, they are accompanied by volcano younger than 300Ka, and/or altered rock younger than 50Ka, within the circular area whose radius is equal to their depths. The heat source volcano tends to have larger ratios of diameter to height, suggesting higher viscosity of its magma, which may emplace at shallower depths acting as heat source.

1. INTRODUCTION

The Hohi geothermal area in middle Kyushu (Fig. 1) is underlain by Quaternary volcanic rocks to form many lava domes including active one. The area provides abundant geothermal resources and three power plants were already set up, 12.5 MW Otake, 110 MW Hatchobaru, and 25 MW Takigami, together with the coming Oguni power plants.

Many wells have been drilled in the area, in which those deeper than 1000m amount to 120 in number. Furthermore, a new project to find promising fields is being carried out by NEDO (New Energy and Industrial Technology Development Organization).

In exploration of geothermal resources, a geologist has been dating numerous volcanic rocks and altered rocks. Obvious relations between volcanic and geothermal activities, however, have been unknown yet. One of the reasons is that we have no adequate methods and minerals which are able to date heat source rock, for example, ranging from 1 to 100 Ka. The TL method of quartz is an exception, but the mineral is rather uncommon in volcanic and altered rocks.

The writer pays attention to TL and FT methods of zircon, which is superior to quartz in the following points: (1) Zircon is common in igneous rock as well as in other rocks. (2) Almost all of the radiometric radiations are caused by elements (U, Th) inside the mineral, resulting in the easier evaluation of the annual dose. (3) The mineral usually remains stable even in altered rocks through hydrothermal alteration.

The ages obtained are probably related to underground temperature conditions represented by “Geothermal Index (GI)”, which compares a depth-temperature curve of a well to the boiling point curve of water. As a result, it has revealed that promising fields should accompany volcanoes younger than 300ka, and/or altered rock younger than 50ka. Other factors as heat source rock will be also discussed.

2. Geothermal Index (GI)

To evaluate temperature conditions of a well, Hayashi (1999) proposed “Geothermal Index (GI)”. In figure 2, Sb is the horizontally hatched area surrounded by the boiling point curve of water and the vertical line corresponding to a temperature of 0ºC. Sm is the vertically hatched area surrounded by the depth-temperature curve and the 0 vertical line. GI is given by GI=100k(Sm/Sb), where k is the “**highest temperature coefficient**”. This k corresponds to the ratio of Sm/Sb when the depth-temperature is vertical, and can be calculated by k=1.20r from 0 to 187ºC, or, $k=1-1.25(1-r)^{1.59}$ above 187ºC, where r is the ratio of the highest temperature measured (H) in a well to the critical point of water (374ºC). Namely, r=H/374.

3. EXPERIMENTAL

3.1 Separation of Zircon

A rock sample only of 100g was crushed down to grains smaller than 0.2mm in diameter. After washing out clay fractions, the grains were dried at temperatures below 100ºC, and magnetic minerals were removed with a hand magnet. The non-magnetic grains were panned to concentrate zircon, which was treated with NO3 (1:1) and HCl (1:1) solutions for one hour each at room temperature to solve the surface contamination. Finally, zircon was purified by the picking technique under a stereoscope.

3.2 TL Dating

The apparatus used for TL dating is the Kyokko TLD System 2500 from Kasei Optonics Co. Ltd. Each of 10 grains from a sample was heated from room temperature up to 500ºC, at a rate of 2ºC/sec. The grains were irradiated with gamma-rays from Co-60 and the artificial TL was then measured to obtain the equivalent dose (ED). The annual dose (AD) was evaluated by counting alpha recoil tracks on CR-90 detector attached to the zircons for one month. A TL age is given by Y=ED/AD.

Hayashi

3.3 Fission Track Dating

Unpolished zircon grains (2π) were etched in an eutectic solution of NaOH + KOH at 237ºC for 48 to 76 hours to reveal spontaneous tracks (Gleadow et al., 1976). The etched grains were irradiated with thermal neutrons in a TRIGA MARK Ⅱ reactor to produce induced tracks. They were etched with the same etchant for 36 hours (re-etch method). Both the tracks in a grain were counted under a microscope with x2000 magnification. A FT age was calculated using the zeta calibration method (Hurford, 1990) with ζ=340±20.

4. RESULTS

4.1 Geothermal Index (GI) of Wells

GI values were calculated for exploratory and production wells, and are shown in Fig. 3, in which the diameter of each circle is half of its depth. The solid part in a circle corresponds to GI, for instance, a solid quarter round is 25 and a solid semicircular is 50 in GI.

All the steam productive wells in the Hohi area have GI values larger than 35, which is the same as other Japanese ones. A production well HT5-1 at Hatchobaru, which reached a temperature of 305ºC (Tanaka and Ejima, 1982), is of the highest rank in GI (53) in the Hohi area. The Takigami production wells range from 31 to 44 reflecting their rather low temperatures. At Oguni, where a new power plant is in the planning stage, GH-9 has GI of 52. Other less active fields are smaller than 30 in GI.

4.2 TL Ages

TL ages of zircon in altered rocks range from 30 to 800 Ka. The youngest age was obtained on a sample from the Komatsuike fumarole at Hatchobaru, where is the most active manifestations in the Hohi area. Other samples from fumaroles, where are now being nearly at the boiling temperature of water, are older, probably depending on their degree of geothermal activity. The TL ages for zircon are older than those for quartz from the same places (Hayashi, 1997; Takashima, 1985).

TL ages of zircon in possible heat source rock are 32 Ka for Hatchobaru and 40 Ka for Otake. Heat source rocks from the other fields are much too old for the method.

The zircon TL method has revealed that it is suitable for samples younger than 100 Ka.

4.3 Fission Track Ages

FT method can be applied to zircon older than 100 Ka, which is too old for the TL method. The FT results range from 180 to 459 Ka, and are plotted in Fig. 3. Heat source rocks are 18 Ka for Takigami, and 310 Ka for Oguni, which is the oldest in the Hohi area. Although many young volcanoes are located in the southeastern part of the area, the geothermal activity there is less active, except active volcano Iwoyama with huge steaming ground at surface temperatures up to 260ºC (Mogi et al., 1994).

5. DISCUSSION

Geothermal Index (GI) is an indicator to evaluate a geothermal well in relation to its depth-temperature curve. Even wells with the depth-temperature curves running along the boiling point curve of water (BPCW) have different GI values depending on the highest temperature attained. This GI can be also applied to surface manifestations: for example, a hot spring at 85ºC is GI = 100 x 0.27 (85 / 100) = 23. Accordingly, GI is able to rank not only geothermal wells but also surface manifestations in order of activity. Japanese steam productive wells are larger than 35, and wells in the recharge area are smaller than 5 in GI. For geothermal exploration, fields with wells larger than 20 or 30 in GI may be possible or promising for the purpose of the conventional geothermal generation.

Thermal manifestations at the surface are of particular interest for the exploration of geothermal resources. Next to the chemical data of geothermal fluids, alteration age will be useful. As mentioned, the obtained TL ages for zircon in altered rock at the surface reflect underground temperature conditions. Younger ages may indicate higher underground temperatures.

Although alteration ages have been measured on quartz, a systematic thermal structure could not be drawn when the mineral is absent in some altered rocks. Since zircon is common in almost all rocks, its TL dating will become popular in the near future.

FT method of zircon can be used for rocks older than 100 Ka and younger than 100 Ma, but it is not good enough for younger zircon whose spontaneous density is low. An alternative technique which can date zircon from 100 to 1000 Ka is expected to develop.

Active geothermal systems usually accompany high-temperature manifestations such as steaming ground and hot springs. As is well known, the chemical analysis of their fluids bring us useful information about underground temperature. In fields where cooled altered rocks are only manifestations, alteration age will be the next piece of valuable information. The TL ages obtained this time may not mean accurate alteration age because TL signals will anneal or become weak depending on the sum of heating temperature and heating time. However, they may show the order of large or small at least, which is enough for the

exploration.
For fields even without altered rock, the age of a volcano will be the last information to guess underground temperature conditions for a geologist. Unfortunately, we do not have dating methods good enough for heat source rocks younger than 1 Ma. Zircon may be the only mineral for this purpose since it is common in various rocks and stable through alteration. A new dating technique for this mineral must be developed.

The zircon FT ages of this time suggest that active geothermal systems require volcano younger than 300 Ka, but do not have a reverse linear relation to their GI values, degree of geothermal activity. Any other factors should exist: for example, volcanoes with higher height / diameter ratios tend to be favorable for heat source, in addition to their volumes. The higher ratios suggest higher viscosity of magma, which is small in specific gravity and may result in emplacement at shallower depths. This kind of discussion on heat source rock, however, may become possible after dating it with accurate methods.

6. CONCLUSIONS

From evaluation of the depth-temperature curve in a well using "Geothermal Index" (GI), and Tl and FT dating of zircon in candidates for heat source rocks and altered ones in the Hohi geothermal area, Japan, it may be concluded:
(1) Steam productive wells in the Hohi area are larger than 35 in GI, similar to other Japanese productive ones.
(2) Steam productive wells are usually accompanied by a volcano younger than 300Ka, and/or altered rock younger than 50Ka, within the circular area whose radius is equal to their depths.
(3) Heat source volcano tends to have higher height/diamater ratios, probably reflecting higher viscosity of its magma.

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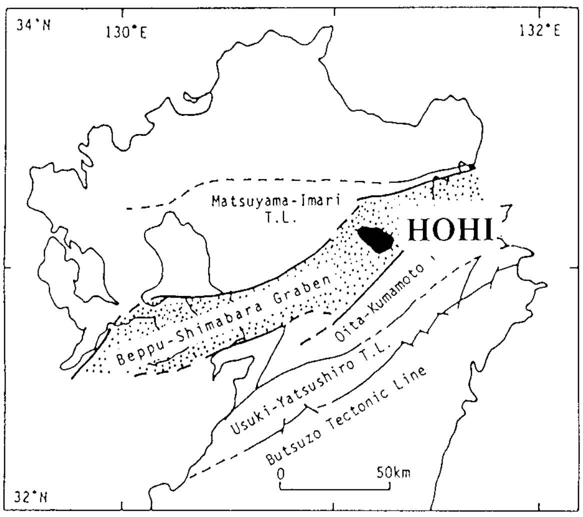

Figure 1. Location of the Hohi geothermal field

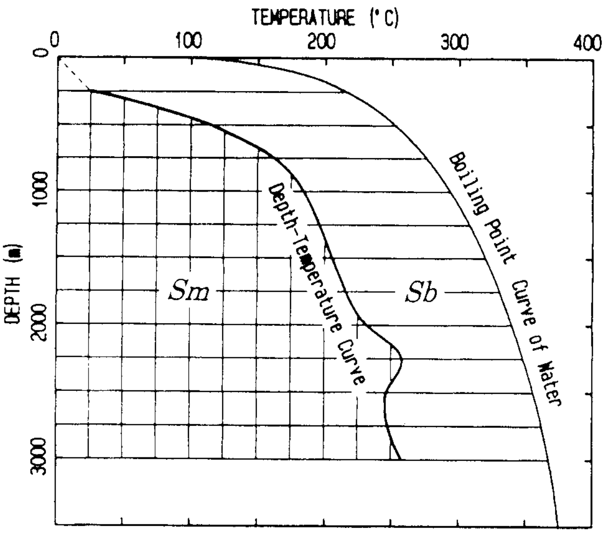

Figure 2. Figure showing the principle of "Geothermal Index"

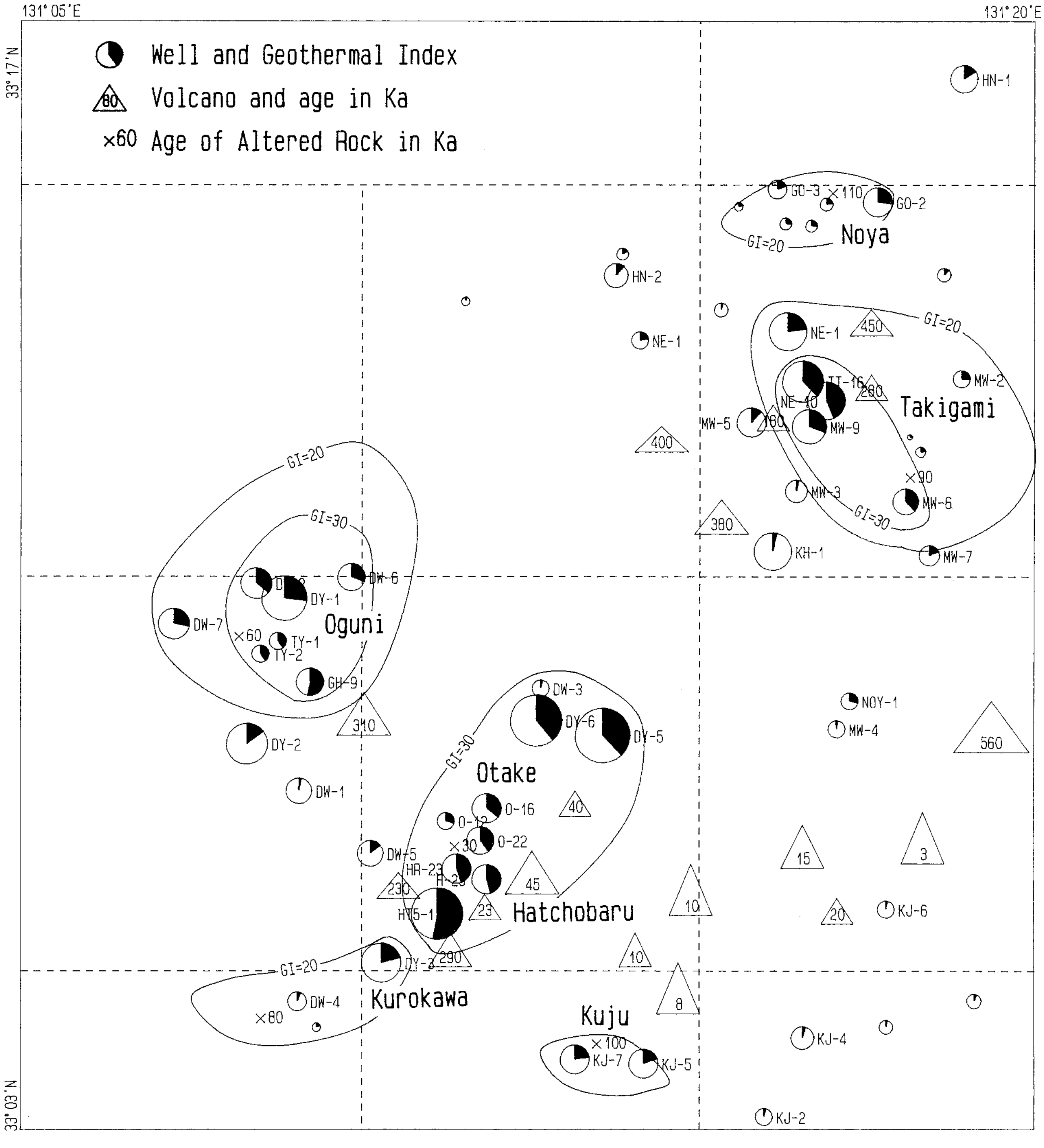

Figure 3. Map showing locations of wells with "Geothermal Index", and volcanoes and altered rocks with radiometric age in Ka in the Hohi geothermal area, Japan. The diameter of the circles is proportional to the depth of wells, and its solid part indicate "Geothermal Index" (GI). Volcano is shown by a triangle with its age inside and the height / diameter is exaggerated by three times. The smallest alteration age in each field is shown by X.