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ALTERATION AGE MAPPING OF SOME JAPANESE GEOTHERMAL FIELDS WITH IMPROVED THERMOLUMINESCENCE DATING METHOD

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ABSTRACT

Improved thermoluminescence (TL) dating of altered rocks were carried out for three areas in northeast Japan. TL dating of altered rocks is unique and very useful because the heat stored in the ground is directly estimated by the age of alteration. Obtained data are plotted to form an alteration age map. Based on this map, geothermally hopeful areas are identified and the relationship between surface alteration age at the drilling site and subsurface temperature is identified. It also is used for the determination of thermal history of the area. Most of hopeful geothermal areas are located at the surface alteration ages younger than 0.3Ma. Subsurface temperatures differ from place to place even if the alteration ages are almost the same. Such difference may attribute to the type and size of hydrothermal system. Overlapping of geothermal activities is identified at the Matsukawa area.

INTRODUCTION

TL is an unique technique for age dating. This method was applied to many geological and archaeological fields and a summerized book (Aitken, 1985) was published. However, TL dating have many uncertainties compared to K-Ar or other radiometric techniques. Accordingly, this method is seldom used for geological materials. However, in cases of geothermal study, TL dating have many advantages: (1) range of dating is few thousand to about one million years, which is apt to heat evaluation but difficult to date by other methods; (2) based on low closing temperature, age of alteration and thermal history of geothermal area can be evaluated; (3) sample for measurement is quartz which is chemically stable and easily found in acidic volcanic rocks and alteration products.

In this paper, a technique of TL dating itself is discussed for the improvement of the method. Then, the data of TL dating of altered rocks are introduced and the way of application of TL ages to geothermal exploration is discussed. Figure 1 is the location map showing the three areas studied in this paper. Samples of volcanic rocks collected from other areas are also used for the discussion of TL dating technique.

PROCEDURE AND PROBLEMS OF TL DATING

TL dating is an application of dosimetry using natural minerals. Minerals in the field are receiving radioactivity from surroundings with the fixed rate annually (Annual dose, AD) and accumulate a total TL in geologic time, which is called a paleo dose (PD). Annual dose is simply calculated from the chemical data of radiogenic elements (U, Th and K) and cosmic rays evaluation. Paleo dose is also obtained from TL glow measurements of both natural and artificially irradiated samples. Then the TL age (t) is calculated by the following simple equation:

\[ t = \frac{PD}{AD} \]

The mineral used in this study is quartz which is chemically stable and has relatively high TL sensitivity. Figure 2 is the newest procedure of TL dating. Details of each process and measurement are described in the previous paper (Takashima, 1985). At present, TL age can not be obtained from the above equation because some unknown factors remained. The way of correction is described later.
Among the problems remaining in TL dating, the following two important points are discussed; (1) saturation of TI glow; (2) wavelength of measured TL glow.

It is not so difficult to obtain paleo dose of saturated samples. Figure 3 is an example of the result for such sample. Very good results are obtained if many measurements were carried out. In Fig. 3, TL growth line is obtained from the least squares method. Using a peak height ratio for the vertical axis in Fig. 3 reduced the error of peak measurements. The sample is Quaternary pyroclastic flow deposit collected from Aizutajima, Fukushima Prefecture, Japan. K-Ar age of this sample is 1.1 -1.2 Ma (Yamaguchi, 1986) and some TL glow curves are shown in Fig. 4.

TL glow measured by different wavelength are drastically changed in the same sample. Figure 5 is the glow curves of Bishop tuff collected from Long Valley area, California, U.S.A. In the previous paper (Takashima and Honda, 1985), this sample is identified as non applicable for TL dating because of no high temperature peaks. However, TL glow of long wavelength side shows a high temperature peak and calculated TL age is close to the K-Ar age of 0.7 Ma (Dalrymple et al., 1965). This phenomenon corresponds to the data of Hashimoto et al. (1987). A photomultiplier tube used for TL detector has the receiving wavelength of 200-700 nm. Wavelength of TI measurements in the previous paper is the same as the above because only infrared cut filter is used. On the other hand, only 590-700 nm TL signal is detected in this study by using longwave path filter. The use of this wavelength is suited for TL dating of altered samples too.

Based on the TL dating of the above age known samples, TL age obtained by the equation of PD/AD tend to be young and must be corrected. At present, figure of 1.29 is multiplied to original TL age. All TL ages appearing in this paper are corrected by this procedure.

There is no discussion for errors in TI dating. It is easy to calculate the error of measurement. However, more important problems remained in TL dating process. Accordingly, there are no errors presented in all data. Roughly, TL ages presented in this paper have an error of about ±30%.
RESULTS OF TL DATING OF ALTERED ROCKS

Numbers of TL ages obtained in the Azuma, Kuri-koma and Hachimantai areas are 20, 24 and 55 respectively. Table 1 is the summary of TL dating of the Azuma area in which all data for TL dating are contained. For other two areas, only age data are plotted on the maps. Age difference from the previous paper (Takashima and Honda, 1985) is caused by use of stable long wavelength TL peaks (Fig. 6).

Figures 7, 8 and 9 are the maps showing alteration zones and TL ages of the above three areas. Simple procedure of TL dating permits the alteration age mapping as shown in the above Figs. 7-9. It is easily said that the thermal manifestations are located on the areas that are characterized by the TL ages younger than about 0.3 Ma. Further considerations about subsurface temperature estimation and thermal history will be carried out in the following sections.

SUBSURFACE TEMPERATURE AND SURFACE ALTERATION AGE

It is possible to compare the measured bore hole temperature and alteration age of the surface drilling site. Figure 10 is the results of that plot for studied three areas. In this figure, subsurface temperature is selected as the data of 1000 m depth and alteration age is the average of nearest data except for additional 1500 m temperature for SN-1 to 4 wells in the Hachimantai area.

Table 1. Summary of TL dating results of altered rocks in the Azuma area

<table>
<thead>
<tr>
<th>No.</th>
<th>Sample</th>
<th>U ppm</th>
<th>Th ppm</th>
<th>K2O ppm</th>
<th>Annual dose (Gy/ka)</th>
<th>Paleor TL age (Ma)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>KR-130</td>
<td>20.8</td>
<td>8.8</td>
<td>0.024</td>
<td>5.351</td>
<td>0.12</td>
</tr>
<tr>
<td>2</td>
<td>MR-457</td>
<td>9.7</td>
<td>1.0</td>
<td>0.036</td>
<td>2.380</td>
<td>0.006</td>
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<tr>
<td>3</td>
<td>MR-397</td>
<td>11.6</td>
<td>0.6</td>
<td>0.005</td>
<td>2.747</td>
<td>0.014</td>
</tr>
<tr>
<td>4</td>
<td>MR-115</td>
<td>1.7</td>
<td>0.4</td>
<td>0.024</td>
<td>0.569</td>
<td>0.049</td>
</tr>
<tr>
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<td>0.591</td>
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<tr>
<td>6</td>
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<td>1.733</td>
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<tr>
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<td>MR-510</td>
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<td>1.000</td>
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<td>538</td>
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<tr>
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<tr>
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<td>3.077</td>
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<tr>
<td>13</td>
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<td>3292</td>
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<tr>
<td>14</td>
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<td>15</td>
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<td>7</td>
<td>2.03</td>
<td>4.157</td>
<td>8500</td>
</tr>
</tbody>
</table>

Annual dose is calculated by the data of Bell (1979)
Figure 7. TL ages and alteration zones of the Azuma area

Figure 8. TL ages and alteration zones of the Kurikoma area
An alteration age has different meaning with its alteration type. Alteration is roughly divided into two types. One is green-colored alteration which formed at conduction dominated large scale hydrothermal system of neutral to alkaline conditions. The other is white-colored alteration which formed at small scale hydrothermal system directly related to the movement of acid fluid or gases.

In Fig. 10, a clear linear relation is found for the data of SN series wells which drilled in large scale green-colored alteration zone (Fig. 9a). For this kind of alteration, subsurface temperature estimation can be done from the TL age data of surface samples. At the depth of 1500m, temperature of SN-2 well is shifted to high from the line drawn from other three wells. It may be attributed to the contribution of Yakeyama Volcano which is considered as a new heat source in this area. It also implies that the contribution of a new heat source can be detected at about 1500m depth on the site of SN-2 well.

For another two areas, the same kind of consideration can be done if enough data are available. Care must be taken for the data of TL age in the locally formed white colored alteration halo. At present, such data is used only for rough estimation of the area.

Figure 10. Relation between alteration age of the surface sample and subsurface temperature
THERMAL HISTORY

Thermal history can be evaluated by the TL age data and characteristics of alteration zones. Figure 11 is an example of the analysis of thermal history of the Kakkonda-Omatsukurazawa area based on the data of Fig. 9b.

Important points of the thermal history are as follows:
(1) Thermal activities are divided into two stages. One is 1 to 0.7 Ma and the other is 0.3 Ma to present;
(2) Time gap is identified between green and white colored alteration zones. In the former area, hydrothermal activity had been ended at 0.7 Ma which was younger than the latter areas where such activity had been ended at 1 Ma. This may be attributed to the green-colored alteration, formed at the large scale conduction dominated hydrothermal systems. Similar phenomenon is also observed for newly occurred hydrothermal activities. In the studied area, such time gap is estimated as about 0.3 Ma;
(3) White-colored acidic alteration tends to become a cap rock for geothermal fluids. Mastskawa area, only one vapor dominated system in Japan, is widely covered by white colored alteration halos. It is considered that the old acidic alteration (older than 1 Ma) acts as a cap rock and new heat sources coming up to form presently active vapor dominated system.

SUMMARY AND CONCLUSIONS

Following results are obtained for three geothermal areas in Japan with the improved TL measurements of altered rocks.
(1) Careful TL measurements of long wavelength (590-700nm) gave a reliable age.
(2) Geothermally hopeful areas are easily identified from the TL ages of altered rocks. In many cases, alteration age less than 0.3 Ma is a limit for hopeful area.
(3) Subsurface temperature can be evaluated from the TL age data of altered sample if the sample is collected from a green colored alteration halo formed by large scale conduction dominated hydrothermal systems.
(4) Overlapping of hydrothermal activity is recognized in the Hachimantai area. In such case, old aged alteration halo play a role for cap rock.
(5) Hydrothermal activity of the large scale conduction dominated hydrothermal system has the longer lifetime than sporadically occurred acidic hydrothermal system. The time gap between the above two systems is about 0.3 Ma at the Hachimantai area.

As a conclusion, TL dating is very useful for geothermal exploration and study. However, further study is needed for the determination of temperature that TL accumulation is re-set after alteration.
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REFERENCES


*in Japanese with English abstract