OTAKE-HATCHOBARU GEOTHERMAL FIELD IN JAPAN IN RELATION TO THE THERMOLUMINESCENCE INDEX (TI)

Masao HAYASHI

Kyushu Sangyo University. 2-3-1 Matsugadai. Fukuoka 813. Japan

Abstract

The thermoluminescence index (TI), a simpler application of the TL dating method, was applied for quartz in volcanic and altered rocks from the Otake-Hatchobaru geothermal field. The heat-source rock for Otake and Hatchobaru has TI of 40 to 45 and 23 (equivalent to ka), respectively. Quartz from steaming grounds is smaller than 1 in Hatchobaru, and that in Otake ranges from 4 to 13 in TI. This may reflect on the reservoir' temperature benveen Hatchoharu (<287° C) arid Otake (<238° C). Some quartz from non-steaming ground are larger than 100 in TI. Although there are hvo explanations for the large TI values: one is the alteration age is old, and the other is the partial annealing of TL signals, the analysis of the paragenesis of alteration minerals suggests the former possibility. Thus, the TI can he used to estimate the age of volcanic eruption as well as hydrothermal alteration as the simplest technique.

1.0 INTRODUCTION

There are various methods to determine the age of young volcanic rocks, which serve as the heat source of active geothennal systems, and the age of alteration occurred during their eruptions. They include techniques of potassium-argon **(*K-Ar*).** fission-track (FT), thermoluminescence (TL), and electron spin resonance (ESR). However, none of these methods are not widely used to geothermal exploration, because of their technical difficulty and analytical limitation.

The thermoluminescence index (TI) proposed by Hayashi and Shinno **(1996)** is a simpler application of the TL dating methods (Takashima, **1985).** The TI can be calculated only by the intensity ratio of natural TL from a mineral between a sample and a standard whose radiometric age is known. The TI. therefore. will be the simplest method to estimate not only the age of Quaternary volcanic rocks but also the age of altered rocks which contain primary and secondary minerals such as quartz and zircon.

The paper presents the results of the first application of this technique to quartz in volcanic and altered rocks from the Otake-Hatchobaru field in Japan. where there have been operating the 12.5MW Otake and the 110MW Hatchobam power plants.

2.0 GEOLOGIC SETTING AND SAMPLES

The Kuju volcanic region in which the Otake-Hatchobaru geothennal field is located is in a volcano- tectonic depression zone, Beppu- Shimabara Graben in middle Kyushu (Fig. **1).** The geothennal field and its surroundings are dominated by Quaternary volcanic rocks (Fig.3). They are divided into two: early Pleistocene Hohi volcanic rocks consisting of pyroxene andesite, and middle to late Pleistocene Kuju volcanic rocks consisting of hornblende andesite to dacite *(Yamasaki et al., 1970). The former contains no primary quartz, while the latter contains*

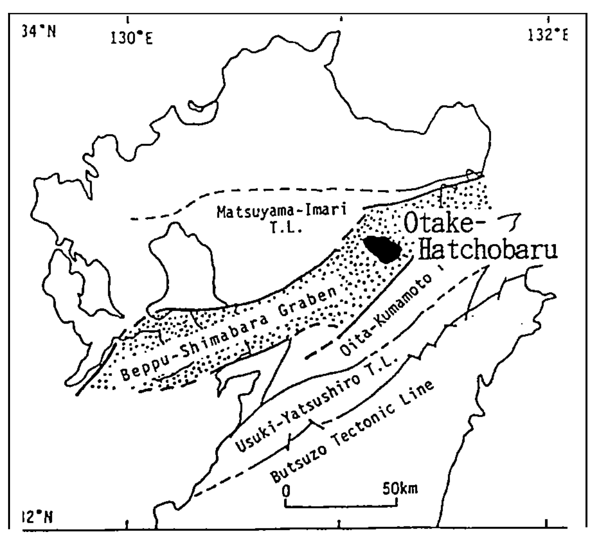


Fig.1. Location map of Otake-Hatchoharu field in middle Kyushu.

it in almost all the samples. The volcanic rock samples collected are listed in Table 1.

There are two kinds of faults ascertained or estimated in the Otake-Hatchobaru field (Ha! ashi and Yamasaki, 1983). Geologically, tlic NW-SE trending faults are dominant, along wluch fumarolcs, hot springs. and altered rocks are distributed here and there (Fig.3). Of these faults. the Otakc fault and tlic Komatsuike fault seem to be related to the geothermal activity at Otake and Hatchobaru, respectively. The NE-SW trending faults were estimated by geophysical surveys and also by llic analysis of drilling cores and cuttings. These two kinds of faults are of lateral types fonned under the EW compressional stress fields (Hayashi and Furutani, 1984).

Altered rocks in the Otake-Hatchobaru field are divided into three types: alunite. kaolin and montmorillonite (Hayashi, 1973). The alunite zones are found to be close along the NW-SE faults, the kaolin zones surround the alunite zones at Hatcliobam, and the montmorillonite zones at Otake. The altered rock samples collected are listed in Table 2.

3.0 EXPEFUMENTS

3.1 Sample preparation

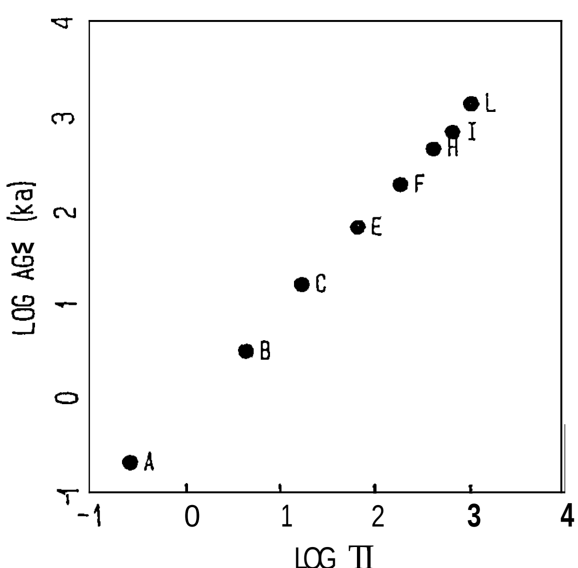
About Ikg of altered rocks was used for the separation of quartz. **A** sample was crushed in water to avoid the partial annealing of TL during crushing. After washing out the clay fractions. the grains were dned at teniperatures below 100°C, and sifted with 25 and 50 mesh sieves. Accordingly, grains with diameters behveen 0.3 and 0.6 mm were collected. Mafic minerals were removed with a hand magnet. The non-magnetic grains were treated with a cnnc HF solution for 5 min *to* solve the surface area of **quart** grains, that had been subjected to the main alfa-radiation. Finally, quartz were purified by the picking technique under a stereoscope.

3.2 Apparatus and TL measurement

The apparatus used is the Kyokko TLD System 2500 from Kasei Optonics Co. Ltd. (Zen and Hayashi, 1992). It **was** originally intended for medical and environmental radiation monitoring. The major specifications of the instrument are as follows: (1)Name: Kyokko TLD System 2500, (2)Range of measurement: 0.01mGy(milli-gray) - 1000Gy(gray), (3)Range of temperature: room temperature - 500°C. (4)Heating rate: 2"C/sec - 25"C/sec (2"C/sec mas used), (5)Heating system: Direct heating system of plate heater, (6)Sample **pit:** 10mm in diameter, (7)Photomultiplier: R-366 with maximum sensitivity at 340nm. and. (8)Calibration of glow: Standard light excited by C-14.

For a measurement of the intensip- of natural TL, **quartz** grains which are clear were selected out of the purified grains. At least. 10 measurements were carried out for a sample to obtain its mean and standard deviation The intensity **was** calculated to integrate the TL signals at temperatures from 150 to 400°C.

*Fig. 2. Thermoluminescence index (TI) of quartz versus radiometric age of volcanic rocks. **A**=Shinyake lava (0.24ka), B=Mayuyama lava (3.1ka), C=Senbongi lava (13ka), E=Nodake lava (80ka), F=Tori-kabuto lava (139ka), H=Noine-yama lava (420ka), I=Kusu group (690ka), L=Shinohara dacite (1,300ka)*



3.3 TI (thermoluminescence index)

Tlie TI (tliermoluminescence index) proposed by Hayashi and Slhinno (1996) is given by tlic equation of $TI=(Tsm/Tst)Yst$, where Tsm is TL intensity of a simple, Tst is TL intensity of the standard. and Yst is age of the standard (ka). **As** an age standard. the Yabakei welded tuff of 990ka was chosen. For tlie quartz with a similar glow-curve, the TI and its radiometric age have a linear relation in a range from 0.2 to 1.300ka without the correction of annual dose (Fig.2).

4.0 RESULTS AND DISCUSSION

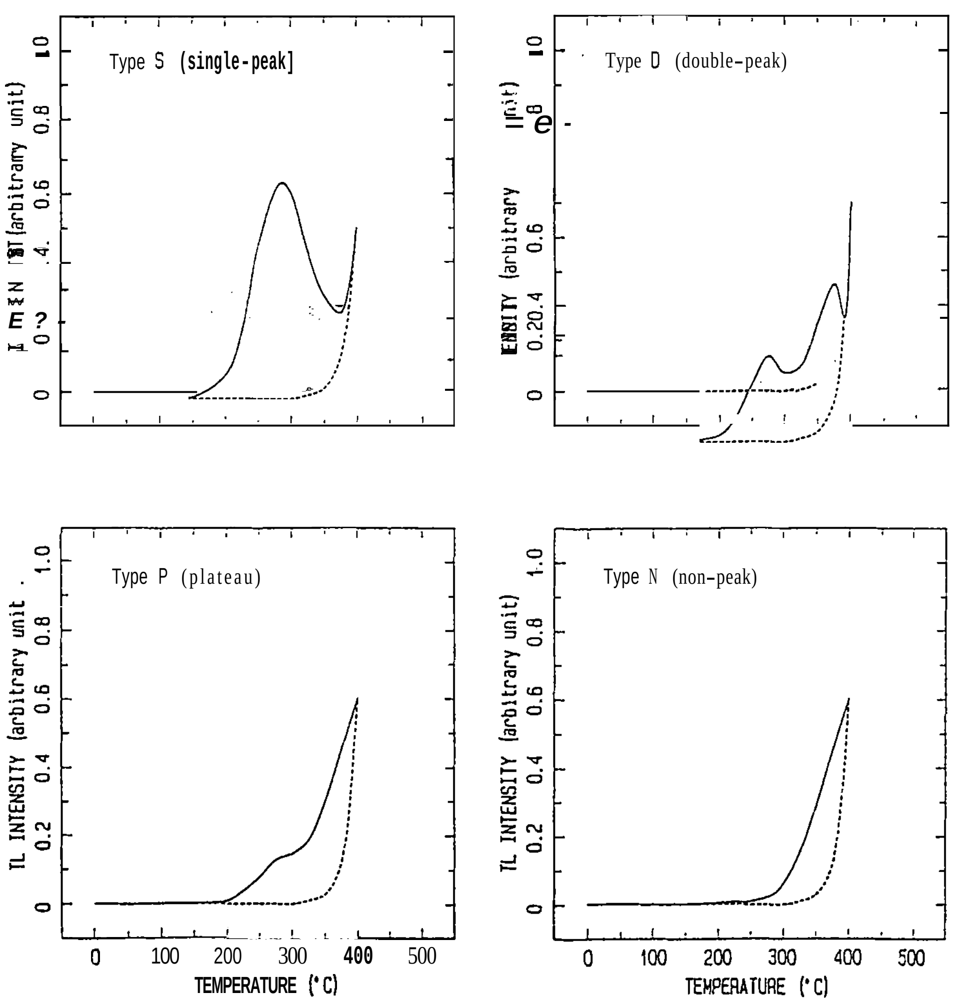


***Fig.3. Types of** TL **glow curves of** quartz **in** volcanic and **altered** rocks.*

4-2. TI for primary *quartz* in the Kuju volcanic rocks

The Kuju volcanic rocks consist of hornblende 'andesite and biotite-hornblende dacite. and most of them contain the primary **quartz** in varying amounts . Their TI values range from 23 to 470, corresponding to 23 to 470 thousand years. Of these. the largest is the Misokobushiyama lava (Ka) with TI=470. The second largest is the Ryoshidake lava (Ke) with TI=290, followed by the Hitomeyama lava (Kc) with TI=200, and the Gotosan lava (Kj) with TI=200. The smallest TI is for the lava forming a crater of Mt.Goto (Ki) with TI=23. This is probably the heat source for the geothennal activity of the Hatchobaru system. Similarly, the second smallest is a crater of Mt. Sensui with TI=40 and that of Mt. Kuroiwa with TI=45, probably corresponding to the heat source for the Otake geothermal system.

As mentioned-above, the TI values of volcanic rocks are, on the whole. consistent with the volcano-stratigraphy established geologically so far (Yamasaki et al., 1970). Moreover, they provide more a detailed history of volcanic activity. The TI. accordingly, is useful for the division of volcanic formations and also for the exploration of heat source for a geothermal system.

Table 1. Thermoluminescence index (TI) of quartz in hornblende andesite to dacite of the Kuju volcanic rocks from the Otake-Hatchobaru field

No.	Formation	Latitude	Longitude	Rock	TI ± σ	Glow curve
1	Misokobushi-L	33° 07' 42"N	131° 11' 37"E	Au-Hy-Hr-AN	470 ± 51	Type S
2	Rhyoishidake-S	33° 05' 14"N	131° 11' 19"E	Hy-Au-Hr-AN	294 ± 20	Type S
3	Rhyoshidake-D	33° 05' 42"N	131" 11' 21"E	Hy-Au-Hr-AN	158 ± 15	Type S
4	Hitomeyama-S	33° 06' 05"N	131" 10' 31"E	Bi-Hr-DA	198 ± 29	Type S
5	Sensuiyaaa-D	33° 07' 11"N	131" 12' 14"E	Hy-Au-Hr-AN	120 ± 13	Type SN
6	Sensuiyama-C	33° 06' 33"N	131" 12' 35"E	Bi-Hr-DA	40 ± 4	Type D
7	Kuroiwayama-D	33° 06' 11"N	131" 12' 33"E	Bi-Hr-DA	45 ± 3	Type SN
8	Kutsukakeyama-D	33° 05' 39"N	131" 12' 52"E	Bi-Hr-DA	39 ± 3	Type D
9	Gotozan-D	33° 05' 55"N	131" 11' 34"E	Hy-Au-Hr-AN	200 ± 10	Type S
10	Gotozan-C	33° 05' 44"N	131" 11' 46"E	Bi-Hr-DA	23 ± 3	Type D

AN=andesite. Bi=biotite. C=crater. Au=augite. DA=dacite. D=dome, Hr=hornblende, Hy=hyperthene. L=lava, S=summit

4-3. TI for quartz in altered rocks

The results of TI measurement for the major primary and **the** minor secondary **quartz** in altered rocks are shown on Table 2 and in Fig.4. The TI ranges from 0.6 to 179, corresponding from 0.6 to 179 thousand years. The smallest is the **quartz** with TI=0.6, which was collected from the Komatsuike steaming ground in Hatchobaru. The second smallest is the quartz with TI=0.9 from the steaming ground on the southeastern extension of the Komatsuike fault. At this site a shallow borehole was dnlled in the search for hot-spring water that produces steam only, indicating the existence of a vapordominated system at shallow depth

The quartz in altered rocks in and around the Otake steaming **ground** has TI of 4 and **6.4.** To the north of Otake, **there** is the Kawara steaming ground, whose TI (13) is somewhat larger than that from the other steaming grounds. **This** may indicate the inferiority of the field in geothermal activity among the four steaming **grounds.** It should be noted that such comparison **as** this **has** become possible, because in this study the TL intensity **was** measured by integrating signals at temperatures between 150 to **400°C.** If the TL emission **was** measured by the peak height **as usual,** most of the quartz from steaming grounds must have been evaluated to be almost equal (zero), since it has no **peak** in most cases.

Larger TI values are above 100, corresponding to be older than 100 thousand years. There will be two major possibilities for llie large TI values. One indicates, of course, the alteration age is old. The other is due to the partial annealing of TL signals of quartz, which is old and has strong TL emission. To distinguish these two, it is necessary to detemine tlie mineral paragenesis of altered rocks examined. When a rock sample contains quartz as the secondary silica mineral (Nos.2 and 16). tlie rock must have been subjected at temperatures above 100° C, which may be enough to anneal almost tlie previous TL signals. Therefore, the TI value for these samples should indicate an approximate alteration age.

On the other hand, when cristobahte or tridymite, low-temperature type silica mineral. is found in a rock sample, there is a possibility that tlie TI value may be older than the age of alteration. However, many of the samples containing cristobalite often have small TI values (Nos. 3, 5, 6, 14, 19, 22 and 23). This suggests that under the temperature at which cristobalite or tridymite was formed, the TL signals would virtually disappear. In Fig. 4, the three samples along the Hatchobaru fault have large TI values from 120 to 160, containing cristobahte or tridymite as alteration minerals. These TI values. therefore, seem to correspond to the alteration age, because the southwestern (downthrown) side of the fault is much inferior in geothennal activity than tlie northeastern side, where the main production zone is for the Hatchobaru power plant. Therefore. the TI values may indicate the relative alteration age in most cases. in spite of the lands of silica minerals.

Table 2. Thermoluminescence index (TI) of quartz in altered rocks from the Otake-Hatchobaru field.

No.	Original rock	Latitude	Longitude	Alteration minerals	TI ± σ	Glow curve
i	Px-andesite	33"07'22"N	131"10'46"E	Cr(10)-Sm(2)	179 ± 61	Type S
2	Hr-andesite	33"07'07"N	131"10'58"E	Qz(18)-Al(8)	92 ± 35	Type SN
3	Hr-andesite	33"07'29"N	131° 11' 35"E	Cr(3)-Sm(4)	14 ± 3	Type P
4	Px-andesite	33"07'08"N	131"11'24"E	Qz(10)-Sm(3)	----	----
5	Hr-andesite	33"07'05"N	131"11'39"E	Cr(12)-Al(5)-Ka(3)	6.4 ± 1.3	Type P
6	Px-andesite	33"07'20'5	131° 11' 43"E	Cr(10)-Al(5)	13 ± 3	Type P
7	Hr-andesite	33° 06' 31'4	131"10'38"E	Cr(7)-Sm(5)	----	
8	Px-andesite	33"06'53"N	131"10'43"E	Cr(6)-Sm(3)	----	----
9	Px-andesite	33"06'59"N	131' 10'58"E	Cr(8)-Sm(2)	----	
10	Px-andesite	33"06'24"N	131"10'58"E	Cr(3)-Ka(3)	----	----
11	Px-andesite	33"06'56"N	131"11'14"E	Cr(7)-Al(8)	----	----
12	Px-andesite	33"06'40"N	131"11'05"E	Cr(6)-Al(5)	----	----
13	Px-andesite	33"06'51"N	131"11'15"E	Cr(6)-Qz(5)-Al(4)	----	----
14	Px-andesite	33° 07' 00"N	131"11'33"E	Cr(9)-Ka(2)	4.0 ± 1.7	Type N
15	Px-andesite	33"06'32"N	131"11'14"E	Cr(5)-Tr(3)-Al(8)	----	----
16	Hr-andesite	33° 06' 37"N	131"11'20"E	Cr(11)-Qz(3)-Ka(3)	43 ± 8	Type SN
17	Px-andesite	33"06'17"N	131"11'14"E	Cr(10)-Ka(2)	65 ± 12	Type SN
18	Hr-andesite	33"06'08"N	131"11'09"E	Cr(7)-Ka(3)	160 ± 22	Type S
19	Hr-andesite	33° 06'15"N	131"11'32"E	Cr(3)-Al(5)-Ka(5)	0.6 ± 0.2	Type N
20	Hr-andesite	33"06'29"N	131° 11'50"E	Cr(7)-Ka(12)	----	----
21	Hr-andesite	33° 06'13"N	131"11'46"E	Cr(6)-Ka(4)	17 ± 2	Type P
22	Hr-andesite	33"06'07"N	131"11'41"E	Cr(7)-Ka(2)	8.1 ± 2.1	Type P
23	Hr-andesite	33"06'04"N	131"11'55"E	Cr(3)-Al(4)-Ka(7)	0.9 ± 0.3	Type N
24	Hr-andesite	33° 06'02"N	131"11'17"E	Al(9)-Ka(1)	124 ± 18	Type S
25	Hr-andesite	33° 05' 50"N	131° 11' 27"E	Cr(9)-Al(2)-Ka(2)	136 ± 29	Type S
26	Hr-andesite	33"05'36"N	131° 11'09"E	Cr(2)-Al(13)	45 ± 15	Type P

The number in parentheses in the column of the alteration minerals means the quartz index, which shows relative contents determined by the X-ray powder diffraction method (Hayashi, **1979).**
Al=alunite, Cr=cristobalite, Ka=kaolin, Qz=Quartz, Sm=smectite, Tr=tridymite

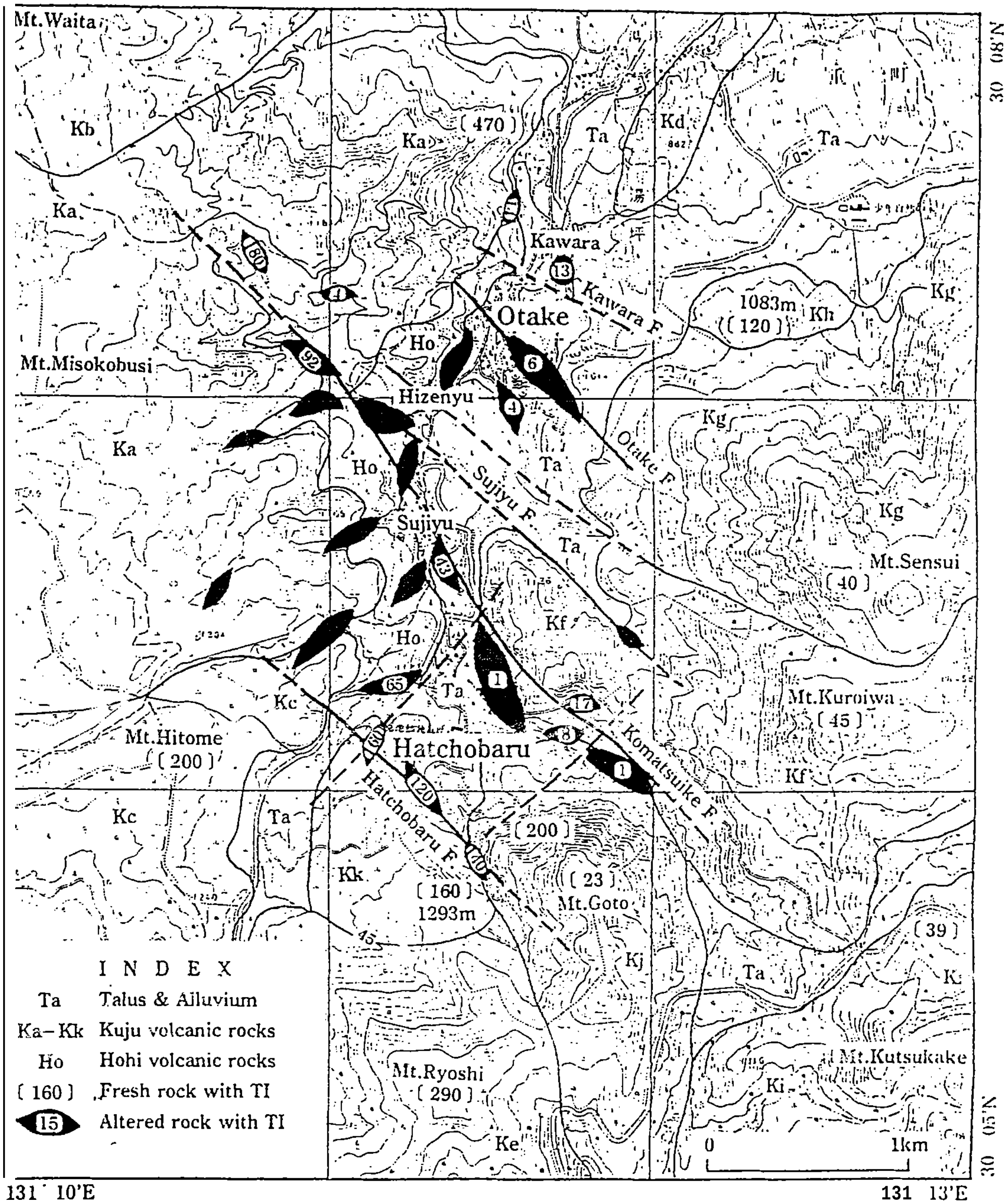


Fig. 4. Distribution of TI of quartz in volcanic and altered rocks from the Otake-Hatchobaru field

4-4. Reservoir temperature and activity index of Otake and Hatchobaru

The Hatchobaru field is one of the most-active water-dominated geothermal systems. According to Baba et al.(1991), its reservoir temperatures measured reach 270°C (H-14; 1,192m), 287°C(H-22; 1,650m),and 278°C(2H-12; 1,500m). These correspond to **85**, 83, and 85 in the activity index (Hayashi et al.(1981), respectively. Accordingly, Hatchobam falls in Type A. On the other hand, the Otake reservoir has a maximum temperature of 238°C(O-22; 1,561m). This corresponds to 65 in the activity index and belongs to Type B.

If the degree of geothermal activity is reflected on the TI value of volcanic and altered rocks on the surface, the thermoluminescence index (TI) can be used as a simple and rapid technique for geothermal exploration, because it is unnecessary for samples to be irradiated with artificial radiation.

Acknowledgements: The X-ray analysis was carried out using and X-ray diffractometer, RIGAKU RAD-IIIA. froin llie Advanced Instruments Center of the Kyushu Sangyo University. For the collection of rock samples, the write is indebted to the staff of Kyushu Electric Co. Ltd.

References

Baba, Y., Kawazoe, S. and Sueyoshi, Y.(1991) Geothermal well drilling in the Otake-Hatchobaru geothennal field. Journ. Japan Geothermal Energy Association, vol.28, 273-296 (in Japanese).

Hayashi, M.(1973) Hydrothermal alteration in the Otake geothermal area, Kyushu. Jour. Japan Geothermal Energy Association, vol. 10, 9-46.

Hayashi, M.(1979) Quantitative descriptions of cores and cuttings from geothennal wells. Japan Geothermal Energy Association, vol. 1, 103-116 (in Japanese).

Hayashi. M. and Furutani, N.(1984) Stress fields of a fracture-type reservoir. Geothermal Resources Cuncil, Transactions. vol.8, 437-440.

Hayashi, M., Taguchi, S. and Yamasaki. T.(1981) Activity index and thermal history of geothennal systems. Geothermal Resources Council. Transactions, vol.5, 177-180.

Hayashi. M. and Shinno, I.(1996) Age estimation of volcanic rocks using natural thermoluminescence intensity of **quartz.** Jour. Fac. International Studies of Culture, Kyushu Sangyo University, No.5. 113-122 (in Japanese).

Hayashi, M. and Yamasaki. T.(1982) Strike-dip determination of fractures in drillcores from the Otake-Hatchobaru geothermal field. "Hydraulic fracturing and geothermal energy" edited by Nemat.Nasser. S., Abe, H. and Hirakawa, S. Martinus Nijhoff Publishers, 331-341.

Takashima, I. (1985) Thermoluminescence dating of volcanic rocks and alteration minerals and their application to geothermal history. Bull. Geol. Surv. Japan, 36, 321-366.

Yamasaki,T., Matsumoto, Y. and Hayashi, M.(1970) The geology and hydrothermal alteration of *Otake* geothemal area, Kuju volcano group. Kyushu, Japan Geothermics, Special Issue 2, 51-62.

Zen, **A.** and Hayashi, M.(1992) Study on thermoluminescence dating of altemtion minerals and its application to geothermal exploration. Geoth Res. Rep., Kyushu Univ..1, 8-49.