Proceedings World Geothermal Congress 2005
Antalya, Turkey, 24-29 April 2005

Precise Thermoluminescence Dating for Heat Source Volcanic Rocks and Alteration Products at the Tawau Geothermal Area, Sabah, Malaysia

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Keywords: Thermoluminescence dating, Quaternary volcano, alteration, Tawau geothermal area, Sabah, Malaysia

ABSTRACT

The Quaternary eruptions are proved by two age data of 27000yBP by ^{14}C and 1.62Ma by K-Ar methods. However, age data is not enough to prove Quaternary volcanic activity. New age data of Quaternary volcanic rocks are obtained for 12 samples by thermoluminecence (TL) method. The youngest age obtained is 0.09Ma for a monogenetic basaltic cinder cone. Ages such young basaltic volcanos are 0.10Ma and 0.11Ma (same outcrop) and 0.14Ma. Ages of dacitic volcanic rocks are widely distributed at the southern foot of the Maria volcano rage from 0.34Ma to 0.45Ma (4 samples). The ages of the underlying andesite lava range form 0.27Ma to 0.52Ma (4 samples). We obtained the preliminary age of 0.7-1.2Ma for this andesite lava formation by the correction of diagenesis. The relation between such age data and stratigraphical succession is still unknown, although new age data clarified the existence of volcanic activity in the Middle Pleistocene. Alteration ages of 13 samples are also measured by the TL method. The youngest ages obtained are 0.15Ma and 0.19Ma for Upper Tawau hot spring area. Other ages are widely scatted from 0.27Ma to 0.66Ma. They were used for the construction of the thermal history of each area. Alteration minerals are identified for 9 locations. The Tawau area is roughly estimated to be in the Middle Pleistocene by the TL age data.

1. INTRODUCTION

Tawau, Sabah is the only geothermal area related to the Quaternary volcano in Malaysia. The age of the basalt in the Tawau geothermal area was 27000yBP by ^{14}C (Wilford, 1967). However, basalt is not good for a geothermal system heat source and ^{14}C age must be carefully treated because it sometimes misleads the eruption history by the measurement of reworked materials. Thermoluminescence (TL) dating has advantages for the direct measurement of original volcanic body or unit and a suitable age range for Quaternary materials (10^3-10^6 years). TL dating is also applicable to the alteration rocks, which gives a new idea for the evaluation of geothermal potential. We measured 12 volcanic rocks and 13 altered rocks by the thermoluminescence method (Takashima et al., 2002). In this paper, we concentrate on the evaluation of error factors for the above TL age data. Geological evolution and preliminary geothermal evaluation are carried out for the Tawau area.

2. GEOLOGY

Based on the geological map reported by Ueno et al. (1994), the outline of volcanic geology is explained as follows. Volcanic rock of this area is divided into four units. The Andrassy volcano, Kinabutan Kechil volcano, Maria volcano and Olivine basalt in ascending order. Diorite intrusives are also distributed. The Andrassy volcano consists of dacite breccia and dacite lava in late Miocene. The Kinabutan Kechil volcano consists of dacite lava in late Miocene. The Maria volcano consists of dacite lava and pyroclastics in late Pliocene to early Pleistocene. The olivine basalt is forms small lava domes and cinder cones. Figure 1 is geologic map and location of TL dating samples

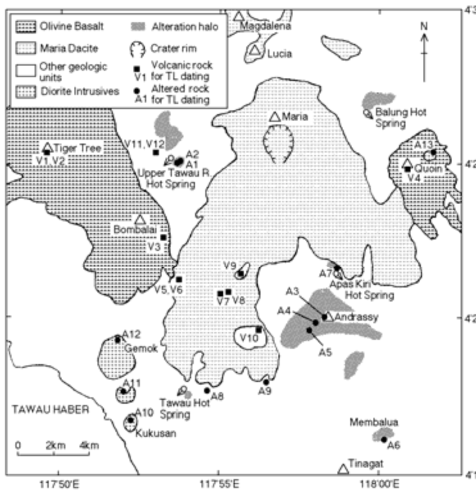

Fig. 1 Distribution of Quaternary volcanic rocks and alteration halos with TL dating samples afterTakashima et al., 2004)

The olivine basalt is actually late Quaternary because ^{14}C age was 27000yBP for charcoal which underlies basalt from Gunung Bombalai (Wilford, 1967). Other ages were determined by stratigraphical correlation and one K-Ar age of 1.62Ma for Maria volcano (Ueno et al., 1994). We revised the age and stratigraphy of the above volcanic units by thermoluminescence dating result and shown in Table. 1.

Table 1 Summary of stratigraphy and age data both reported and TL (after Takashima et al., 2004)

Stratigraphy (modified from Ueno et al., 1994)	Formation name in this paper	Reported age	TL age (this paper)
VOLCANIC ROCKS			
PLEISTOCENE			
Olivine Basalt	Olivine Basalt	27000 yBP (C-14)*	0.09-0.14Ma
Maria Volcano and Their Equivalents	Maria Dacite	1.62 Ma (K-Ar)**	0.34-0.45Ma
MIDDLE MIOCENE - PLOCENE			
Andrassy and Kinabutan Kechil Volcanoes	Andrassy Dacite	6.4 Ma (K-Ar)**	
Magdalena-Lucia Volcano	Upper Tawau Andesite		(0.7-1.2Ma)***
Tinagat Volcano	Tinagat Andesite	13.6-70.7Ma(FT)**	
Altered Andesite	Altered Andesite		(0.27,0.38Ma)****
INTRUSIVE ROCKS			
Diorite Porphyrite	Diorite Intrusives		(0.41-0.62Ma)****

* Kirk (1968) ** Ueno et al. (1994) *** Corrected age of weathering ****Alteration age

3.THERMOLUMINESCENCE MEASUREMENT

Themoluminescence (TL) age determination of volcanic rocks is established by the important finding of red color usage (Hashimoto and Habuki, 1987) and was extensively studied over many Japanese volcanic areas (ex. Ichikawa et al., 1982; Takashima & Watanabe, 1994). However, most geologists and volcanologists ignore the age data obtained by TL. One of the reasons for the low reputation is no standardization of method. There are many varieties of methods for TL age determination. Sometimes, completely different ages are reported on the same horizon samples with no interpretations.

We now think that the established TL age determination is only applied to volcanic rocks using quartz. Other important condition are selection of hard and compact rock which are stable and free from water content change and chemical leaching.

TL is at the developing stage. Many new proposals for techniques present themselves. In such cases, fixed nomenclature will be difficult. Different from such on going techniques, TL age determination of volcanic rock is established and needs acceptance from users (geologist, archaeologist and other many other researchers).

Many factors control the TL age. In the case of the Tawau sample, accuracy of the chemical analyses, effects of diagenesisin and cosmic ray contribution are considered for volcanic rocks. The TL age of altered rock has many unknown factors and the obtained age of the data is estimated.

3.1 Errors in Chemical Analyses of Radiometric Elements

The annual percentage is calculated from the contents of the U, Th and K. Gamma ray spectrometer are used for the U and Th analyses. Gamma ray instruments are assembled using the 75mm in diameter, NaI scintillator and 1024 cannel analyzer.

Resolution of energy is about 8% FWHM and impossible to separate individual daughter nuclides. The contents of U and Th are obtained from calibration data using standard samples. Errors are calculated from the standard deviations of three measurements and counts error. Error versus content of both elements are shown in Fig. 2.

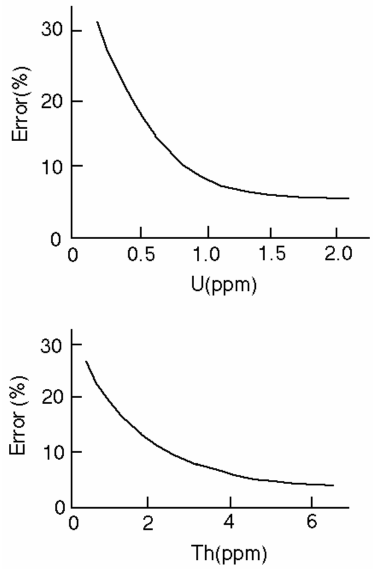

Fig. 2 Errors of U and Th by Gamma Ray Spectrometer.

X-ray fluorescence is used for K analysis. The energy-dispersive type (Seiko Instruments Inc. SEA2010) is used in this study. Accuracy of the Energy-dispersive type is not proved. However, using the fundamental parameter correction, the data has enough accuracy to use our TL dating. The calibration line of K_2O is shown in Fig. 3 for 16 standard samples (GJ-1, JG-2 and other Geological Survey of Japan Rock Reference Samples). Figure 4 is a collation of energy-dispersive type (EDX) with wave length-dispersive type (WDX) in K_2O contents. Errors less than 5% are expected for K_2O contents.

Errors of the annual dose calculation are based on the above data. The maximum of 15% error is obtained for low U contents (<0.69ppm) MS0406A sample from the propagation of errors.

The total error of the TL age is calculated from both chemical analyses and light intensity measurements. The range is 16% to 30% as shown in Tables 2 and 3.

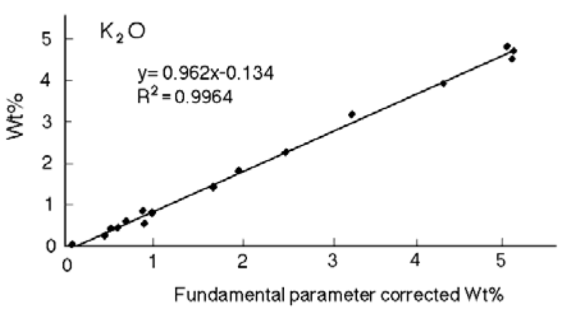

Fig. 3 Calibration line of K_2O by use of EDX.

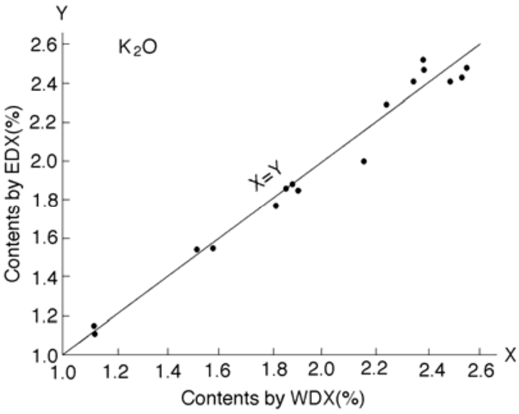

Fig. 4 Calibration between EDX and WDX measurements.

3.2 Effect of Diagenesis

Age obtained by TL method tends to the younger side (Yamagata et al., 2004). The most important factor is diagenesis. Samples affected by the reduction of trapped electrons are seen in samples affected by diagenesis. Indicators of the diagenesis grade contains smectite. It was first reported for TL dating of the Tawau area. Figure 5 shows the relation between 001 refraction intensity and TL ages. A similar phenomena is recognized for TL ages of the Hachimantai area (Mukaikubo and Takashima, in preparation).

The theoretical analyses are not yet done. It is a very important character of TL dating because TL ages tend to young.

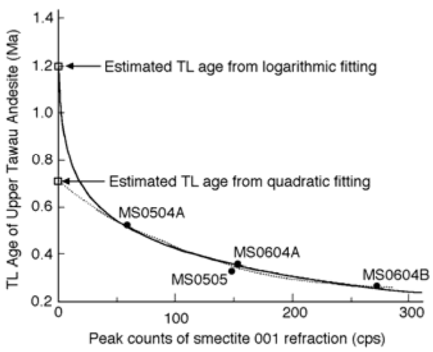

Fig. 5 Relation of smectite contents and TL age (after Takashima et al., 2004)

3.3 Cosmic Ray Evaluation

Evaluation of cosmic ray contribution is difficult for old age samples. The present outcrop is not an original deposit. Erosion contributes to deepfissures in the surface. The first step evaluation of erosion depth is carried out by the combination of a summit level map. The average erosion rate in the Japanese mountains are(0.1mm/y; Kaizuka, 1969).

In the applied above data, the cosmic ray contribution of all volcanic rocks for TL dating are negligible.

4. AGE OF VOLCANIC ROCKS

Table 2 shows the 12 TL eruption age data of the Tawau area. Only two K-Ar ages are reported in this area. One is Late Miocene (6.4Ma) for the Angrassy Volcano and the other is Early Pleistocene (1.62Ma) for the Maria Volcano (Ueno et al., 1994). The younger limit is determined as 27000 BP by ^{14}C age by a carbonized tree trunk in a dacite breccia (Kirk, 1968). However, such carbon date has the possibility to indicate the re-sedimentation age. Our TL data shows true ages of lava or pyroclastic products.

The youngest is 76 ka for Bombalai basalt lava. Olivine basalt group ranges 76-136ka and has a time gap between bodies. The Maria Volcano and the Kinabutan Kechil Volcano are almost same age. Further study is needed to establish volcano stratigraphy.

Locality No.	Sample No.	U (ppm)	Th (ppm)	K_2O (%)	Annual Dose (mGy/a)	Paleodose (Gy)	TL age (Ma)	Remaks
	(Olivine Basalt)							
V1	MS0406A	0.69	2.91	1.13	1.09	113	0.10±0.02	
V2	MS0406B	0.83	2.76	1.12	1.01	109	0.11±0.02	
V3	MS0407	1.31	4.88	1.58	1.35	121	0.090±0.014	
V4	MS0704	1.44	5.53	1.86	2.13	300	0.14±0.03	
	(Maria Dacite)							
V5	MS0501A	1.21	5.37	1.52	1.53	682	0.45±0.11	
V6	MS0501B	2.25	9.15	1.82	2.16	728	0.34±0.06	
V7	MS0502	2.75	10.37	2.15	2.53	985	0.39±0.07	
V8	MS0503	2.23	9.72	1.90	2.05	700	0.34±0.07	
	(Upper Tawau Andesite)							
V9	MS0504A	1.97	7.01	1.88	2.15	1253	(0.52)*	Weakly weathered
V10	MS0505	2.04	7.13	2.73	2.91	962	(0.33)*	Do.
V11	MS0604A	1.91	7.63	2.59	3.1	1100	(0.36)*	Do.
V12	MS0604B	2.02	7.5	2.7	2.9	777	(0.27)*	Do.

* Age data for weathering correction (see text)

Table 2 TL age of volcanic rocks (after Takashima et al., 2004)

5. AGE OF ALTERED ROCKS

Table 3 shows the 13 TL alteration age data of the Tawau area. The ages of the two samples from the upper Tawau river are 155ka and 194ka. These are good indicators for geothermal reservoirs. Alteration ages for other areas are old. We didn't get resolution for the relationship between geothermal potential and alteration age. Accordingly, alteration age date must be used in connection with other data.

The age of diorite intrusives have cooling temperatures under 50□. The upper horizon of the diorite group is eroded out and appeared at the surface around 500ka.

6. GEOLOGICAL EVOLUTION

Based on the TL age data of volcanic rocks and alteration products, geological evolution of the Tawau area is inferred (Fig. 6). From the data we obtained, Tawau is in the middle area in geothermal prospects.

Olivine Basalt, the youngest formation, was formed as monogenetic volcano. It would be come up from

Locality No.	Sample No.	U (ppm)	Th (ppm)	K_2O (%)	Water (%)	Annual Dose (mGy/a)	Paleodose (Gy)	TL age (Ma)	Alteration Type
	(Upper Tawau Hot Spring Area)								
A1	MS03	7.00	13.09	0.05	7.7	4.53	702	0.15±0.05	Silicified
A2	MS0602	3.46	12.09	0.01	6.2	3.43	666	0.19±0.06	Silicified
	(Andrassy Alteration Area)								
A3	MS0508	0.76	3.14	2.53	0	3.16	1862	0.59±0.18	Silicified
A4	MS0509	1.94	8.32	2.93	12.1	4.21	1652	0.39±0.12	Acidic (White)
A5	MS0510	2.34	7.53	0.8	10.1	2.73	1808	0.66±0.20	Acidic (White)
	(Membalua Alteration Area)								
A6	MS0512	1.26	7.32	1.47	16.9	2.47	1279	0.52±0.16	Acidic (White)
	(Apas Kiri Hot Spring Area)								
A7	MS01	1.72	6.92	1.50	5.0	2.18	1623	0.32±0.10	Alkaline (Green)
	(Regional Green Colored Alteration−Altered Andesite)								
A8	MS0405	1.59	6.20	1.96	0	2.48	941	0.38±0.11	Alkaline (Green)
A9	MS0507	2.24	7.63	2.78	0	3.43	914	0.27±0.08	Alkaline (Green)
	(Diorite Intrusives)								
A10	MS0401A	1.96	7.45	2.45	0	2.89	1182	0.41±0.08	Alkaline (Green)
A11	MS0402	1.76	6.42	2.40	0	2.67	1662	0.62±0.12	Alkaline (Green)
A12	MS0403	1.76	6.88	2.42	0	2.83	1345	0.48±0.10	Alkaline (Green)
A13	MS0705	1.75	6.15	2.33	0	2.74	1200	0.44±0.09	Alkaline (Green)

Table 3 TL age of altered rocks (after Takashima et al., 2004)

deep magma reservoir. However, dacitic Maria Volcanic Rock Group comes up from a shallow magma reservoir because the volume of eruption products were large and made up of a calc alkaline type rock. The next important program is to determine the depth of such a magma reservoir. We plan to measure mineral chemistry by EPMA and apply it to geo-barometer.

The recommended surveys for the next step are gravity, remote sensing and MT methods to analyze regional geologic and resisitivity structure. Then select for a promising area and continue a more detailed survey.

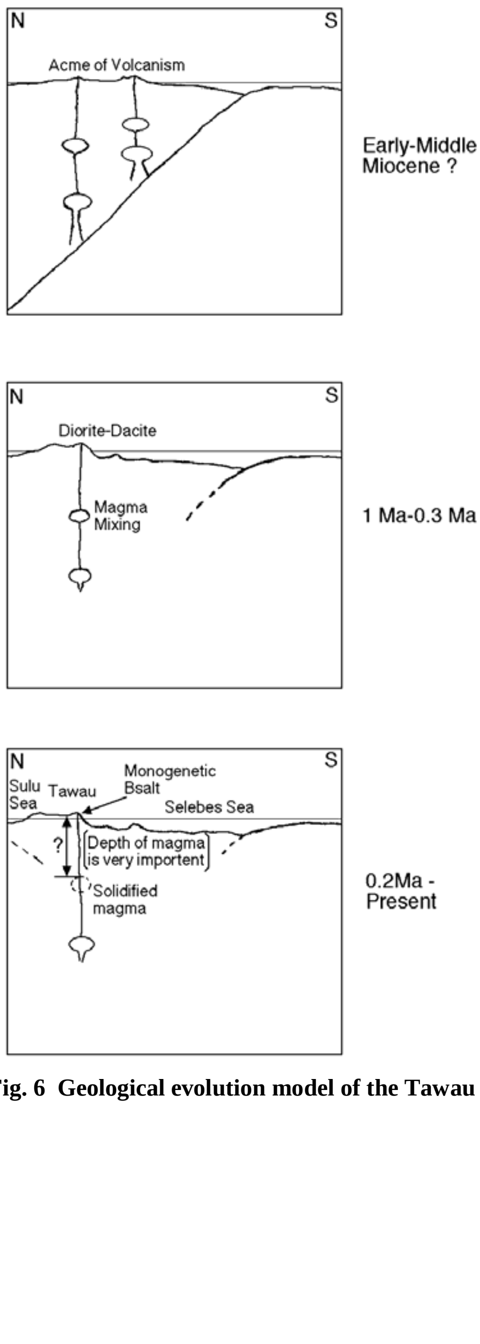

Fig. 6 Geological evolution model of the Tawau area.

ACKNOWLEDGEMENTS

We express our sincere thanks to Dr. Ang Num Kiat, Director of Mineral and Geoscience Department Malaysia (Sabah), for his permission for our cooperation study. We also give our sincere gratitude to Dr. Adam Liau, Mineral and Geoscience Department Malaysia (Sabah), for arranging all aspect of this cooperative work. We give our sincere thanks for Mr. Kyoji Sasaki, Akita University, for his help with experiments.

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