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日本地熱学会誌
第26巻 第3号 (2004)
273頁～283頁

J. Geotherm.
Res. Soc. Japan
Vol. 26, No. 3 (2004)
P. 273～P. 283

Thermoluminescence Age Determination of Quaternary Volcanic Rocks and Alteration Products at Tawau Area, Sabah, Malaysia

Isao TAKASHIMA*, Azhar Ahmad NAZRI**, LIM Peng Siong***, Takahiro KOSEKI#, Youji MOURI##, Asnawir NASUTION### and I.G.B. EDDY SUCIPTA*

(Received 13 January 2004, Accepted 13 April 2004)

Abstract

Tawau in Sabah is only one geothermal area related to the Quaternary volcano in Malaysia. Many hot springs and alteration halos are recognized in this area. The Quaternary eruptions were proved by two age data of 27000yBP by ^{14}C and 1.62Ma by K-Ar methods. However, the age data are not enough to prove Quaternary volcanic activity. New age data of Quaternary volcanic rocks have been obtained for 12 samples by thermoluminecence (TL) method. The youngest age obtained is 0.09Ma for a monogenetic basaltic cinder cone. Ages of such young basaltic volcanos are 0.10Ma and 0.11Ma (same outcrop) and 0.14Ma. Ages of dacitic volcanic rocks widely distributed at the southern foot of Maria volcano rage from 0.34Ma to 0.45Ma (4 samples). The ages of underlying andesite lava range form 0.27Ma to 0.52Ma (4 samples). We obtained preliminary age of 0.7～1.2Ma for this andesite lava formation by weathering correction. Although the relation between such age data and stratigraphical succession is still unknown, such new age data clarified the existence of volcanic activity in the Middle Pleistocene. Alteration ages of 13 samples were also measured by TL method. The youngest ages obtained are 0.15Ma and 0.19Ma for the Upper Tawau hot spring area. Other ages are widely scatted from 0.27Ma to 0.66Ma. They were used for construction of thermal history of each area. Alteration minerals were identified for 9 locations. Temperature inferred from alteration minerals is roughly estimated around 100～200°C. Tawau area is expected to be a target for further geothermal exploration for medium temperature (around 200°C) based on the preliminary assessment by the above TL ages and other reported data.

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

*Research Institute of Materials and Resources, Akita University, 1-1 Tegatagakuen-cho, Akita 010-8502, Japan
**Minerals and Geoscience Department Malaysia, Tabung Haji Bldg. Jl.Tun Razak 50658, Kuala Lumpur, Malaysia
***Sabah Representative, Mitubishi Materials Natural Resources Development Corp., Geo-Enviro Technology, 19-3, Block D, Inanam Business Centre, Mile 6 Jl. Tuaran, 88450 Kota Kinabalu, Malaysia
#Akita Branch, Mitubishi Materials Natural Resources Development Corp., 5-24 Sanno Nakazono, Akita 010-0953, Japan
##Tohoku Office, Ministry of Land, Infrastructure and Transport, 5-6-6 Koriyama, Taihaku-ku, Sendai 982-0003, Japan
###Directorate of Volcanology and Geological Hazard Mitigation, Jl. Diponegoro No.57, Bandung 40122, Indonesia
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1. Introduction

Many hot springs are found around the Tawau area, Semporna Peninsula, southeastern Sabah. Since the first geothermal prospect was carried out by New Zealand expert in 1979, many research works have been done by foreign and Malaysian scientists in this area (Tating, 2000). Lim et al. (1991) reported comprehensive data and analyses of geothermal fields in the Semporna Peninsula. The highest temperature recognized in this area is 75.6°C and heat loss (discharge) is 28.65MWt at Apas Kiri (Lim et al., 1991).

Tawau in Sabah is believed to be only one geothermal area related to the Quaternary volcanos in Malaysia. Volcanic geology are clarified by the work of many researchers (ex. Kirk (1968) ; Ueno et al. (1964) ; Tjia et al. (1992) ; unpublished map by Geological Suevey of Malaysia). However only two Quaternary ages were reported for basalt (27,000yBP by ^{14}C ; Kirk, 1968) and the dacite lava (1.62Ma by K-Ar ; Ueno et al., 1994) in the Tawau geothermal area.

In order to identify the eruption age, we measured 12 samples from three volcanic formations by thermoluminescence (TL) method and preliminary results were already published (Takashima et al., 2002). We checked for such data more precisely and obtained final ages. We also examined for alteration ages and alteration minerals. Based on such data and many other data reported so far, preliminary assessment of geothermal potential were carried out. Figure 1 shows location of study area and hot spring distribution in the Semporna Peninsula and the Tawau area.

2. Outline of geology and geothermal features

Based on the geological map reported by Ueno et al. (1994), the Late Miocene-Holocene volcanic rocks

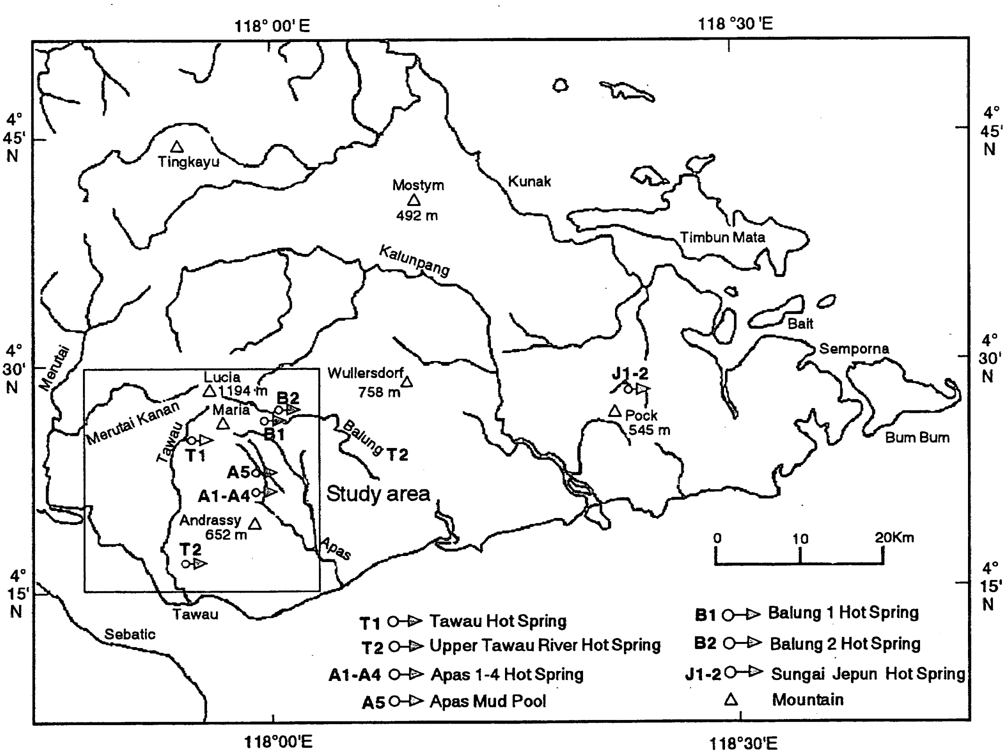

Fig. 1 Hot spring distribution of the Tawau area and study area (modified from Lim et al., 1991).

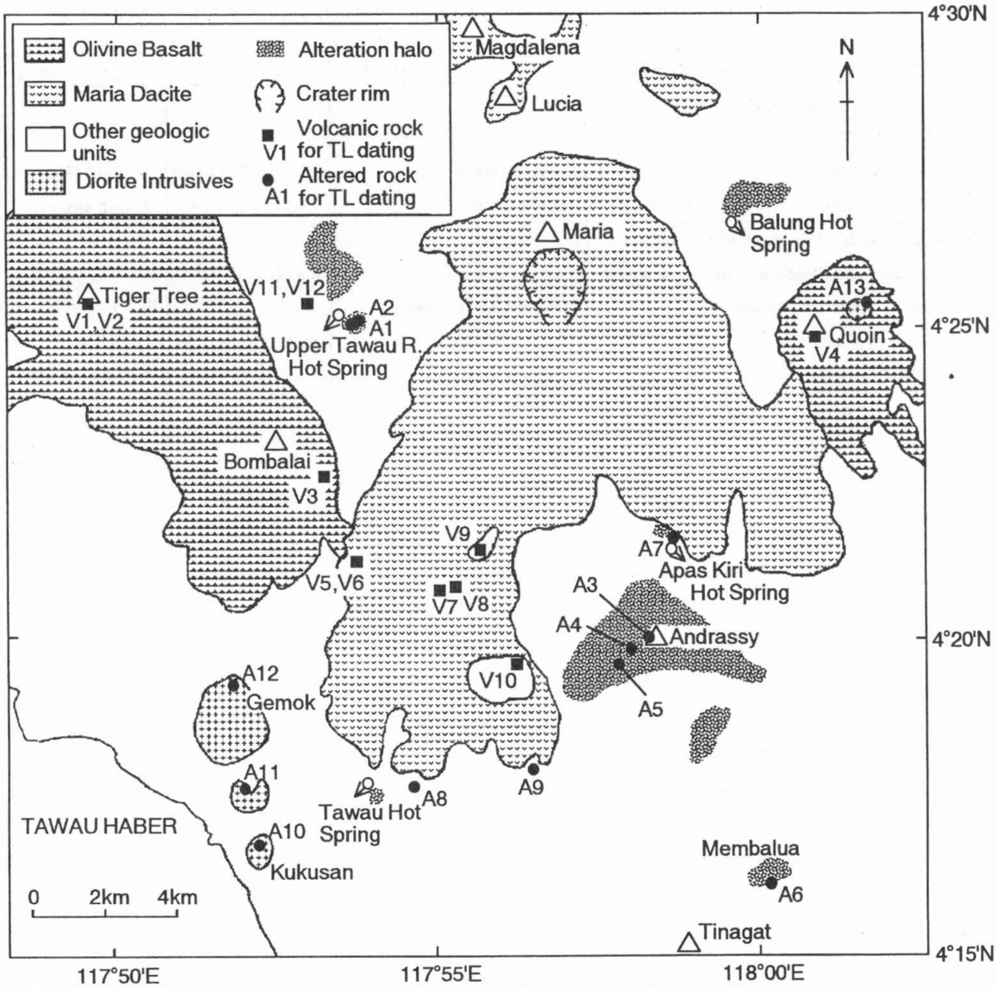

Fig. 2 Distribution of Quaternary volcanic rocks and alteration halos with localities of TL dating samples (Geology is modified from Ueno et al. (1994) and unpublished data of Geological Survey of Malaysia, Sabah).

of this area are divided into 6 units. The Altered Andesite, Hornblend Andesite of Tinagat Volcano, Volcanic Rocks of Magdalena-Lucia Volcano, Volcanic Rocks of Andrassy and Kinabutan Kechil Volcanoes, Volcanic Rocks of Maria Volcano and Their Equivalents, and Olivine Basalt in ascending order. Diorite Intrusives are also distributed. The Altered Andesite and Tinagat Volcano are considered to be Middle Miocene. The Magdalena-Lucia Volcano consists of hypersthene andesite lava and pyroclastics of Late Miocene. The Andrassy and Kinabutan Kechil Volcano consists of dacite lava of Late Miocene. The Maria Volcano consists of dacite lava and pyroclastics of Late Pliocene to Early Pleistocene. The Olivine Basalt forms small lava domes and cinder cones and considered to be Late Pleistocene. Based on the geological study by Ueno et al. (1994) and Geological Survey of Malaysia (unpublished data), we modified and simplified geology as shown in Fig. 2. We tentatively re-named such geological units to more simple forms based our TL ages as shown in Table 1.

Six hot springs are recognized in this area (Fig. 1). Features of such hot springs were reported by

Table 1 Summary of stratigraphy and age data of both reported and TL method.

Stratigraphy (modified from Ueno et al., 1994)	Formation name in this paper	Reported age	TL age (this study)
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

Lim et al. (1991) and followings are simplified introduction based on their report. Temperature range of such hot springs is 75°C at Apas Kiri to 32°C at Upper Tawau River hot spring. Types of hot spring are near neutral sodium chloride and sulphate water. Water chemistry indicates that highest temperature estimated by Na-K-Ca geothermometer (Truesdell, 1975) is 194°C at Apas Kiri.

Alteration areas are indicated in Fig. 2. Most of them are white colored acidic alteration and few silicified rocks at Upper Tawau River hot spring and near sumit of Mt. Andrassy. Green colored regional alteration is also recognized for older formations and Diorite Intrusives. Calcareous travertine is recognized at the Apas Kiri area.

3. Alteration minerals

We collected 26 altered samples from 9 areas for preliminary alteration study. Table 2 shows type of alteration and mineral assemblage. Alteration type of the study area is divided into four. Silicified and white colored argillized zones are formed by acidic hydrothermal alteration. Calcareous travertine may be formed by near neutral high HCO_3 hot water at Apas Kiri area. Regional green colored alteration is widely recognized for distribution area of older formations. Minerals identified are quartz, alunite and sericite at Upper Tawau hot spring. X-ray diffraction of typical samples are shown in Fig. 3.

Mineral assemblages of all the alteration zones are commonly found in medium temperature (100~200°C) hydrothermal systems. Aragonite is found newly formed deposits at Apas Kiri and it converts into calcite with time. Epistilbite is first finding in this area. Finding of epidote and actinolite, high grade alteration minerals, were reported for Apas Kiri area (Lim et al., 1991) but we can not recognize such minerals in our samples.

4. Samples for TL dating

TL dating is applied to 12 volcanic rocks and 13 alteration products. Figure 2 shows the sample locations of them. In this paper, sampling for dating and other works have been done following the geological study of Ueno et al. (1994) and Geological Survey of Malaysia (unpublished data). Samples are collected from volcanic rocks of Upper Tawau Andesite (4 samples), Maria Dacite (4 samples) and Olivine Basalt (4

Table 2 Preliminary identification of alteration minerals for nine areas.

Area (Sample number)	Type of Alteration	Mineral assemblage
Upper Tawau River Hot Spring (4)	Silicified	Qz Al–Qz
NW of Upper Tawau River Hot Spring (3)	Argillized (white color)	Qz Qz–Se Qz–Se–Al
Tawau Hot Spring (2)	Argillized (white color)	Ka–Qz Ka–Qz–S/M
Andrassy (3)	Silicified and argillized (white color)	Qz–Al Qz–Sm–Se–Ka Qz–Ka
Membalua (1)	Silicified and argillized (white color)	Qz–S/M
Apas Kiri Hot Spring (6)	Calcareous travertine	Ar Ar–Ca Ca Ca–Qz
Apas Kiri Hot Spring (1)	Regional Green Colored (alkaline)	Qz–Es–S/M–Ch
East of Tawau Hot Spring (1)	Regional Green Colored (alkaline)	Sm–Qz–Ab-Ch-Ze Ab-Sm–Qz–Ch
Geomok, Kukusan and Quoin (5)	Regional Green Colored (alkaline) (diorite)	Ab-Qz–Ch–Se Ab-Qz–Ch Ab-Qz–Ch–Es Ab-Qz–Se–Ch–Es

Qz: quartz, Al: alunite, Se: sericite, Ka: kaolinite, Sm: smectite (montmorillonite), S/M: sericite-montmorillonite mixed layer, Ar: aragonite, Ca: calcite, Ab: albite, Ch: chlorite, Es: epistilbite, Ze: unidentified zeolite

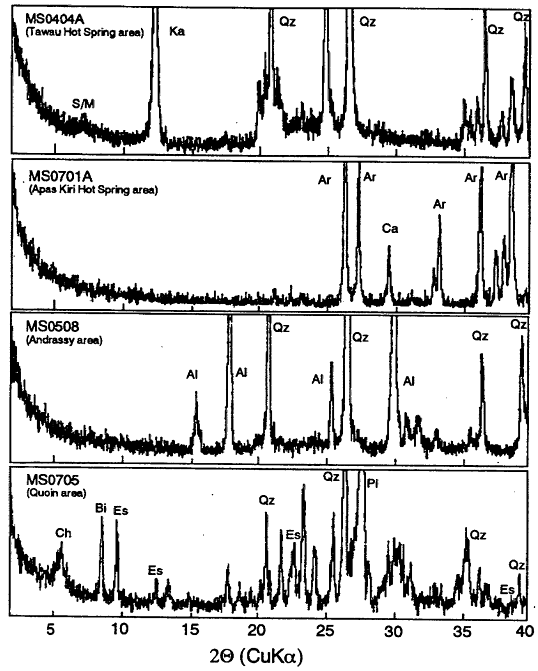

Fig. 3 X-ray diffraction patterns of some altered rocks. Abbreviation of minerals ; Pl : plagioclase, Bi : biotite, other symbols : same as those in Table 2.

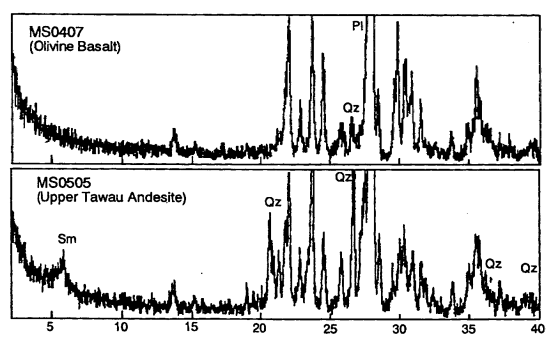

Fig. 4 X-ray diffraction patterns of volcanic rock for TL dating. Sample contains smectite (below) shows younger TL age and made weathering correction. Abbreviation of minerals are same as Table 2 and Fig. 3.

samples). All the volcanic rock samples are fresh in appearance but few smectite is recognized by X-ray diffraction in all 4 samples of Upper Tawau Andesits. No smectite is detected for other 8 samples. Figure 4 is X-ray diffraction patterns of fresh and smectite bearing samples. We try to correct the TL age of smectite bearing formation and describe later. Followings are simple description of samples ;

V1 and V2 : Basalt lava block collected from Tiger Tree cinder cone. Dark gray colored hard rock. Olivine and plagioclase phenocrysts are observed.

V3 : Basalt lava collected from SE of Bombalai cinder cone. Dark gray hard rock with cavities. Olivine, plagioclase and corroded big quartz up to 5mm are observed.

V4 : Basalt lava collected from near summit of Quoin dome. Dark gray colored hard rock. Olivine and corroded big quartz up to 7mm are observed.

V5 and V6 : Dacitic andesite rock block of tuff breccia of the Maria Dacite Formation. Dark gray colored crystal rich rock.

V7 and V8 : Gray colored dacite lava of the Maria Dacite Formation. Crystal rich rock. Biotite and quartz are predominant.

V9 and V10 : Dark gray to black andesite lava of the Upper Tawau Andesite Formation. Only plagioclase phenocryst can be observed.

V11and V12 : Black colored andesite lava of the Upper Tawau Andesite Formation. Few hornblende are recognized.

Altered samples are collected from 9 areas in Table 2. Type of alteration is also shown in Table 2. Among them, 13 samples are selected and used for TL dating. Figure 2 shows sampling locations of 13 samples.

Slicified rock, white colored alteration, are products of acidic alteration. Green colored alteration products are also collected from study area. Samples are not covered whole alteration halos but dating of 13 altered rocks give basic data for historical evolution of hydrothermal systems. All selected samples for TL dating contain quartz which is the best mineral for measurement. We also collected Diorite Intrusives. They contain chlorite and sericite. Accordingly, obtained TL ages may indicate alteration period.

5. TL Age determination of volcanic rocks

Procedure of TL age determination is three different steps. First, quartz is separated from rock samples. Second is TL light emission measurements both natural and gamma-ray irradiated quartz. Third is chemical analyses of radiometric elements (U, Th and K_2O). From the second step, accumulated dose during geologic time (paleodose, PD) can be obtained. From the third step, annually receiving dose (annual dose, AD) can be evaluated. Then TL age is simply calculated by the equation (TL age = PD/AD). Experimental procedure are almost same as that of Takashima and Watanabe (1994).

Typical glow curves and a growth curve to get paleodose are shown in Figs. 5 and 6. Table 3 shows TL ages of 12 samples. Ages of the Olivin Basalt are range from 0.09 to 0.14Ma. Samples are collected three locations, such as Tiger Tree (V1, V2), Bombalai (V3) and Quoin (V4) which form monogenic cinder cone or dome. Obtained ages are not big difference

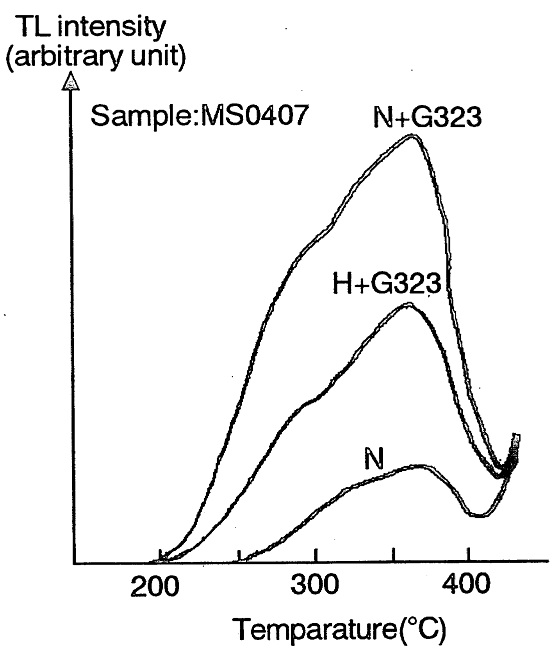

Fig. 5 TL glow patterns of volcanic rock from the Olivine Basalt Formation.

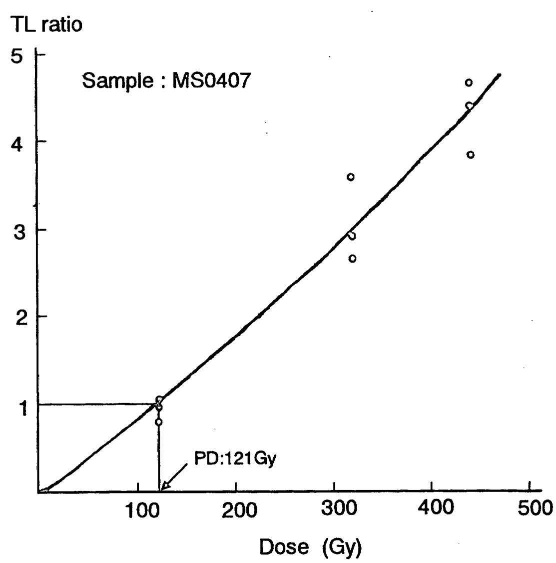

Fig. 6 Growth curve of volcanic rock from the Olivine Basalt Formation.

Table 3 TL ages of volcanic rocks for three formations.

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	3.10	1100	(0.36)*	Do.
V12	MS0604B	2.02	7.50	2.70	2.90	777	(0.27)*	Do.

* Age data for weathering correction (see text)

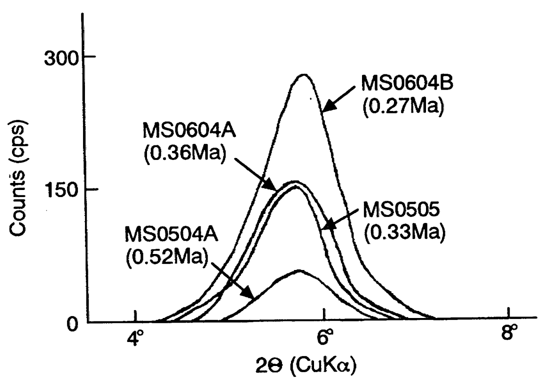

Fig. 7 Background subtracted 001 peak intensity of the Upper Tawau Andesite Formation. High peak sample shows younger TL age.

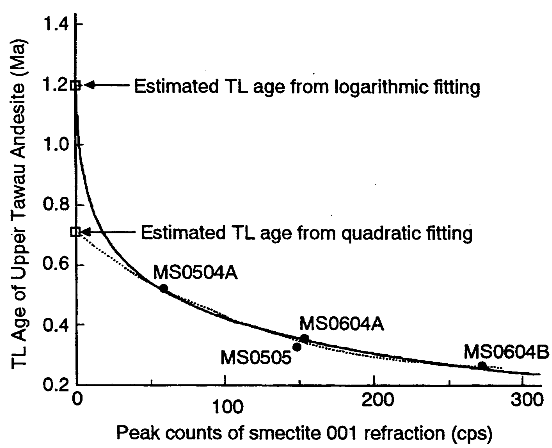

Fig. 8 Diagram plotted intensity of smectite 001 refraction versus TL age for the Upper Tawau Andesite Formation. Formation age of 0.7 Ma and 1.2 Ma are tentatively obtained for weathering (smectite) correction.

even if the location is different. Ages of the Maria Dacite are range from 0.34 to 0.45Ma.

For TL data of the Upper Tawau Andesite, age shift to younger side is expected because rock samples suffered from weathering. The sample with high 001 peak height of smectite (background subtraction intensity of around 6° peak as shown in Fig. 4 below) shows a tendency to younger TL age (Fig. 7). We plotted 4 data to the diagram of TL age versus peak height and extrapolate the peak height to zero position. Two different equations are applied and we obtained 0.7 and 1.2Ma for such treatment (Fig. 8). Life time of TL signal was theoretically proposed and estimated for various peak temperatures preserved ones (Aitken, 1985 ; Takashima and Honda, 1985). TL signal tends to decrease if the sample have been preserved at high temperature. Decrease of natural TL signal gives young TL age. However, precise evaluation is difficult because some physical factors are still unknown.

Table 4 TL ages of altered rocks from six different alteration zones.

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	0.80	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)

This is first trial and no theoretical or existing data to evaluate the reliability. Accordingly, obtained TL age of 0.7～1.2Ma is only preliminary assessment and will discuss later to compare with the reported age.

6. TL age determination of altered rocks

Alteration ages of 13 samples were determined. Procedure of measurement is almost same as that of volcanic rocks. Table 4 is the results of measurements for altered rocks. Mineral used is secondary quartz or original quartz phenocryst. All samples reacted with high temperature fluid and TL signals might have reset to zero at that time. Start of TL age of altered rock is not clear but time of cooling down near atmospheric temperature (around 40～50°C).

The date is divided into 4 areas and 2 regional green colored alteration. The youngest ages obtained are 0.15 and 0.19Ma for silicified rocks of the Upper Tawau hot spring area. Altration age for presently active Apas Kiri geothermal areas is 0.32Ma. Alteration ages for no hot spring areas are older than Upper Tawau and Apasu Kiri hot spring areas (0.39～0.66Ma for Andrassy area and 0.52Ma for Membalua area). TL ages of regional green colored alteration of the Altered Andesite unit are 0.27and 0.38Ma and those of the Diorite Intrusives are 0.41～0.62Ma. These alteration ages may indicate that the time when rock units came up to near surface.

7. Discussion

7 −(1) Comparison between TL age of volcanic rocks and reported data

Only two K-Ar ages were reported in this area. One is Late Miocene (6.4Ma) for Andrassy Volcano and the other is Early Pleistocene (1.62Ma) for Maria Volcano (Ueno et al., 1994).

Very big difference is recognized between K-Ar (6.4Ma) and TL (1.2Ma for oldest estimation for weathering correction) for Andrassy Volcano. Two possible ideas are come up. One is the correction of weathering is not adequate. Second is miss-identification of unit for TL and K-Ar dating. No fixed answer is obtained for this big gap. In case of Maria Dacite, quite big difference is also recognized in ages between K-Ar

(1.62Ma) and TL (0.33∼0.46Ma). The reason for such big difference is also not clear. TL ages are reliable because experimental errors are not so big and rocks are fresh and hard. Unfortunately, sampling location for K-Ar dating was not described in Ueno et al. (1994). One possibility is measurement of different geologic unit. Additional dating by K-Ar or other methods are need for same samples which we measured. Even if further study for field and experiment, at least one unit of the Maria Dacite is surly considered to be Middle Pleistocene. Very diversified Fission Track ages of 13.6∼70.7Ma were reported for the Tinagat Andesite (Ueno et al., 1994) but difficult to evaluate such data.

Younger limit of eruption of this area was determined as 27000 yBP for the Olivine Basalt by ^{14}C age of carbonized tree trunk in a dacite breccia (Kirk, 1968). Another ^{14}C age of 24ka (Bellwood, 1988 ; Sabah Museum and State Archives data) was introduced by Tjia et al. (1992). We obtained the ages of 0.09∼0.14Ma for 4 olivine basalt samples. The TL ages directly show the time of formation of lava or lithic fragments of the Olivine Basalt unit. There are some possibility to found more younger units, major eruptions of the Olivine Basalt are estimated around 0.1Ma.

7 −(2) Preliminary assessment of geothermal potential at Tawau area

Probability of geothermal development of the Tawau area is roughly estimated by heat source (age and volume of lava and pyroclastics), history of hydrothermal activity (alteration) and other reported data.

Volcanic activity of the Olivine Basalt, the youngest eruption, was of monogenetic type and expected deep magma chamber. Thus it would be difficult to become heat source for geothermal reservoir. However, the Maria Dacite Group must form more shallow magma reservoir because volume of eruption products were big and calc-alkaline type rock. Total volume of eruption products for Late Pliocene to Middle Pleistocene Maria Dacite is roughly estimate about few km^3. Magma volume is expected ten times of such eruption products. Geothermal potential is evaluated by the plot of magma volume of about 100 km^3 (Takashima et al., 2002) and TL ages of Maria Dacite (0.34∼0.45Ma) to Smith and Shaw (1975) diagram, Maria volcanic area is put on the marginal zone from 300°C to little potential.

Hydrothermal activity to form alteration zones at present hot spring areas are not so old. Ages of regional green colored alteration also show the high temperature (100∼200°C?) until 0.3∼0.6Ma (ages of Altered Andsite and Diorite Intrusives). Alteration minerals identified at many areas are also medium temperature origin.

As a conclusion, high potential is not expected in the Tawau area from the evaluation of heat from magama and ages and minerals of alteration zones. However, there are high possibility to exist medium temperature (100∼200°C) reservoirs at Tawau area. Geothermometer also supports the medium temperature reservoirs at Apas Kiri (194°C) and 167°C at Tawau hot spring (Lim et al., 1991). Recommended surveys for next step are gravity, remote sensing and MT methods for analyze regional geologic and resisitivity structure. Then select for promising area and continue more detailed survey.

8. Conclusions

TL dating of 12 samples for three formations identified the newest eruption age of 0.09M a to 0.14Ma for the Olivine Basalt, 0.34Ma to 0.45Ma for the Maria Dacite and 0.7∼1.2Ma (weathering corrected age) for the Upper Tawau Andesite. It clearly indicates the presence of big dacite eruption in the Middle Pleistocene.

Alteration ages of 13 samples indicate that age of presently active hot spring areas shows the youngest age group of 0.15Ma and 0.19Ma at Upper Tawau River hot spring, and 0.32Ma at Apas Kiri hot spring. Other ages have a wide range between 0.27Ma to 0.66Ma. However, all ages are not so old indicating high underground temperatures until few hundred thousand years ago.

Alteration minerals identifed are quartz, alunite, sericite, kaolinite, smectite, sericite-smectite mixed layer, aragonite, calcite, albite, chlorite and epistilbite. These alteration minearals indicate that the expecting temperatures of hydrothermal activity are not so high (100~200°C).

Combined such age and mineral data, and reported data, reservoir temperature of the Tawau area is expected to be medium (<200°C) but worth for further exploration.

Acknowledgements

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

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マレーシア・サバ州タワウ地域の第四紀火山岩と変質岩の熱ルミネッセンス年代

高島　勲・Azhar Ahmad NAZRI・LIM Peng Siong・小関武宏・毛利陽司・
Asnawir NASUTION・I.G.B. EDDY SUCIPTA

概　要

マレーシア・サバ州タワウ地域には多くの温泉地があり，最高温度 74°C，地化学温度 190°C 以上と報告されている。また，変質帯も発達しており，地熱開発の期待が持たれている。この地域にはマレーシア唯一の第四紀火山が存在し，熱源となる可能性も考えられるが，これまでに実施された年代測定はわずかである。このため，火山岩 12 個について熱ルミネッセンス年代測定を行った。また，地熱評価のために 13 個の変質岩についても同じ手法で年代測定を行うとともに，変質鉱物を同定した。

火山岩については，本地域で最も新しい活動とされている Olivine Basalt 4 試料の年代として 0.09～0.14 Ma，地熱地域の中心に広く分布する Maria Dacite 4 試料の年代として 0.34～0.45 Ma を得た。また，これらの下部層とされている Upper Tawau Andesite 4 試料の年代は 0.52 Ma より若い測定値となったが，試料に少量のスメクタイトが存在し，風化の影響が推定された。この補正法として TL 年代とスメクタイトの 001 面回折強度の関係を図示し，予察的な年代として 0.7～1.2 Ma を得た。これらの TL 年代は既存の ^{14}C 及び K-Ar 法による報告年代とかなり異なるが，新たなデータとして今後の層序及び地熱評価に利用できる。

変質年代は 6 地点について行い，現在温泉湧出がみられる 2 地域で 0.15～0.19 Ma（Upper Tawau Hot Spring area）及び 0.32 Ma（Apas Kiri area）と最も新しい値が得られた。現在熱徴候のない地域の白色変質帯はそれより古く 0.39～0.66 Ma となった。また，広域的な緑色変質と Diorite Intrusive 岩体の年代は 0.27～0.62 Ma で，比較的最近上昇を始め，地表付近の低温環境になったものと推定される。

変質鉱物として認められたものは，白色変質帯では，石英，明ばん石，セリサイト，カオリン，スメクタイトなどで，100～200°C 程度の熱水温度が推定された。広域緑色変質にみられる変質鉱物は，石英，曹長石，緑泥石，スメクタイト，剥沸石などである。このほか，石灰質温泉沈殿物からアラゴナイトと方解石が認められた。

これらのデータから，本地域の予察的な地熱評価として，既存の蒸気発電を行うほどの高温貯留層存在の可能性は低いが，中程度（200°C 程度）の火山性地熱を対象に探査を行う価値は十分あるものと思われる。