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THERMOLUMINESCENCE DATING OF IGNIMBRITES AND HYDROTHERMALLY ALTERED ROCKS IN THE TAUPO VOLCANIC ZONE

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SUMMARY - The central Taupo Volcanic Zone (TVZ) of New Zealand is one of the most active areas of rhyolite volcanism and geothermal activity in the world. The absolute ages of many rhyolitic eruptives have been measured, but as yet the chronology of the geothermal systems is unknown. We report preliminary data from a pilot study using the thermoluminescence (TL) method to date both fresh and hydrothermally altered ignimbrites in the TVZ. Six unaltered, welded ignimbrites from the ubiquitous Whakamaru-group (4 from Whakamaru Ignimbite and 2 from Te Whaiti Ignimbrite) range from 297 ka to 333 ka, in agreement with published age data. The TL age of 194 ka for fresh pumice tuff from the Ohakuri Ignimbrite is consistent with its stratigraphic position. Two hydrothermally altered Ohakuri Ignimbrite samples gave 68 ka and 113 ka ages, which, as would be expected, are younger than for the fresh rock. We established a method of analyzing quartz grain size to use in the evaluation of beta ray contribution in the rock, and cosmic ray contribution in annual dose evaluation process. This pilot study of TL dating in the TVZ has been successful, and has encouraged us to undertake a comprehensive age mapping programme of both fresh and hydrothermally altered rocks in the Taupo Volcanic Zone.

1. INTRODUCTION

One of the least understood aspects of geothermal activity in the Taupo Volcanic Zone (TVZ) is the chronology of the systems. When did they come into existence and, for the very few extinct systems, how long did they last before dying? Wood (1995) summarised what little geological evidence exists, and postulated that many currently active systems were generated, or at least enhanced, by large rhyolitic magma chambers that accumulated in the upper crust during the major eruptive episodes that shaped the TVZ in the 0.35 - 0.15 Ma period. In contrast, Bibby et al. (1995) have cast doubt on a direct association between hydrothermal systems and magma chambers, implying that TVZ geothermal systems are essentially stable over periods of 200 000 - 500 000 years, and are not perturbed by single intrusive events.

No absolute ages have previously been obtained on samples from TVZ geothermal systems because the methods for dating such rocks are limited. Recently however, thermoluminescence (TL) dating has been successfully applied to welded tuffs and altered minerals in Japan (Takashima, 1995a; Takashima et al., 1990), and the Philippines (Takashima and Reyes, 1990). It was decided that the TVZ would be suitable for similar studies, particularly as it is characterised by areas of altered ground and has many ignimbrites which occur both at the surface and in drilled geothermal fields. One of the advantages of TL dating is its easy operation. For example, the history of Unzen has been identified using more than 50 TL age data points (Takashima and Watanabe, 1994).

We plan to study the history of caldera-forming eruptions with related hydrothermal activity in the TVZ with a view to understanding the chronological development of important geothermal reservoirs. This paper deals with preliminary considerations of the applicability and accuracy of the TL dating method for TVZ fields, and reports results from a pilot study carried out in 1995-1996.

2. GEOLOGICAL SAMPLES

It was decided to start by sampling surface outcrops of unaltered Whakamaru-group ignimbrites, and both fresh and hydrothermally altered Ohakuri Ignimbrite.

The Whakamaru-group ignimbrites were chosen because they are widespread, quartz-rich rocks erupted during one of the largest episodes of rhyolite magma discharge in the history of the TVZ. They are believed to have been erupted from a large caldera complex extending between Lake Taupo and the Waikato River (Fig. 1). At least eight separate ignimbrites are included in the group, totalling ~1000 km^3, with recently determined $^{40}Ar/^{39}Ar$ ages ranging from 0.32 f0.04 My to 0.34 f0.01 My (Houghton et al., 1995). This episode marks a hiatus in the development of the TVZ, and has been used by Wilson et *al.* (1995) to define an old (pre-Whakamaru) and young TVZ. Altered ignimbrites assigned to the Whakamaru-group (eg. Wairakei Ignimbrite at Wairakei, and Rangitaiki Ignimbrite at Ohaaki) have been drilled at depth in eight geothermal fields as shown on Fig. 1. In three other fields (Reporoa, Rotorua, and Tauhara), drillholes terminated in strata known to be younger, and Whakamaru-group ignimbrites are presumed to be present deeper down.

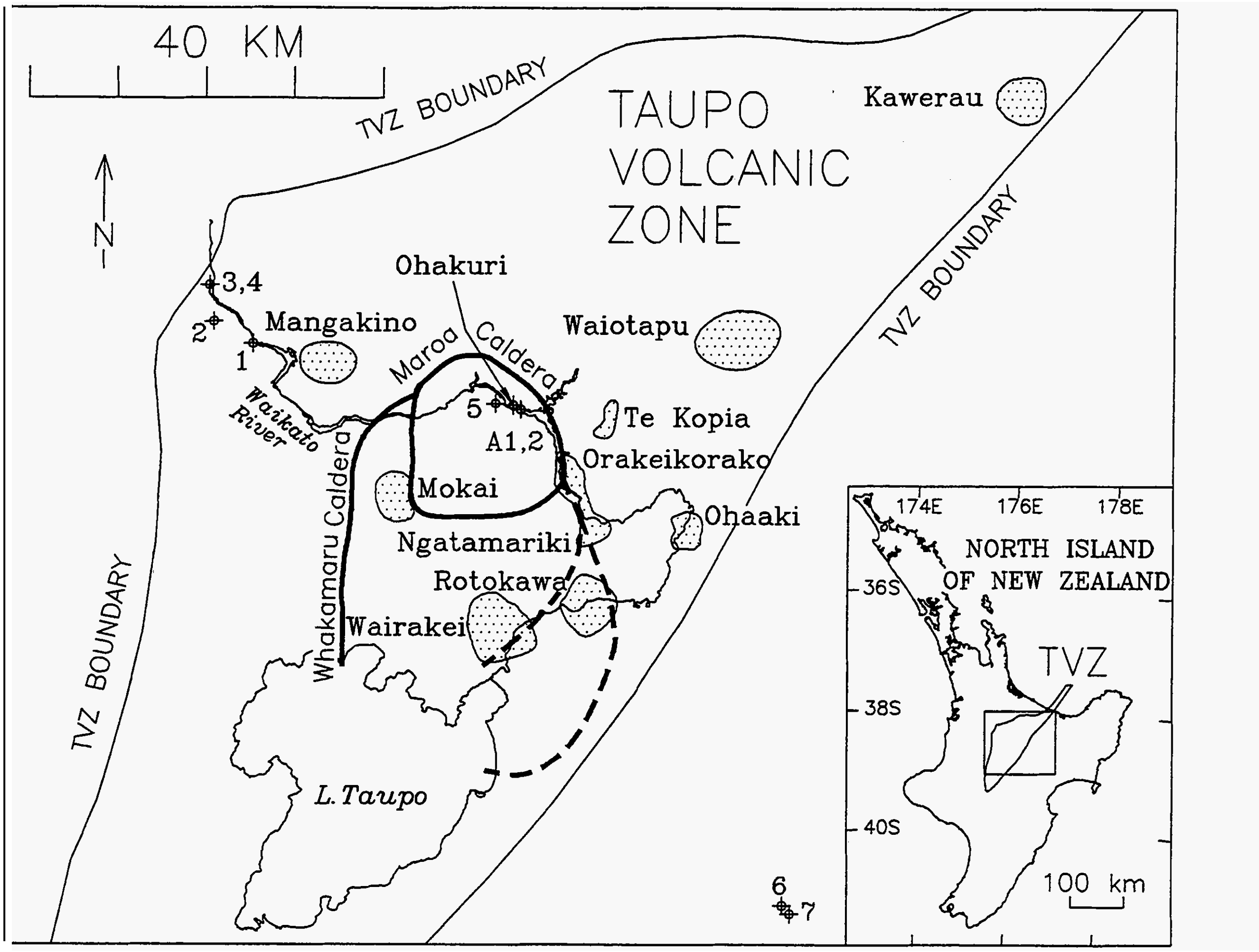

Fig. 1. Map of the central Taupo Volcanic Zone showing the location of samples: 1-4 are Whakamaru Ignimbrite, 5 is Ohakuri Ignimbrite, 6-7 are Te Whaiti Ignimbrite, A1 and A2 are hydrothemally altered Ohakuri Ignimbrite. Also shown as dotted areas are those geothermal fields in which Whakamaru-group ignimbrites have been penetrated in drillholes. The approximate boundaries of the Whakamaru caldera (source of the Whakamaru-group ignimbrites) and Maroa caldera (source of the Ohakuri Ignimbrite) are shown as heavy lines.

Samples of welded, quartz-rich Whakamaru-group ignimbrites were collected at outcrops of the Whakamaru Ignimbrite in the Waikato River valley near the western margin of the TVZ (samples 1-4), and from the stratigraphically older Te Whaiti Ignimbrite where it laps onto Mesozoic greywackes outside the TVZ to the east (samples 6, 7).

The Ohakuri Ignimbrite was chosen because it is the main rock type exposed at the Surface in the fossil Ohakuri geothermal system (Fig. 1). Here, hydrothermally altered ignimbrite can be traced laterally into fresh rock, giving an opportunity to use TL to determine apparent age variation resulting from geothermal activity. Fission track (Zircon) ages of 0.25 ±0.03 My and 0.30 ±0.03 My have been measured on Ohakuri Ignimbrite (Grindley et al., 1994), but recent field observations (C J N Wilson, C P Wood, unpublished data) suggest it is actually younger than the Mamaku Ignimbrite which has a $^{40}Ar/^{39}Ar$ age of 0.22 My (Houghton et al., 1995). The source of Ohakuri Ignimbrite has been suggested as the northern Maroa Caldera (Wood, 1995). It has not been certainly identified in geothermal drillholes, except possibly in the nearby Atiamuri area (Wood, 1995).

Quartz-bearing fresh Ohakuri Ignimbrite (sample 5) was collected from west of Ohakuri dam, and two altered samples (samples Al, A2) came from the well-exposed fossil system at Ohakuri dam. The fresh rock is a soft, pumice lithic tuff, whereas the altered material is silicified and hard. Henneberger (1983) has described the alteration type as essentially quartz + adularia, with minor pyrite and chlorite.

3. DATING PROCEDURE AND RESULTS

TL dating is an application of dosimetry using natural minerals. Minerals in the field absorb radiation from surrounding radioactive materials and cosmic rays at a fixed rate (annual dose is denoted by AD) and exhibit TL due to a total dose over geologic time, known as a paleodose (PD). The AD is calculated from the chemical data of radioactive elements (U, Th, K) and cosmic ray evaluation. The PD is determined from the TL glow curves obtained fiom both **natural** and artificially irradiated samples. The TL age (t) is calculated by the simple equation, t = PD/AD. Figure 2 is the schematic explanation of the TL dating method.

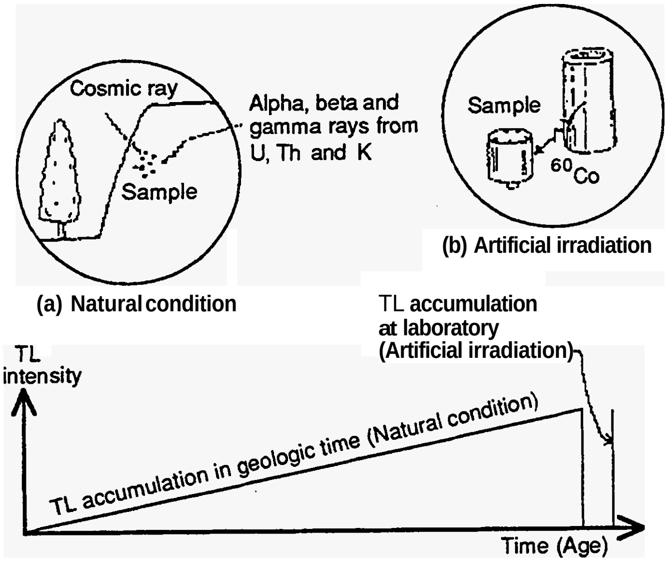

Fig. 2 - Schematic explanation of TL dating.

The experimental procedure of TL dating was described by Takashima and Honda (1988), and is briefly explained here. **Quartz** was the mineral used for dating because it gives reliable age data. Samples were collected fiom unweathered, uniform rock, and later dried at room temperature in the dark. Then **320-400** g of the sample was crushed by a stainless steel mortar and/or ball mill, and sieved to pass 20 mesh. 290 g were then put in a plastic container for counting in a gamma ray spectrometer. A fraction of the finer than 20 mesh sample was further crushed to give **60** - 200 mesh *grains*. After water washing, the *grains* were separated into magnetic and non-magnetic **portions** by an isodynamic separator. The non-magnetic *grains* were treated with both 24% HF solution and HCl (1:1) for about 20 minutes at 50°C each. Sample weight averaged 10 - **50** g, adjusted to give a final product of **0.5** - 1 g. Aluminium sheets were used to keep the separated samples from exposure to light.

The TL emission was measured **using** a Kyokko 2500 TLD Dosimeter, with heating rate of 200°C/min. Twenty **milligrams** of the sample was set in the molybdenum heater with 10 mm diameter pit. Two filter systems were used. One was an **infrared** filter (Toshiba **IRA-10**) only, the other was an infrared filter plus long wave pass filter (**ESCO** Products **OG-550**). Receiving wavelength of the former **was 300-700 nm** and that of latter was **550-700nm**. Basically, the latter filter system is used in measurement because the red colour signal is high temperature and stable (Hashimoto *et al.*, 1987). The former filter system is used for samples which have only blue light emission. Measurements were carried out for natural and gamma ray irradiated samples. Figure **3** is an example of TL glows of natural and gamma ray irradiated samples. Based on these data, paleodose (PD) was calculated fiom the growth curve (Fig. 4). Each sample was measured **three** times on average, and the PD error was estimated by the deviation **from** theoretical curve.

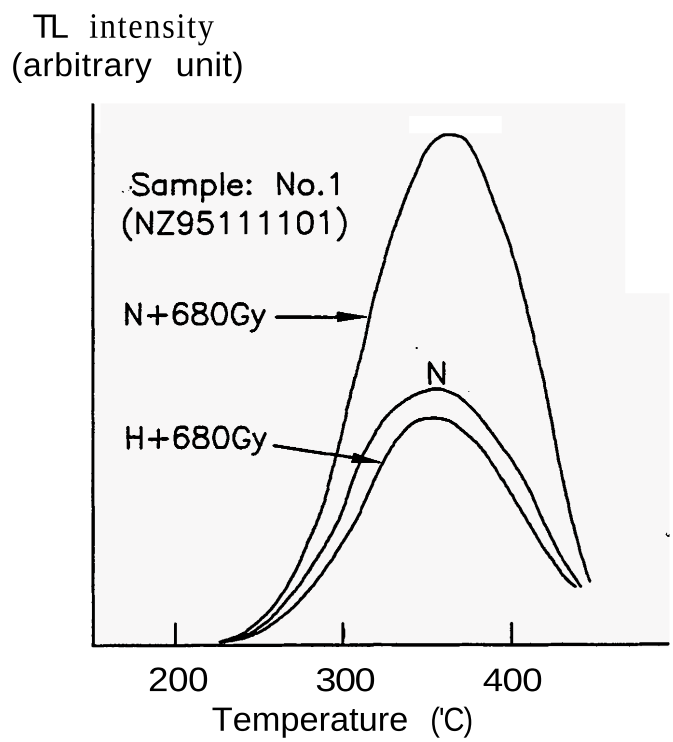

Fig. 3 · TL glow curves of **quartz** separated fiom ignimbrite.

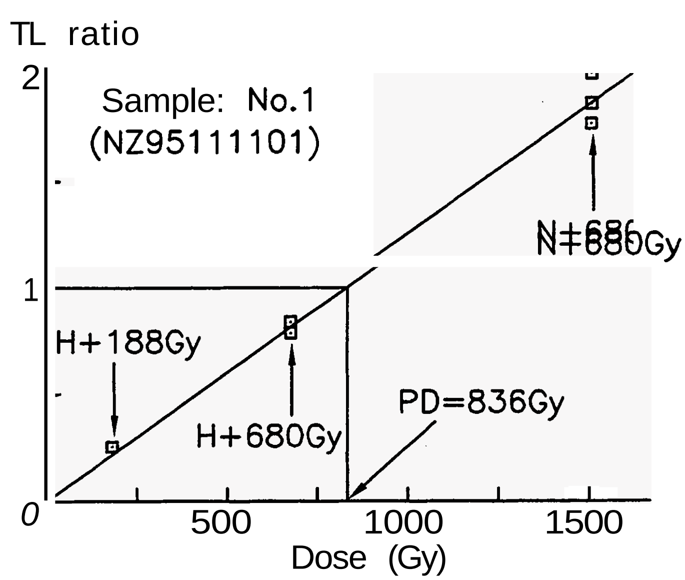

Fig. 4 - TL growth curve of ignimbrite.

Chemical analyses were made by gamma ray spectrometry using a **76** x **76 mm NaI** scintillator crystal detector. **NBS** standards were used. The error of the U and Th measurements was less than **10%**, and that of K was less than 3% in 24h operation. **Annual** dose was

TABLE 1: Summary of TL dating of Whakamaru Ignimbrite (samples 1-4), unaltered Ohakuri Ignimbrite (sample 5), Te Whaiti Ignimbrite (samples 6-7), and hydrothermally altered Ohakuri Ignimbrite (samples A1, A2).

No.	Sample	U (ppm)	Th (ppm)	K_2O (%)	Quartz grain size (mm)	Annual dose (mGy/y)	Paleodose (Gy)	TL age (ka)
1	NZ95111101	2.5	9.4	2.76	1.76	2.54	836	329±49
2	NZ95111102	2.5	9.7	2.72	2.11	2.43	770	317±53
3	NZ95111103	2.7	11.3	3.20	1.99	2.87	956	333±82
4	NZ95111104	2.9	11.6	3.21	1.44	3.14	932	297+45
5	NZ95111106	2.3	8.2	2.78	0.57	2.83	549	194±47
6	NZ95111201	2.7	10.2	3.05	1.14	3.13	1000	319±73
7	NZ95111202	3.5	13.2	3.66	0.93	4.15	1290	311±79
	(altered rocks)							
A1	NZ95111105A	1.4	5.7	7.07	0.61	6.02	681	113±59
A2	NZ95111105B	1.9	6.6	8.04	0.53	6.96	473	68±21

calculated from the data proposed by Bell (1979) and water calibration introduced by Aitken (1985, p.75).

Beta dose attenuation and cosmic ray contribution are important factors for collecting precise TL age data. The treatment method used in this study is discussed in a later chapter.

Table 1 gives the TL age data of the samples collected for this study. The error of the TL ages is a combination of paleodose measurement and annual dose calculation.

4. DISCUSSION

Many factors control the TL age data, as discussed in previous papers (Takashima and Watanabe, 1994; Takashima, 1995b). In this paper, the beta ray contribution is considered precisely because the large quartz *grain* size of all samples has a large effect on the calculation of annual dose. Beta dose attenuation as a function of quartz grain size is discussed by Mejdahl (1979)

Accordingly, we measured quartz grain size for all samples using thinsections, and determining the average diameter of from 3 to 5 of the largest grains. The grain sizes shown in Table 1 are such data. The grain size observed in thin section often does not represent the maximum diameter of quartz in the rock. However, experience has shown that selecting a small sample of the largest grains on a thin section usually closely approximates the largest grain size present in the rock.

The contribution of cosmic rays was neglected because the samples were assumed to have been buried for much of their geological history, and hence had received a very low total cosmic ray dose. The high concentrations of radiometric elements also diluted the contribution rate of cosmic rays. Evidence in support is provided by the comparison of samples 3 and 4. Both are samples of Whakamaru Ignimbrite exposed within 20 m of each other, but sample 4 came from inside a tunnel where it was shielded from cosmic rays. Their TL ages are not significantly different.

5. CONCLUSIONS

The TL ages for the Whakamaru-group ignimbrites (Tab. 1) range fiom about 0.30 Ma to 0.33 Ma, showing excellent agreement with recently published $^{40}Ar/^{39}Ar$ ages (Houghton *et al.*, 1995) in the 0.32 Ma to 0.34 Ma range. The Ohakuri Ignimbrite age of about 0.19 Ma supports recent field observations that the Unit is younger than the 0.22 Ma Mamaku Ignimbrite. The two samples of hydrothermally altered Ohakuri Ignimbrite both give quartz TL ages (~68 ka and ~113 ka) which are younger than the fresh tuff, as could be expected. As yet, the significance of the ages is hard to determine, but does suggest that hydrothermal activity occurred at Ohakuri over a period of some tens of thousands of years at that locality.

The pilot study has shown that the method adopted, using quartz grain size in evaluating beta ray and gamma ray contribution to the annual dose was successful. The technique is clearly applicable to the Whakamaru-group ignimbrites which are the most widespread of TVZ ignimbrites, and are ubiquitous in TVZ geothermal fields. The results fiom the Ohakuri Ignimbrite suite promise, for the first time, to yield estimates of the absolute time range of a TVZ geothermal system. Further work is planned for the 1996-97 year.

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7. REFERENCES

Aitken, M.J. 1985. Thermoluminescence dating. Academic Press, 359 pp.

Bell, W.T. 1979. Thermoluminescence dating: radiation dose-rate data. ***Archaeometry,*** V0.21: 243-245.

Bibby, H.M., Caldwell, T.G., Davey, F.J., Webb, T.H. 1995. Geophysical evidence on the structure of the Taupo Volcanic Zone and its hydrothermal circulation. ***J. Volcan. Geoth. Res.,*** 68: 29-58.

Grindley, G.W., Mumme, T.C., Kohn, B.P. 1994. Stratigraphy, paleomagnetism, geochronology and structure of silicic volcanic rocks, Waiotapu/Paeroa Range area, New Zealand. ***J. Geothermics,*** 23: 473-***500.***

Hashimoto, T., Yokosaka, K. and Habuki, H. 1987. Emission properties of thermoluminescence **from** natural quartz-Blue and red TL response to absorbed dose. ***Nuci.*** Tracks *Radiat. Meas.*, Vol.13: 57-66.

Henneberger, R.C. 1983. Petrology and evolution of the Ohakuri hydrothermal system, Taupo Volcanic Zone, New Zealand. Unpublished MSc thesis, University of Auckland.

Houghton, B.F., Wilson, C.J.N., McWilliams, M.O., Lanphere, M.A., Weaver, S.D., Briggs, R.M., Pringle, M.S. 1995. Chronology and dynamics of a large silicic magma system: central Taupo Volcanic Zone, New Zealand. *Geology,* 23: 13-16.

Mejdahl, V. 1979. Thermoluminescence dating: **beta-**dose attenuation in quartz ***grains.*** ***Archaeometry,*** V01.21: 61-72.

Takashima, I. 1995a. Thermal history of the Akinomiya-Oyasu geothermal field, Northeast Japan. Proc. ***World Geoth. Congress,*** Florence, Italy, 1995: 1067-1070.

Takashima, I. 1995b. Thermoluminescence dating: with special reference to accuracy and reliability of age determination using quartz of volcanic rocks. ***Quaternary Research,*** 34: 209-220.*

Takashima, I. and Honda, S. 1988. Alteration age mapping of some Japanese geothermal fields with improved thermoluminescence dating method. ***Geothermal Resources Council, Transactions,*** Vol. 12: 313-319.

Takashima, I., Honda, S. and Naya, H. 1990. TL ages of the Hokkaido pyroclastic flow deposits, Aomori Prefecture, Northeast Japan. ***J. Min. Petr. Econ. Geol.,*** 85: 459-468.*

Takashima, I. and Reyes, A.G. 1990. Alteration and TL age of the Palinpinon geothermal area, Negros Island, Southern Philippines. ***J. Geoth. Research Soc. Japan,*** Vol. 12: 315-325.

Takashima, I. and Watanabe, K. 1994. Thermoluminescence age determination of lava flows/domes and collapsed materials at Unzen Volcano, SW Japan. Bull. ***Voclanol. Soc. Japan,*** 39: 1-12.

Tamanyu, S. 1996. Report of the 17th New Zealand Geothermal Workshop and PACRIM '95. ***J. Geoth. Energy Research*** and ***Develop.*** 21: 17-27 (in Japanese).

Wilson, C.J.N., Houghton, B.F., McWilliams, M.O., Lanphere, M.A., Weaver, S.D., Briggs, R.M. 1995. Volcanic and structural evolution of Taupo Volcanic Zone, New Zealand: a review. **J. *Volcan. Geoth. Res.,*** 68: 1-28.

Wood, C.P. 1995. Calderas and geothermal systems in the Taupo Volcanic Zone, New Zealand. Proc. ***World Geoth. Congress, Florence, Italy*** 1995: 1331-1336.

* in Japanese with English abstract.