Proceedings World Geothermal Congress 2000
Kyushu - Tohoku, Japan, May 28 - June 10, 2000

FISSION TRACK THERMAL HISTORY ANALYSIS IN GEOTHERMAL FIELD USING HEAVY ION IRRADIATION METHOD

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Key words: Fission track; track length; heavy ion irradiation; thermal history; Goto-Fukue Island

ABSTRACT

Geothermal manifestations such as hydrothermal alteration haloes have been reported to occur in the Goto-Fukue Island, SW Japan. In order to clarify the timing and magnitude of paleo-geothermal activities in the island, a fission track (FT) thermo-chronologic study has been carried out for granite-porphyry drilling core samples collected at several depths. For the purpose of FT length analysis, a technique to detect confined uranium-238 FTs in samples with low spontaneous track density ($<<10^6/cm^2$) has been investigated by using heavy ion irradiation. Five zircon FT ages obtained in this study become progressively young from 11.3 Ma to 6.6 Ma with increasing depth. Based on track length (TL) distribution for the shallowest sample (115 m deep), FT age of 11.3 Ma is interpreted as the age of original cooling of the granite-porphry intrusion. TL distributions for three samples from deeper portions (279-1134 m) indicate that samples have experienced a thermal event that caused track annealing at a certain stage of track accumulation in zircon. Pre-existing tracks have completely annealed in the deepest sample (1481 m deep) and no short tracks are found. The timing of the thermal event can be interpreted to be around 6.6 Ma. These results allow a chronological reconstruction of geothermal activity related with rhyolite dyke intrusion.

1. INTRODUCTION

At the early stage of geothermal resource exploration, surface manifestations, such as hydrothermal alteration haloes, are important indicators. However, these indicators, more often than not, result from multiple geothermal heating events. The heat sources responsible for these thermal manifestations may be older than 0.5 Ma, too old for effective geothermal energy generation. Thus it is important to determine the precise age of prospective heat sources to design the further exploration strategies. Thus a thermo-chronologic study around the target area is essential for strategic decision making in exploration.

Among the common radiometric dating methods, the FT method using zircon has some advantages for dating altered acidic volcanic rock samples, because zircons are chemically resistant against hydrothermal alteration. Also the analysis of the FT single grain age distribution combined with zircon crystal habit information makes it possible to eliminate the detrital age components that are occasionally inherited from the basement. Additionally, an unique feature of the FT method is based on the analysis of TL distribution.

The original mean length of newly formed FTs in zircon is 10 to 11 μm and it shrinks due to thermal annealing at temperatures above and within the partial annealing zone (PAZ). At high temperatures above the PAZ, spontaneous track density (as well as FT age) remains zero because FTs anneal immediately after their formation and no track accumulates in zircon. Although FTs accumulate within the PAZ through geologic time, each track partially anneals depending on the duration and the temperature of heating. The recently proposed temperature range of zircon PAZ is about 210-340 °C at the effective heating period of 1 million years (Yamada *et al.* 1995; Tagami *et al.* 1998). Some of the apparent FT ages contain mixed information derived both from older tracks with lengths reduced by annealing during thermal reprinting event and from newer tracks with original lengths generated after the temperature cooled below the PAZ, an examination of TL distribution can clearly distinguish these mixed ages from the original ages and/or the reset ages composed of tracks without any significant TL reduction. Therefore FT dating combined with TL measurement can be potentially used to reconstruct the initiation and the cessation history of geothermal activity.

A limitation of this technique is insufficient number of spontaneously accumulated tracks in young samples and low probability of finding confined FTs which have preserved both ends within the zircon crystal, a prerequisite for accurate length measurement. The heavy ion irradiation technique, which involves bombardments of the zircon with nickel ions (Watanabe *et al.,* 1991), increases the chances of observing confined tracks in samples with low spontaneous track density ($<<10^6/cm^2$). Yamada *et al.* (1998) confirmed the remarkable increase in detection efficiency of confined FTs compared with other conventional methods.

In this preliminary study, the history of geothermal activity in the Goto-Fukue Island, SW Japan was examined using the above-mentioned FT thermo-chronologic approach. Zircons from drill core samples in three wells collected at several depth intervals in a Miocine granite-porphyry intrusion were analyzed. This pluton has experienced various degrees of thermal overprint and hydrothermal alteration related with rhyolite dyke rocks of unknown age.

2. STUDY AREA AND SAMPLES

The Goto-Fukue Island is located in the western part of the

Nagasaki Prefecture, SW Japan (Fig. 1). The island is mainly composed of five geological rock units listed in order from the oldest to the youngest. The basement of the area, the Goto Group, is Early to Middle Miocene, non-marine sedimentary rocks (alternation of sandstones and mudstones with tuffaceous rocks) exposed over the island. Miocene felsic volcanic rocks, the Fukue Rhyolites (rhyolite tuff, welded tuff and rhyolite lava flows) are distributed within the NE-SW trending depression zone in the central part of the island. Miocene intrusives consisting of granite, granodiorite and granodiorite porphyry, the Goto Granites; mainly crop out in the central part of the island. Rhyolite dyke rocks intrude into the Goto Granite and the Goto Group. Quaternary basalt lava flows overlie in the northwestern and southeastern parts of the island.

The relative timing of igneous activity (the Fukue Rhyolites and the Goto Granites) has been controversial (e.g. Ueda, 1961; Kamata and Watanabe, 1969). Field observations suggest that the Fukue Rhyolites are older than the granodiorite porphyry, a member of the Goto Granites (Himeno *et al.,* 1997). Although many radiometric (whole rock K-Ar and zircon FT) ages have been reported (Miyachi, 1988; NEDO, 1990; Ishikawa and Tagami, 1991; Himeno *et al.,* 1997), some of the determined ages disagree with field observation, The young radiometric ages that contradict observed cross-cutting relationships most likely reflect partial resetting during the complexed paleo-geothermal history of this area. At least two or more independent events of intensive paleo-geothermal activity affected the island as indicated by the distribution of hydrothermal alteration zones. There is a pyrophyllite deposit in the Goto mine area and a hot spring at Arakawa town. NEDO (1990) also reported hydrothermal alteration zones around the drill site FS-2 and 3 (Fig. 1) and suggested that these alteration haloes might be related with rhyolite dyke intruding the the Goto Granites, found at a depth of ca. 1km.

Samples for FT analysis were collected at several depths ranging from 115 m to 1481 m, from the drill core FS-2, 3, and 4 (Fig. 1). Modern temperatures of samples increase from 21°C at 115 m deep in the FS-2 to 81°C at 1481 m deep in the FS-3. All analyzed samples are of the Goto Granites. The granite-porphyry sample at 115 m depth shows no significant alteration based on XRD analysis and thin section observations. The other samples, on the other hand, suffered varying degrees of hydrothermal alteration, especially the sample from 1481 m, which shows chlorite alteration.

3. EXPERIMENTAL METHOD

Zircon grains were separated using the standard magnetic and heavy liquid techniques, then mounted in teflon sheets. These mounts were polished to expose internal surface, etched for 45 hours in a NaOH+KOH eutectic melt at 230 °C and attached with mica detectors (Gleadow, 1981). FT ages were determined using the zeta calibration method (Hurford and Green, 1983).

For the TL measurement, the heavy ion irradiation technique was used. Firstly the additionally prepared zircon mounts were bombarded with high energy heavy ions (Ni^{11+} with □100 MeV) using a tandem van de Graaff accelerator at the Tandem Laboratory of Kyushu University (Fig. 2). Chemical etching of the sample enlarges the damaged zones resulting from irradiation. These damaged zones effectively intersect and etch confined FTs. Because the heavy ion tracks are perpendicular to the crystal surface (Fig. 2), they do not disturb the identification and measurement of horizontal confined FTs. Induced TLs were also measured under the same system for normalization to a non-annealed sample.

4. RESULTS AND INTERPRETATION

FT ages and TL distributions determined in this study are shown in Fig. 3. FT ages become progressively young from 11.3 Ma to 6.6 Ma with increasing depth. This suggests that some of the determined FT ages are influenced by thermal annealing and that these samples have experienced thermal overprints since the intrusion and cooling of the Goto Granites. TL distribution patterns enhance the interpretation of the age data. TL distribution for a shallow sample collected at 115 m depth from which the oldest FT age was obtained, shows an average TL of 10.8 μm with no significantly short tracks. On the other hand, TL distributions for samples collected at depths ranging from 287 m to 1134 m clearly include short tracks (e.g. 4-8 μm) as well as long ones (e.g. 8-13 μm), suggesting that these samples have experienced thermal annealing at a certain stage of track accumulation. Thus these three FT ages in Fig. 3 contain mixed information in terms of pre- and post- heating event. The deepest sample at 1481 m, for which the youngest FT age was determined, also doesn't show any short tracks. This means that all the accumulated tracks before the heating event have totally annealed and FT age contains the only age information after resetting of zircon FT system. The thermal history of the study area is reconstructed as shown in Fig. 4 with aid of FT thermo-chronologic study using heavy ion irradiation method.

ACKNOWLEDGEMENTS

We would like to thank Drs. H. Nakamura and S. Mitarai in the Tandem Accelerator Laboratory of Kyushu University for their technical support during the heavy ion irradiation. We are grateful to Dr. T. Honda at Musashi Institute of Technology for his help in thermal neutron irradiation. We deeply appreciate two anonymous reviewers for their constructive comments. This study was financially supported by a Grants-in-Aid for Scientific Research from the Ministry of Education, Japan (No. 09875257).

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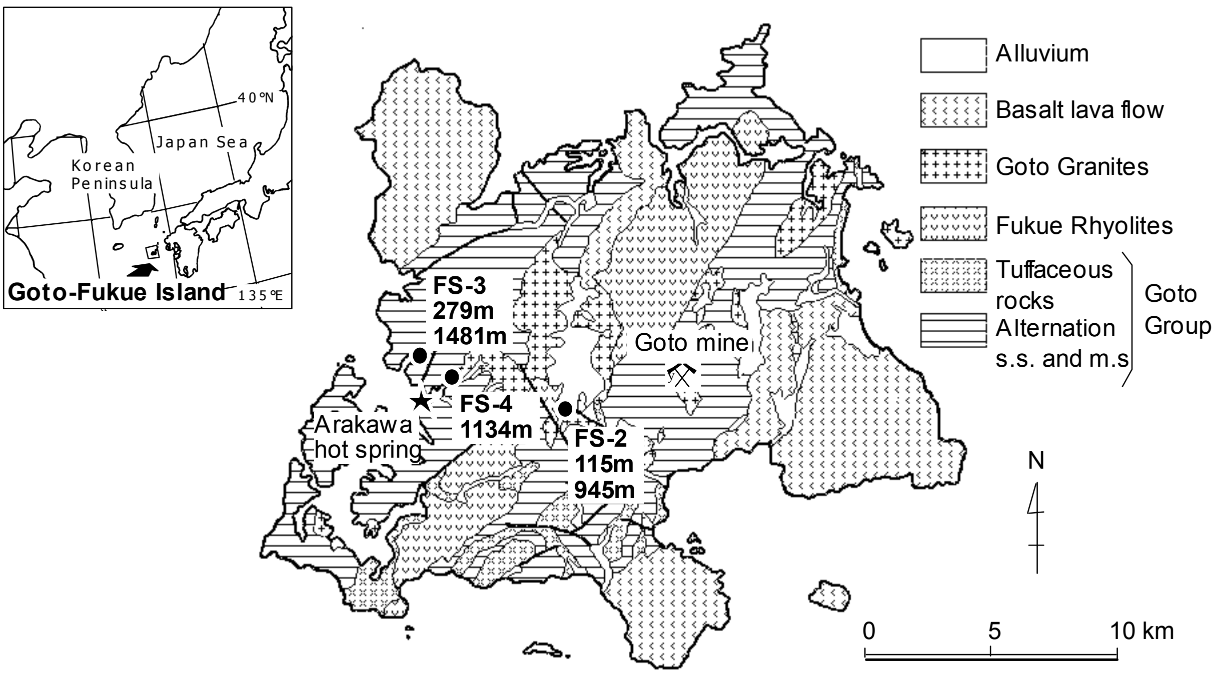

Fig. 1. Location and geology of the Goto-Fukue Island (after Matsui and Kawada, 1986). The granit-porphry samples for fission track study were collected from the drill holes FS-2, 3 and 4 at depth shown in the figure.

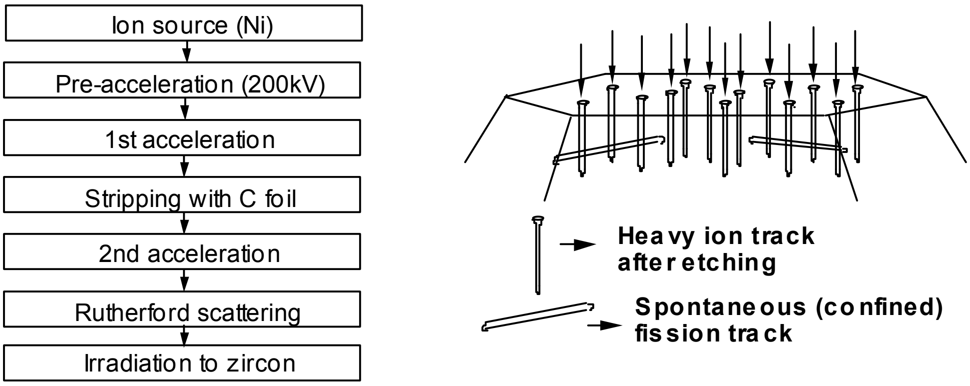

Fig. 2. Schematic figure showing heavy ion irradiation method (Watanabe et al. 1991).

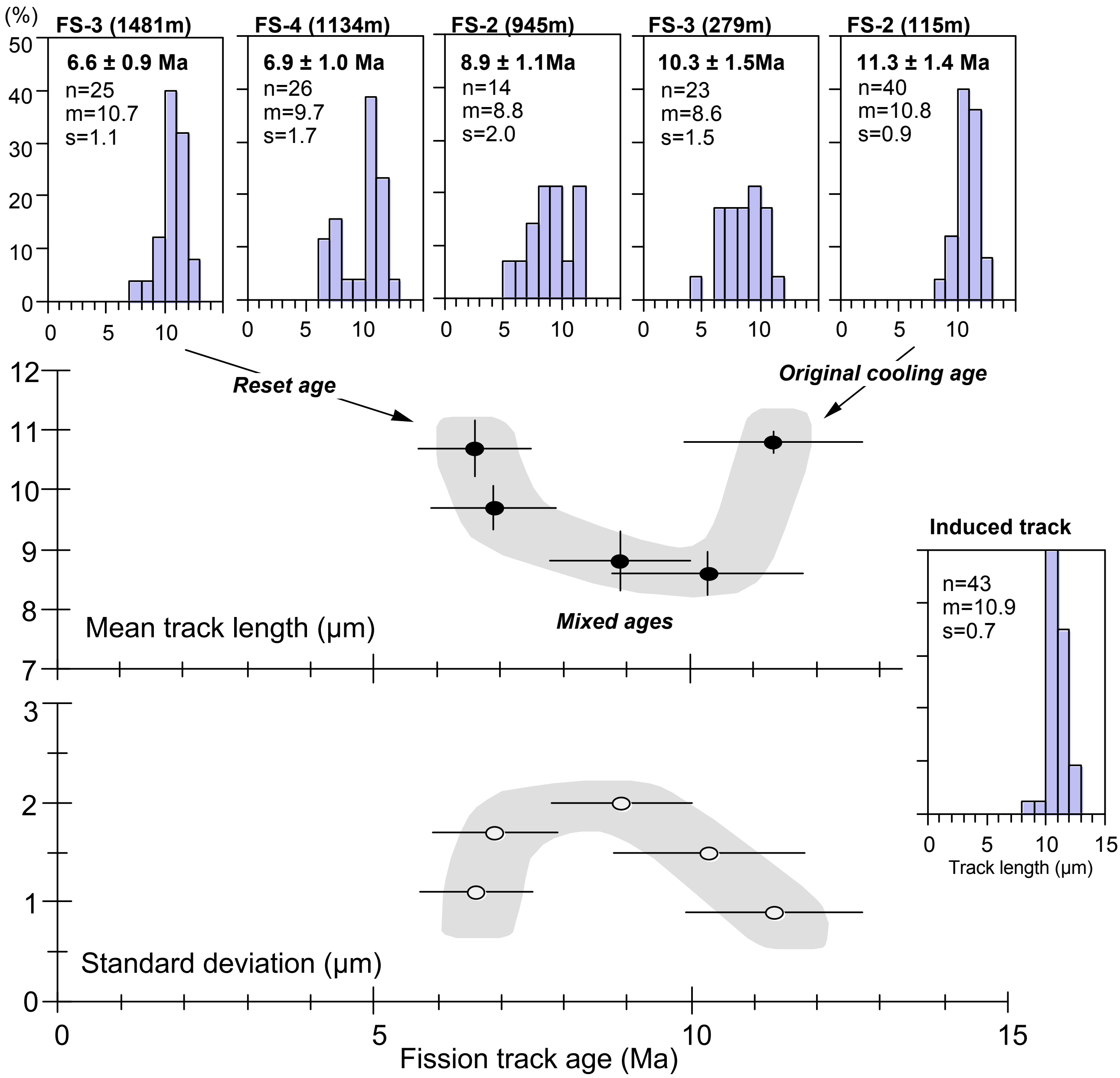

Fig. 3. Interrelationships between mean track length, standard deviation of the distribution of track lengths and zircon FT age for the granite-porphry drill core samples from the Goto-Fukue Island (data are after Kuroki, 1990). The "boomerang" trends indicate a partial to complete thermal overprint of pre-existing tracks. Track length distribution for the oldest sample (11.3 Ma) shows uni-modal pattern with no short (<<8μm) tracks. This indicates the sample has experienced no annealing since the original cooling of the granite-porphry intrusion. As the sampling depths increase (from 279 m to 1134 m), obtained ages become progressively young and partially annealed tracks (e.g. 4-8 μm) mixed with long ones (e.g. 8-13 μm) are found. These samples have experienced a thermal event to cause track annealing in zircon at a certain stage of track accumulation. Pre-existed tracks have completely annealed and no short tracks are found in the youngest sample (6.6 Ma). The timing of the thermal event can be interpreted to be around 6.6 Ma.

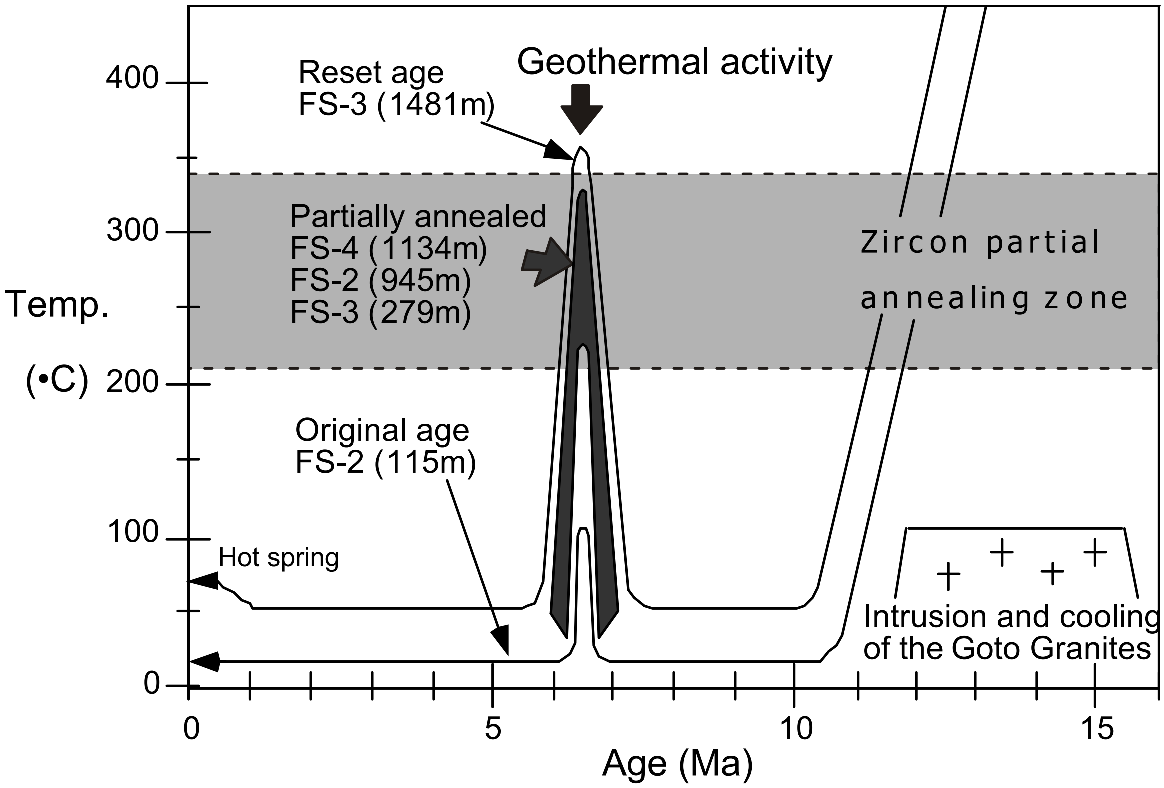

Fig. 4. Thermal history reconstructed for a granite-porphry rock body based on fission track data.