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Zircon Fission-track Dating of the Hiyoriyama Cryptodome at Kuttara Volcano, Southwestern Hokkaido, Japan

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Zircon fission-track dating was applied to determine the age of the Hiyoriyama Cryptodome in the Noboribetsu Geothermal Field, Kuttara Volcano, southwestern Hokkaido, Japan. We dated two rock samples (HY-10 and HY-11) collected from the wall of an explosion crater at the summit of the cryptodome. A total of 20.5 kg of dacite (HY-10) and 25.5 kg of dacite (HY-11) was crushed, and 1004 (HY-10) and 1008 (HY-11) zircon grains were used to determine the relatively young fission-track ages. Dating was performed using the external detector method, and the ages were calculated from the densities of spontaneous and induced tracks in the whole zircon grains. The obtained ages are 15±4 ka (HY-10) and 14±4 ka (HY-11), which are the same within error. The dating results suggest that the cryptodome formed at *ca.* 15 ka.

Key words: Fission-track dating, zircon, Hiyoriyama Cryptodome, Noboribetsu Geothermal Field, Kuttara Volcano

1. Introduction

Fission-track dating is a radiometric dating method based on counting the number of damage trails left by fission fragments in uranium-bearing minerals, such as zircon and apatite, and in glasses (Fleischer *et al.,* 1975; Hurford, 1990; Wagner and Van den haute, 1992). This method is commonly used for samples in the age range of 10^5 to 10^8 years, but may be applied to younger samples in the range of 10^3 to 10^4 years by measuring a large number of mineral grains (Danhara, 1995; Wagner, 1998; Kameyama *et al.,* 2005; Takagi *et al.,* 2007).

In the present study, we applied fission-track zircon dating to a Quaternary subaerial dacite cryptodome at Hiyoriyama (the Hiyoriyama Cryptodome) in the Noboribetsu Geothermal Field, Kuttara Volcano, southwestern Hokkaido, Japan. No previous study has reported geochronological data for the cryptodome, and fission-track dating of zircon from the cryptodome provides an insight into the history of dome formation and the evolution of the Kuttara Volcano.

2. Hiyoriyama Cryptodome

The Hiyoriyama Cryptodome is located in the northern part of the Noboribetsu Geothermal Field, in the western part of Kuttara Volcano (Fig. 1). The Kuttara Volcano consists mainly of an andesitic stratovolcano that reaches an elevation of 549 m above sea level, with a small caldera (Lake Kuttara) on the summit. The volcano evolved over the period 80–45 ka, involving early silicic explosive activity and subsequent stratovolcano building associated with caldera collapse at 40 ka (Katsui *et al.,* 1988; Yamagata, 1994; Moriizumi, 1998; Moriya, 2003). The Noboribetsu Geothermal Field is inferred to have formed after the collapse of the caldera (Katsui *et al.,* 1988). The geothermal field is approximately 1 km wide (northeast-southwest) and 1.5 km long (northwest-southeast).

The Hiyoriyama Cryptodome (Fig. 2) is elliptical in plan view, ranging in diameter from 350 m (northeast-southwest) to 550 m (northwest-southeast). It rises 130 m above the surrounding area, with the highest point being 377 m above sea level. The surface of the cryptodome is covered with sediments up to 15 m thick (Katsui *et al.,* 1988). An explosion crater occurs at the summit (Fig. 3). The crater is 55×95 m in size (elongate northwest-southeast) and 20 m deep, and contains active fumaroles.

The Hiyoriyama Cryptodome consists of coherent dacite that is well exposed on the wall of the summit explosion crater, where it appears massive with columnar joints spaced at intervals of 100–150 cm. The dacite is grey and porphyritic, containing phenocrysts of plagioclase (<4 mm long, 21–25 vol.%), quartz (<5 mm, 6–8 vol.%), hypersthene (<2 mm, 4–6 vol.%), trace

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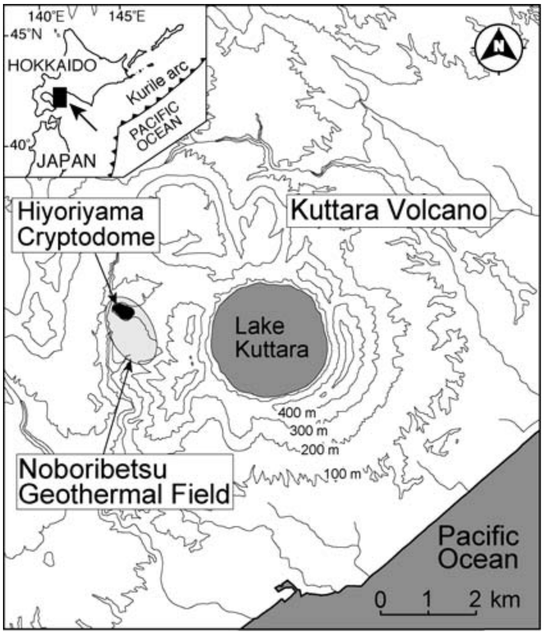

Fig. 1. Location of the Hiyoriyama Cryptodome in the Noboribetsu Geothermal Field, Kuttara Volcano, southwestern Hokkaido, Japan.

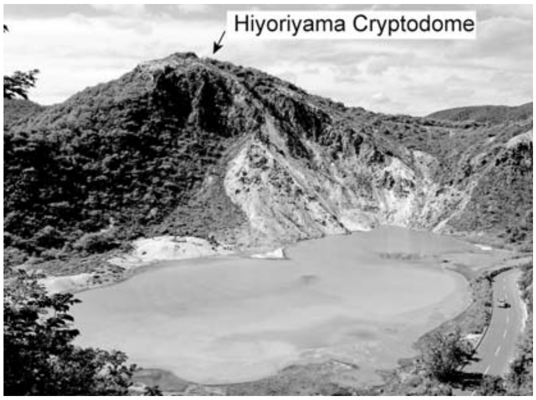

Fig. 2. Photograph of the Hiyoriyama Cryptodome (viewed from the south). The cryptodome contains an explosion crater at the summit, within which are active fumaroles.

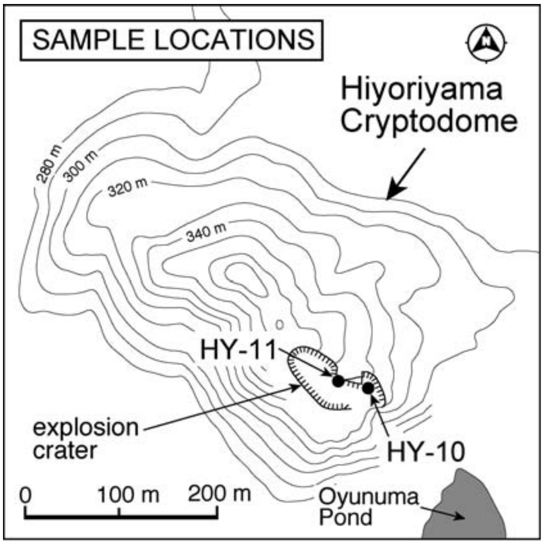

Fig. 3. Locations of rock samples (HY-10 and HY-11) used for fission-track dating.

amounts of augite (< 1 mm) and opaque minerals (< 0.5 mm), and rare hornblende (< 0.2 mm). The groundmass (62–66 vol.%) is granophyric, containing silica minerals, feldspars, and opaque minerals of < 0.1 mm across. Table 1 lists the whole-rock major element chemical composition of the dacite, which contains 70 wt.% SiO_2, 3.5 wt.% Na_2O, and 1.5 wt.% K_2O.

3. Fission-track age determination

We determined fission-track ages for two rock samples (HY-10 and HY-11). Sample HY-10 is a fresh, coherent dacite that was collected from the eastern wall of the explosion crater at the summit of the Hiyoriyama Cryptodome (Fig. 3). A total of 20.5 kg of the dacite was crushed, and about 3000 zircon grains were separated using conventional heavy liquid and magnetic techniques. Relatively large zircon grains with planar crystal faces were separated for fission-track dating, with 1004 grains being analyzed. The zircon grains are uniformly short, prismatic, colorless, and 0.1–0.5 mm long (Fig. 4).

Sample HY-11 is a fresh, coherent dacite collected from the northeastern wall of the explosion crater (Fig. 3). A total of 25.5 kg of the dacite was crushed, and about 3000 zircon grains were separated. Relatively large zircon grains with planar crystal faces were separated for fission-track dating, with 1008 grains being analyzed. The zircon grains separated from HY-11 are identical in shape and size to those from HY-10.

The zircon grains were mounted in a PFA sheet (Danhara *et al.,* 1993) and etched with KOH: NaOH eutectic etchant at 225℃ for 51 hours (HY-10) or 62 hours (HY-11). The etching time is appropriate for the appearance of isotropic fission tracks along various crystal axes (see Iwano *et al.,* 1992; Danhara, 1995). Figure 5 shows examples of fission tracks in the zircon grains. The zircon grains were then packed for irradiation between NIST-SRM612 glass dosimeters. Diallyl phthalate (DAP) plastic detectors (Yoshioka *et al.,* 2003) were used for induced-track counts of zircon and

Table 1. Whole-rock major-element compositions of dacites from the Hiyoriyama Cryptodome, as determined by X-ray fluorescence (Rigaku RIX-2000) at Shimane University, Japan, following the analytical method proposed by Kimura and Yamada (1996).

Sample No.	Nb-83a	Nb-83b
SiO_2 (wt. %)	70.05	69.80
TiO_2	0.41	0.40
Al_2O_3	15.29	15.59
Fe_2O_3*	4.42	4.38
MnO	0.09	0.09
MgO	1.07	1.08
CaO	3.83	4.02
Na_2O	3.43	3.51
K_2O	1.55	1.51
P_2O_5	0.08	0.08
Total	100.22	100.46
L.O.I.	1.33	1.18

Fe_2O_3* = total iron as Fe_2O_3. L.O.I. = loss on ignition.

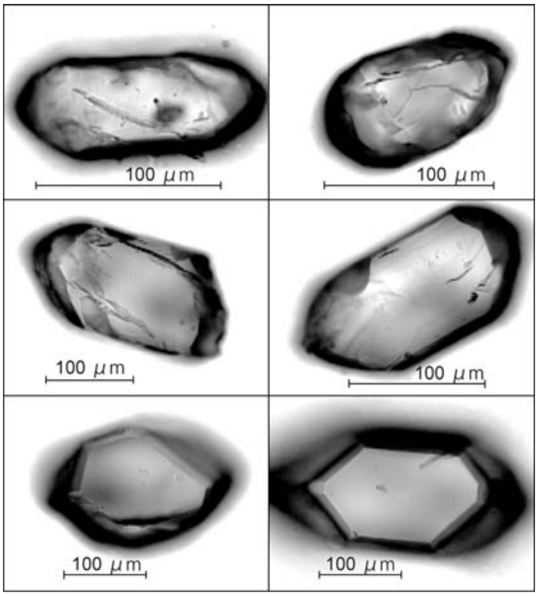

Fig. 4. Representative zircon crystals used for fission-track dating (sample HY-10). Photomicrographs taken after etching.

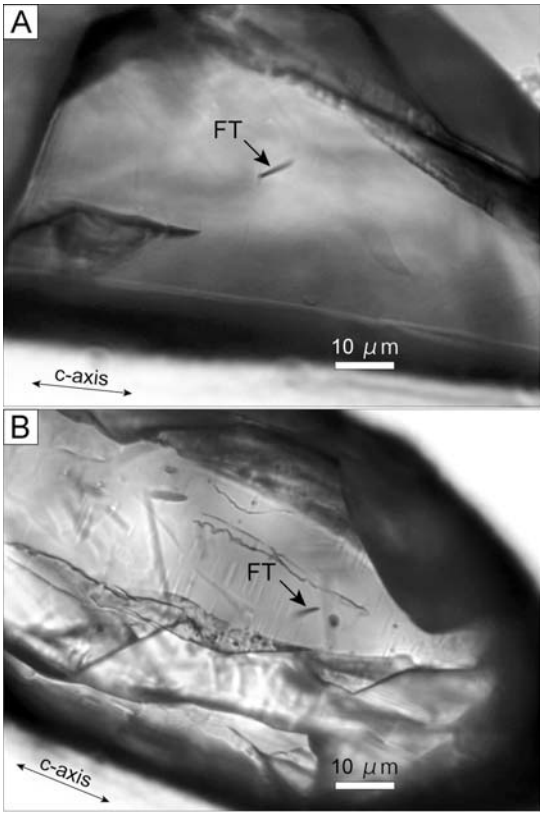

Fig. 5. Photomicrographs of fission tracks in zircon grains. (A) Zircon grain number 119 in sample HY-10, (B) zircon grain number 388 in sample HY-10. Fission tracks (FT) are shown by solid arrows. Also shown is the orientation of the *c*-axis for each zircon crystal.

the glass dosimeter. These samples were irradiated in a pneumatic tube of the JRR-4 reactor (HY-10) or JRR-3 reactor (HY-11) at the Japan Atomic Energy Agency (JAEA).

The fission-track ages were measured using the external detector method (ED2; Danhara *et al.,* 1991, 2003) and employing the standardization of fission-track calibration recommended by the International Union of Geological Sciences (IUGS) Subcommission on Geochronology (Hurford, 1990). The ages were calibrated by the zeta calibration approach (Hurford and Green, 1983) using a zeta factor of 350 ± 3 yr cm^2 determined from the known age of the standards (Danhara *et al.,* 2003) for HY-10, and a zeta factor of 371 ± 3 yr cm^2 (Danhara and Iwano, 2009) for HY-11. The data were examined to determine whether the grains belonged to a single population, using the χ^2 test with a statistical significance of 5% (Galbraith, 1981; Green, 1981). The ages were calculated using the densities of spontaneous and induced tracks for all zircon grains, regardless of the presence or absence of spontaneous tracks.

4. Results and discussion

Table 2 lists the results of fission-track dating. Sample HY-10 yields 17 spontaneous tracks in the 1004 zircon

Table 2. Fission-track zircon ages of the Hiyoriyama Cryptodome.

Sample name	Mineral	Number of crystals	Spontaneous ρ_s (cm^{-2})	Ns	Induced × 10^{-5} ρ_i (cm^{-2})	Ni	P (χ^2) (%)	Dosimeter ρ_d (×10^4cm^{-2})	Nd	r	U (ppm)	Age (ka) (±1σ)
HY-10	zircon	1004	8.75×10^2	17	1.42×10^6	27612	99	7.144	4287	0.101	170	15 ± 4
HY-11	zircon	1008	6.58×10^2	12	2.32×10^6	42383	99	13.34	6405	0.177	140	14 ± 4

ρ and N represent the track density and total number of fission tracks counted, respectively. Analyses were performed using the external detector method (ED 2; Danhara *et al.,* 2003) applied to the natural crystal surfaces. A NIST-SRM612 standard glass was used as a dosimeter. P (χ^2) is the probability of obtaining the χ^2 value for ν degrees of freedom (ν=number of crystals - 1; Galbraith, 1981). r is the correction coefficient between ρ_s and ρ_i. U is the uranium content. Zircon grains were irradiated using the pneumatic tube of reactor unit JRR-4 (for HY-10) or JRR-3 (for HY-11) at the Japan Atomic Energy Agency (JAEA). The age was calculated using a zeta calibration factor $\zeta_{ED\,2}=350\pm3$ (1σ) for HY-10 (Danhara *et al.,* 2003), and $\zeta_{ED\,2}=371\pm3$ (1σ) for HY-11 (Danhara and Iwano, 2009). Ages are expressed in ka (10^3 years) with an error range of 1σ.

grains, with a density of spontaneous tracks of $8.75\times10^2\,cm^{-2}$. The density of induced tracks for zircon grains is $1.42\times10^6\,cm^{-2}$. Because the zircon grains were separated from a coherent dacite, all the grains are considered to belong to a single population. The χ^2 test yields a value of 99%; therefore, the fission-track age can be calculated using the densities of spontaneous and induced tracks for all 1004 zircon grains. Sample HY-10 yields a fission-track age of 15±4 ka.

Sample HY-11 yields 12 spontaneous tracks from the 1008 zircon grains, with a density of spontaneous tracks of $6.58\times10^2\,cm^{-2}$. The density of induced tracks for the zircon grains is $2.32\times10^6\,cm^{-2}$. The χ^2 test yields a value of 99%; consequently, the fission-track age can be calculated using the densities of spontaneous and induced tracks for all 1008 zircon grains. Sample HY-11 yields a fission-track age of 14±4 ka. The ages obtained from HY-10 (15±4 ka) and HY-11 (14±4 ka) are the same within error. The weighted average of the two ages is 15±3 ka, suggesting the Hiyoriyama Cryptodome formed at *ca.* 15 ka.

The Noboribetsu Geothermal Field is inferred to have formed after 40 ka, following caldera collapse and associated with post-caldera volcanism of the Kuttara Volcano (Katsui *et al.,* 1988; Yamagata, 1994; Moriizumi, 1998; Moriya, 2003). The fission-track ages obtained for the Hiyoriyama Cryptodome (15±4 and 14±4 ka) are consistent with the eruption history of the Kuttara volcano. The average uranium contents of the zircon crystals used for fission-track dating are 170 ppm (HY-10) and 140 ppm (HY-11) (Table 2), which are within the standard range for zircons in volcanic rocks (mode, 100–200 ppm; Danhara *et al.,* 2004). The present results show that fission-track dating is applicable in determining the age of formation of late Quaternary volcanic domes.

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(Editional handling Noriko Hasebe)

北海道南西部クッタラ火山日和山潜在ドームのフィッショントラック年代

後藤芳彦・檀原　徹

北海道南西部クッタラ火山日和山潜在ドームのフィッショントラック年代測定を行った．測定は日和山潜在ドームの山頂爆裂火口から採取した 2 個のデイサイト試料（試料名 HY-10, 20.5 kg および HY-11, 25.5 kg）から分離した 1004 個および 1008 個のジルコンについて行い，測定法はジルコンの外部面を用いる外部ディテクター法（ED2）を用いた．その結果，HY-10 から 15±4 ka, HY-11 から 14±4 ka の年代値が得られた．これらの年代値は誤差の範囲内で一致する．日和山潜在ドームの形成年代は，約 15000 年前であると考えられる．