国立科博専報，(51), pp. 45–51 , 2016 年 3 月 28 日
Mem. Natl. Mus. Nat. Sci., Tokyo, (51), pp. 45–51, March 28, 2016

Zircon U–Pb Dating of the Akashima Formation, Oga Peninsula, Akita Prefecture, Japan

Kenichiro Tani*, Yukiyasu Tsutsumi, Masako Shigeoka and Kazumi Yokoyama

Department of Geology and Paleontology, National Museum of Nature and Science,
4–1–1 Amakubo, Tsukuba, Ibaraki 305–0005, Japan
*E-mail: kentani@kahaku.go.jp

Abstract. Comprehensive zircon U–Pb ages have been obtained using laser-ablation ICP-MS from igneous rocks in the Akashima Formation exposed in the northwestern part of the Oga Peninsula, Akita Prefecture, Japan. The Akashima Formation, mainly composed of dacitic welded lappilli-tuff, was previously considered to represent part of the type locality for the Miocene "Green Tuff" in the Northeast Japan Arc. However, recent SHRIMP zircon U–Pb dating showed that at least part of the Akashima Formation was formed in the Late Cretaceous at 72 Ma (Kano *et al*., 2012), raising questions about the age and distribution of the formation. We have newly analyzed seven tuff samples that broadly cover the exposures that have been mapped as the Akashima Formation. All of the obtained igneous zircon U–Pb ages cluster at ~72 Ma, concordant with the recent SHRIMP zircon ages, confirming that the Akashima Formation was generated during Late Cretaceous episodic volcanism. However, three samples analyzed from the abundant granitic xenoliths entrained in the volcanic breccia of the Akashima Formation yielded distinctively older ages of ~92 Ma, indicating that an unexposed Late Cretaceous granitic basement underlies the Oga Peninsula region. Furthermore, NE-trending porphyritic rhyolite dikes that intrude the Akashima Formation showed much younger ages of ~32 Ma. These Oligocene ages are contemporaneous with the previously reported radiometric ages of the rhyolitic lava and volcaniclastic rocks of the overlying Monzen Formation, suggesting that these dikes represent the magma feeding system of the Monzen Formation volcanism. These new ages provide important temporal constraints for the tectonic reconstruction of pre-Cenozoic Northeast Japan Arc before the formation of the Sea of Japan.
Key words: Zircon U–Pb ages, Akashima Formation, Cretaceous volcanism, Granitic basement

Introduction

Voluminous silicic volcanic rocks are widely distributed along the coastal regions of the Sea of Japan in the Northeast and Southwest Japan Arcs. Since these silicic volcanic rocks are commonly overlain by Miocene submarine sediments, previous studies have suggested that they are associated with Miocene magmatism during the opening of the Sea of Japan, and have termed them the "Green Tuff" (e.g. Huzioka 1956). However, since these volcanic deposits have commonly experienced hydrothermal alteration, the previous temporal constraints mostly relied on limited biostratigraphic ages or zircon fission-track (FT) ages and lacked direct dating of the volcanic rocks by more reliable radiometric ages.

The Oga Peninsula is located on the northwestern coast of Akita Prefecture, in the Northeast Japan Arc (Fig. 1). It is predominantly composed of volcanic sequences that are overlain by post-Middle Miocene marine sediments, and has long been regarded as the type locality for the "Green Tuff" in northeast Japan (e.g. Kobayashi *et al*., 2004). The volcanic rocks in the Oga Peninsula have been divided into four units, the Akashima, Monzen, Nomuragawa, and Daishima Formations, in order of oldest to youngest, on the

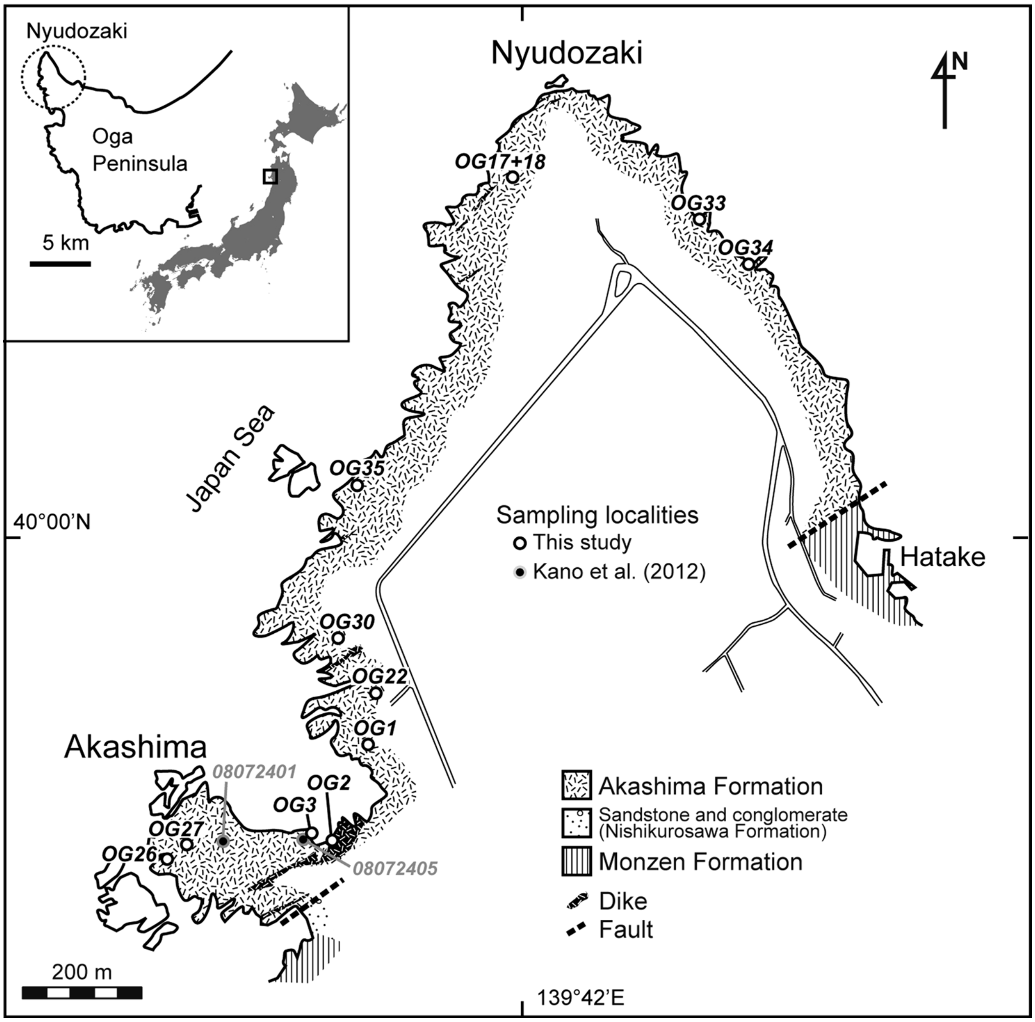

Fig. 1. Geologic map of the Nyudozaki region with sampling locations (modified after Kano *et al*., 2012).

basis of lithological analysis of the volcanic deposits (Kobayashi *et al*., 2008). Based on zircon FT and K–Ar ages, the Monzen Formation is considered to be the product of Late Oligocene volcanism (Kano *et al*., 2007), whereas the Nomuragawa and Daishima Formations represent younger Middle Miocene volcanic activity (Kobayashi *et al*., 2004).

The Akashima Formation, which comprises the lowermost unit exposed in the area and is the main focus of this study, is distributed in the Nyudozaki area (Fig. 1), located at the northwestern end of the peninsula. Even though the direct contact is unclear, the Akashima Formation is considered to be in fault contact with the overlying Monzen Formation (Kano *et al*., 2011). The formation is composed predominantly of dacitic welded lappilli-tuff and volcanic breccia that is more than 200 m thick. The volcanic breccia contains abundant granitic xenoliths (Fig. 2a). The lithology, shapes, and sizes of the granitic xenoliths are highly variable, but consist mostly of rounded clasts of biotite-hornblende granite, biotite granite, and fine-grained aplitic granite, and range in size from a centimeter to several meters in diameter.

Various ages have been reported from the dacitic tuff of the Akashima Formation. Suzuki *et* *al*. (1980) reported Early Eocene zircon FT ages of 49.3 to 51.4 Ma. Conversely, Ohguchi *et al*. (1979) reported Oligocene whole-rock K–Ar ages (30 to 38 Ma) and Eocene to Late Cretaceous zircon FT ages (61 to 67 Ma) from the welded tuff. More recently, Kano *et al*. (2012) conducted a multi-chronological study of the welded dacite lapilli-tuff samples of the Akashima Formation. The zircon U–Pb ages obtained by Sensitive High Resolution Ion Microprobe (SHRIMP-II) yielded well-defined magmatic ages of 72 Ma, whereas zircon FT ages ranged from 65 to 63 Ma, and Ar–Ar plagioclase plateau age yielded a much younger age of 33.65 Ma. The discrepancy of the ages obtained by different geochronological methods for the same samples has been explained by the Cretaceous volcanic rocks being hydrothermally altered by the Oligocene magmatic activity at ~34 Ma, with intermediate zircon FT ages resulting from partial thermal resetting (Kano *et al*., 2012). This is the first reliable evidence that Late Cretaceous volcanic rocks are distributed in the Northeast Japan Arc. However, since the analyzed tuff samples of Kano *et al*. (2012) were only collected from the western part of Nyudozaki (Fig. 1), it was not certain whether the entire formation was formed in the Cretaceous or whether an unrecognized hiatus is present between the studied area and other parts of the formation with younger Eocene to Oligocene ages.

Samples and Analytical Method

A total of twelve samples were analyzed for zircon U–Pb dating (Table 1). Seven samples of dacitic welded tuff and dacitic matrix of volcanic breccia from the Akashima Formation were selected (OG3, OG26, OG27, OG30, OG33, OG34, and OG35) to broadly cover the distribution of the formation (Fig. 1). Furthermore, three samples of granitic xenoliths entrained in the volcanic breccia (OG1, OG18, and OG22) and two samples collected from porphyritic rhyolite dikes that intrude the Akashima Formation (OG2 and OG17) were also analyzed for comparison. These dikes are oriented in NE–SW direction, and contains abundant quartz crystals up to ~5 mm in diameter.

Part of the tuff samples (OG26, OG30, OG34, and OG35) were crushed by the selective fragmentation device using high-voltage pulsed electric discharges (selFrag-Lab) installed in the National Institute of Polar Research, Japan, to maximize the yield of zircon recovery. Other samples were crushed using conventional stamp mills. The heavy minerals were concentrated by panning and further processed with a hand magnet, and the remaining fractions were purified using heavy liquid (diiodomethane) separation. Euhedral zircon grains were then handpicked under a stereo microscope, mounted in epoxy, and polished down to grain centers. Internal structures and zonings of the zircons were observed in backscattered electron and cathodoluminescence (CL) images using the JEOL JSM-6610 scanning electron microprobe at the National Museum of Nature and Science, Japan. The zircon U–Pb dating was conducted using the laser-ablation ICP-MS system (Agilent 7700x quadrupole ICP-MS equipped with NWR213 laser ablation system) installed in the National Museum of Nature and Science. The analyzed spot size was 25 μm, and detailed experimental conditions and procedures are described in Tsutsumi *et al*. (2012). The sample U–Pb measurements were calibrated against zircon standard FC-1 (1099 Ma; Paces & Miller, 1993) and abundances of U and Th were calibrated against the NIST SRM 610 glass standard. The mean age calculations and outputs of Tera–Wasserburg Concordia plots were conducted using Isoplot v.3.71 (Ludwig, 2003). Outliers excluded from mean age calculations are selected on the basis of statistical variation only.

Results

Most of the analyzed zircon grains exhibit magmatic oscillatory and/or sector zonings and lack textural evidence for secondary modifica-

Table 1. Sampling localities, lithology, and mean ages of the studied samples.

Sample Name	Sample Location (WGS84)	Rock Type	^{207}Pb-corrected mean ^{206}Pb/^{238}U age
OG3	39°59.732′N 139°41.767′E	Matrix of the welded volcanic breccia	71.8 ± 1.4 Ma
OG26	39°59.712′N 139°41.602′E	Matrix of the volcanic breccia.	71.4 ± 1.3 Ma
OG27	39°59.727′N 139°41.624′E	Trachytic tuff.	72.7 ± 1.6 Ma
OG30	39°59.916′N 139°41.804′E	Dacitic block within the volcanic breccia.	71.77 ± 0.88 Ma
OG33	40°00.289′N 139°42.217′E	Matrix of the welded volcanic breccia	73.2 ± 1.1 Ma
OG34	40°00.243′N 139°42.304′E	Matrix of the welded volcanic breccia	72.6 ± 1.3 Ma
OG35	40°00.065′N 139°41.835′E	Matrix of the welded dacitic tuff	72.1 ± 1.1 Ma
OG1	39°59.820′N 139°41.840′E	Biotite-granite xenolith	91.15 ± 0.91 Ma
OG18	40°00.343′N 139°42.004′E	Biotite-granite xenolith	92.68 ± 0.77 Ma
OG22	39°59.870′N 139°41.847′E	Fine-grained aplitic granite xenolith	92.7 ± 1.1 Ma
OG2	39°59.730′N 139°41.813′E	Porphyritic rhyolite dike	31.47 ± 0.67 Ma
OG17	40°00.343′N 139°42.004′E	Porphyritic rhyolite dike	32.29 ± 0.85 Ma

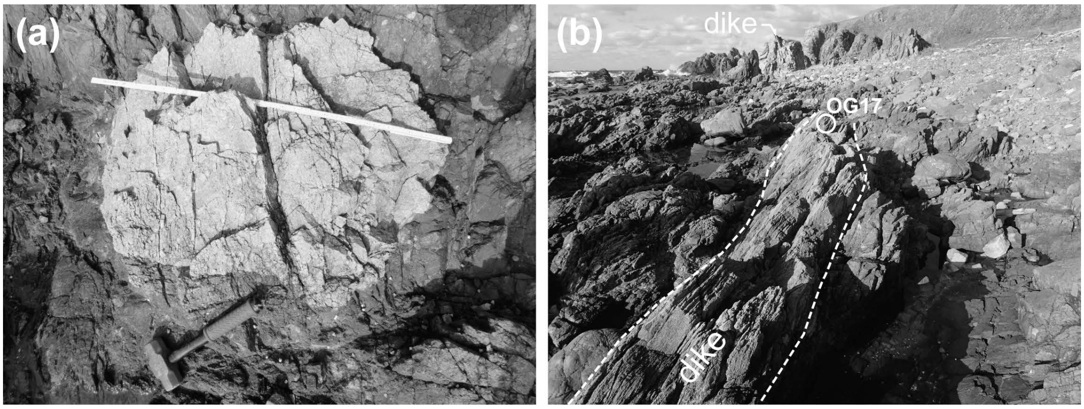

Fig. 2. Outcrop photos of the Akashima Formation. (a) Biotite granite xenolith (OG18) in the volcanic breccia of Akashima Formation. Scale = 80 cm. (b) Porphyritic rhyolite dike intruding into volcanic breccia. Thickness of the dike = ~60 cm. White circle corresponds to location where OG17 was sampled. Locations on the map is in Fig. 1 and coordinates are given in Table 1.

tion, suggesting that the obtained ages for each sample represent the timing of magmatic crystallization of the zircon. The weighted mean ^{207}Pb-corrected ^{206}Pb/^{238}U ages and Tera–Wasserburg Concordia plots are shown in Fig. 3. The U and Pb isotopic compositions and U and Th abundances of the analyzed zircons and CL images of the analyzed zircons can be provided upon request to the authors.

All of the analyzed welded tuff and volcanic breccia matrix samples show a tight cluster of ages from 71.4 ± 1.3 to 73.2 ± 1.1 Ma (Fig. 3), concordant with the SHRIMP zircon U–Pb ages of 71.53 ± 0.64 and 72.03 ± 0.65 Ma of Kano *et al.* (2012). Because of the igneous morphology of the zircon, we interpret that the well-constrained ages of ~72 Ma best represent the age of the volcanism that deposited the Akashima Formation.

The granitic xenoliths in the volcanic breccia also show a tight cluster of ages from 91.15 ± 0.91 to 92.7 ± 1.1 Ma (Fig. 3), but are clearly older than the ages of the accompanying volcanic rocks of the Akashima Formation. It should be noted that despite the variable lithology of the granite xenoliths, the three analyzed samples yielded almost concordant ages of ~92 Ma. This suggests that at least part of the Oga Peninsula is underlain by granitic pluton(s) of this age, fragments of which were subse-

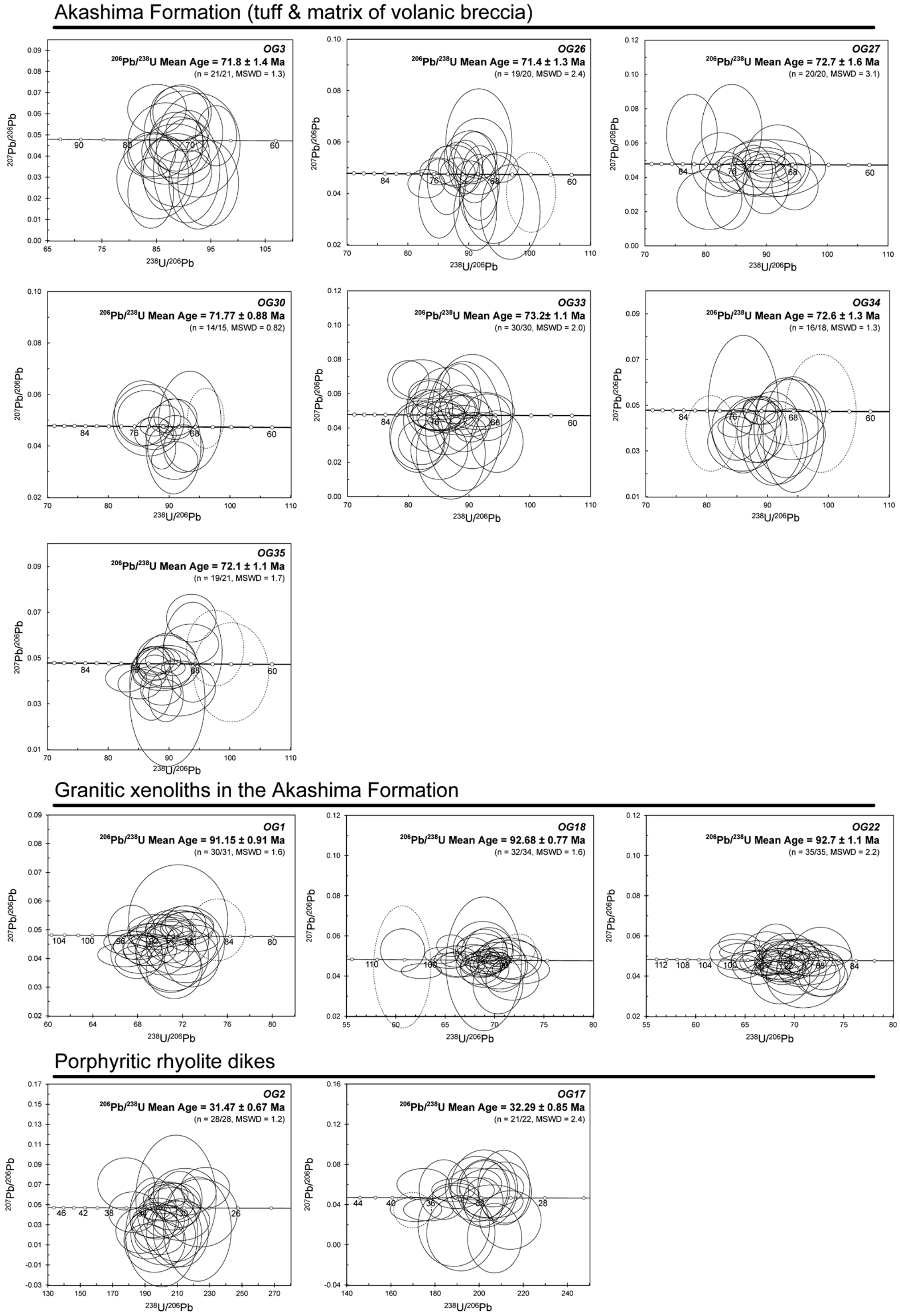

Fig. 3. Tera–Wasserburg concordia plots of the analyzed samples. Error ellipses represent 68.3% confidence intervals. Quoted ages are weighted means of ^{207}Pb-corrected $^{206}Pb/^{238}U$ spot ages (n analyses, errors at 95% confidence intervals). Solid ellipses, analyses used in weighted mean age calculation; dotted ellipses, excluded analyses.

quently entrained as xenoliths during the ~72 Ma volcanism that generated the Akashima Formation.

Two porphyritic rhyolite dikes showed much younger Oligocene ages of 31.47 ± 0.67 and 32.29 ± 0.85 Ma (Fig. 3). Both dikes (OG2 and OG17) are part of the NE-trending silicic dike systems that intrude the Akashima Formation (Fig. 2b). New zircon ages show that these dikes are associated with Oligocene magmatism, and are unrelated to the Cretaceous volcanic activity of the Akashima Formation.

Discussion

Our results show that the dacitic welded tuff and the volcanic breccia of the Akashima Formation were generated by episodic Cretaceous volcanism at ~72 Ma, confirming the results of Kano *et al*. (2012). These are the first reliable evidence that Late Cretaceous silicic volcanism existed in the Northeast Japan Arc, and would have been active almost simultaneously with voluminous silicic volcanism in the Southwest Japan Arc (e.g. Nohi Rhyolite, ~70 Ma, 5000–7000 km^3; Shirahase, 2005). Further geochronological studies of the silicic volcanic sequences in the Northeast Japan Arc are necessary to understand the extent of this Cretaceous silicic volcanism discovered in the Oga Peninsula.

The discovery of Late Cretaceous, ~92 Ma, granitic rocks beneath the Oga Peninsula provides an important constraint on the basement structures of the Northeast Japan Arc since the western half of the arc is predominantly covered by Cenozoic volcanic and sedimentary rocks. The nearest exposed granitic bodies to the Oga Peninsula are the Taiheizan granites, located ~45 km west of the Oga Peninsula. However recent uraninite dating of the Taiheizan granites show older Early Cretaceous ages of 101–102 Ma (Yokoyama *et al*., 2016). Granitic rocks occur on the Shirakami Mountains, Akita Prefecture, ~50 km north of the Oga Peninsula. They also show Early Cretaceous ages of 105–109 Ma (Yokoyama *et al*., 2016). Late Cretaceous granitic bodies that can be correlated to the granitic xenoliths of the Akashima Formation are the granitic complex in the Asahi Mountains, Yamagata Prefecture, ~160 km south of Oga Peninsula, where new uraninite ages of 90–100 Ma (Yokoyama *et al*., 2016) are reported. Our results suggest that a zone of Late Cretaceous granitic plutons may extend north beneath the Oga Peninsula.

The newly obtained Oligocene ages (31.47 ± 0.67 and 32.29 ± 0.85 Ma) from the porphyritic dikes fall within the range of the K–Ar ages (26–34 Ma) of the rhyolites that comprise the overlying Monzen Formation (Suzuki, 1980; Kano *et al*., 2007). This suggests that the studied silicic dikes that intrude the Akashima Formation were the feeder dikes for the volcanism related to the formation of Monzen Formation. Furthermore, the presence of abundant Oligocene dikes most likely accounts for the heat source that disturbed previously reported Ar–Ar and FT ages of the Akashima Formation, supporting the conclusion of Kano *et al*. (2012).

These three magmatic episodes, ~92 Ma granitic basement, ~72 Ma dacitic volcanism, ~32 Ma rhyolitic volcanism, revealed in the Oga Peninsula provide important temporal constraint for tectonic reconstruction of the NE Japan Arc to the eastern Eurasia margin before the opening of the Sea of Japan.

Acknowledgements

The authors thank Drs. Kenji Horie and Mami Takehara of National Institute of Polar Research for the usage of the selFrag Lab, and Dr. Iona McIntosh of Japan Agency for Marine-Earth Science and Technology for improving the English and providing constructive comments on the manuscript.

References

Huzioka, H., 1956. Study of Green Tuff. *Kagaku*, **26**: 440–446 (in Japanese).

Kano, K., K. Uto & T. Ohguchim 2007. Eocene to Oligocene marine transgression on the Japan Sea coast:

implication to the opening of the Japan Sea. *Journal of Asian Earth Sciences*, **30**: 20–32.

Kano, K., T. Ohguchi, Y. Yanagisawa, Y. Awata, N. Kobayashi, Y. Sato, S. Hayashi, H. Kitazato, K. Ogasawara & M. Komazawa, 2011. *Geology of the Toga and Funakawa district, 2nd Edition, Quadrangle Series 1:50000, Geological Survey of Japan/AIST*, 127 p (in Japanese with English abstract).

Kano, K., K. Tani, H. Iwano, T. Danhara, O. Ishizuka, T. Ohguchi & D. J. Dunkley, 2012. Radiometric ages of the Akashima Formation, Oga Peninsula, NE Japan. *The Journal of the Geological Society of Japan*, **118**: 351–364 (in Japanese with English abstract).

Kobayashi, N., K. Kano & T. Ohguchi, 2004. The Nomuragawa Formation: proposal for a new stratigraphic unit in the west Oga Peninsula, NE Japan. *Journal of the Japanese Association for Petroleum Technology*, **69**: 374–384 (in Japanese with English abstract).

Kobayashi, N., T. Ohguchi & K. Kano, 2008. Stratigraphic revision of the Monzen Formation, Oga Peninsula, NE Japan. *Bulletin of the Geological Survey of Japan*, **59**: 211–224 (in Japanese with English abstract).

Ludwig, K. R., 2003. User's Manual for Isoplot 3.00: A Geochronological Toolkit for Microsoft Excel. *Berkeley Geochronology Center, Special Publication*, **4**.

Ohguchi, T., K. Yanai, Y. Ueda & S. Tamanyu, 1979. The lithofacies and the radiometric ages of the Nyudozaki igneous rock (Tertiary), Oga Peninsula, Northeast Japan. *Journal of the Japanese Association of Mineralogists, Petrologists and Economic Geologists*, **74**: 207–216 (in Japanese with English abstract).

Paces, J. B. & J. D. Miller, 1993. Precise U–Pb ages of Duluth Complex and related mafic intrusions, northeastern Minnesota: geochronological insights to physical, petrogenetic, paleomagnetic, and tectonomagmatic processes associated with the 1.1 Ga midcontinent rift system. *Journal of Geophysical Research*, **98**: 13997–14013.

Shirahase, T., 2005. Rb-Sr whole-Rock isochron ages and Sr isotopic ratios of the Nohi Rhyolite. *Monograph, Association for the Geological Collaboration in Japan*, **53**: 119–127 (in Japanese with English abstract).

Suzuki, T., 1980. Fission track ages of the Tertiary volcanic rocks in the Oga Peninsula, northern Japan. *The Journal of the Geological Society of Japan*, **86**: 441–453 (in Japanese with English abstract).

Tsutsumi, Y., K. Horie, T. Sano, R. Miyawaki, K. Momma, S. Matsubara, M. Shigeoka & K. Yokoyama, 2012. LA-ICP-MS and SHRIMP ages of zircons in chevkinite and monazite tuffs from the Boso Peninsula, Central Japan. *Bulletin of the National Museum of Nature and Science*, **38**: 15–32.

Yokoyama, K., M. Shigeoka, Y. Otomo, K. Tokuno & Y. Tsutsumi, 2016. Uraninite and Thorite ages of around 400 granitoids in the Japanese Islands. *Memoirs of the National Museum of Nature and Science*, **51**: 1–24.

秋田県男鹿半島赤島層のジルコンU–Pb年代

谷　健一郎・堤　之恭・重岡昌子・横山一己

秋田県男鹿半島北西部の入道崎付近に露出する赤島層について系統的なジルコンU–Pb年代測定を行った．赤島層はデイサイト質溶結火山礫凝灰岩を主体とし，一部に基盤由来の花崗岩質捕獲岩を大量に含む．年代測定を行った赤島層凝灰岩類はいずれも72 Ma前後の後期白亜紀の年代を示すのに対し，赤島層を貫く北東系の石英斑岩岩脈群は32 Maに集中する．また花崗岩捕獲岩からは92 Ma前後の年代が得られた．これらの結果は赤島層が西南日本の濃飛流紋岩類などの大規模酸性火山活動と同時期の火山活動によって形成され，このような火成活動が現在の東北日本地域にも及んでいたことを示す．また男鹿半島の伏在基盤として朝日山地東部の花崗岩類と対比される白亜紀花崗岩類が存在することも明らかになった．さらには石英斑岩岩脈の漸新世の活動は上位の門前層の溶岩・火砕岩の年代と一致し，これらの岩脈群が門前層の供給岩脈であった可能性が高い．これらの年代は日本海形成前の東北日本とユーラシア大陸東縁部との対比を行う上で重要な制約となる．