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Petrological Study of Cretaceous Granitoids and Triassic Sandstones in Sado Island

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Abstract. Sado Island is composed mostly of Tertiary volcanic and sedimentary rocks. Pre-Tertiary basement rocks occurring locally on the island are Cretaceous granitoids, pre-Cretaceous sedimentary rocks and ophiolitic rocks. Ages of the Cretaceous granitoids were obtained by Inductively coupled plasma mass spectrometry and electron probe micro analyzer. The ages are 101–105 Ma, similar to granitoids occurring on the coastal area of south Primorye, Far East Russia.

Age patterns of the detrital monazite and zircon in the Triassic sandstones have a peak at 500 Ma. It indicates that Triassic sediments were derived from a terrane including the Khanka and Jiamusi blocks in Far East Asia, as well as the sandstones from the Nabae and Yakuno groups in the Maizuru Belt. In addition to the Maizuru Belt in the Japanese Islands, both the granitoids and sandstones are probably connected with the south Primorye in Russia.
Key words: granite, Triassic, zircon, monazite, age

Introduction

In the Sado Island, outcrops of the basement rocks are restricted in two area: Washizaki and Akadomari areas (Fig. 1). In the Washizaki area, an ophiolitic assemblage is observed. They are serpeninized peridotite, gabbro, metabasite, chert, limestone and clastic sediments. Itasaka *et al.* (1994) found Late Triassic radiolarian from the sedimentary sequence. Middle Permian fusulinids and Latest Triassic or Early Jurassic radiolarians were reported from this area (cf. Ichida *et al.*, 2010). A Cretaceous granitoid body also occurs in the area. The K–Ar age of the granitoid was reported to be 99 Ma (MITI, 1994). Whereas, in the Akadomari area, a mud-sandstone sequence, chert and limestone blocks are found. Ichida *et al.* (2010) reported Middle Permian fusulinids in the limestone blocks from the Akadomari area. Carboniferous or Permian bryozoans, Early Jurassic radiolarians and late Middle Permian radiolarians were also reported in this area (cf. Ichida *et al.*, 2010).

Granitic bodies were found in four localities from the Washizaki and Akadomari areas. K–Ar ages of the rocks are from 95 Ma to 103 Ma (Fig.

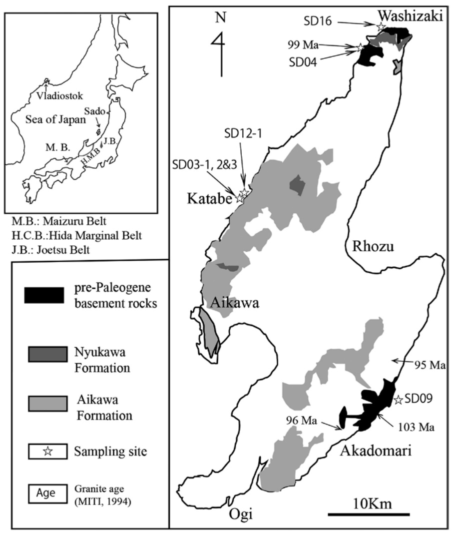

Fig. 1. Distribution of pre-Tertiary basement rocks on Sado Island and sampling sites for age analyses.

1: MITI, 1994). The Kawabe conglomerate layer in the Aikawa Formation is composed mostly of granitic blocks with a subordinate amount of volcanic matrix. Age of the granite was reported as 43 Ma which was obtained by the fission track method (Ganzawa, 1982).

There are many discussions about the assignment of the basement rocks with tectonic belts in the main land of the Japanese Islands. Komatsu *et al*. (1985) thought that Sado Island is an extension of the Maizuru belt as well as the Joetsu Belt. Ichida *et al*. (2010) considered that the basement rocks are an extension of the Maizuru Belt or ultra-Tanba Belt based on the fossils in the limestone block.

In this study, we analyzed monazites by Electron Probe Micro Analyzer (EPMA) and zircons by Inductively Coupled Plasma Mass Spectrometry (ICP-MS) to obtain mineral ages of pre-Cretaceous sandstones in the terrigenous sequences. In addition to the rocks, we obtained mineral ages of the Cretaceous granitoids and Tertiary volcanic rocks to confirm their ages that were obtained by K–Ar and fission track methods. As comparable samples, we analyzed the Triassic and Permian sandstones in the South Primorye in Russia.

Samples

Sandstone samples were collected from the intercalated sequences of mudstone and sandstone from the Washizaki and Akadomari areas (Fig. 1). From the Primorye, we had collected the Triassic and Permian sandstones. In a previous study (Yokoyama *et al*., 2009), we analyzed Triassic sandstones from the Abrek Bay area, south Primorye, Russia and from the Nabae and Yakuno groups in the Maizuru Belt. Present samples were collected from the Vlagiostok, south Primorye.

Granitic samples were collected from the relatively large body in the Washizaki area and from the Katabe conglomerate layer. The conglomerate layer belongs to the Aikawa Formation and contains abundant granite blocks up to 2 m in diameter. The matrix of the conglomerate is brecciated volcanic rocks, showing that the granitic body was crushed by the intrusion of the volcanic rocks. We analyzed zircons of the volcanic rocks in the matrix to obtain the age of the volcanic intrusion. In the Tertiary sequence of Sado Island, the lowest stratum is the Nyukawa Formation. The volcanic rock of the formation was also collected to obtain the age of the first volcanic activity from the Tertiary sequence on Sado Island.

Age results

All the samples were crushed in a stainless-steel vessel and heavy fractions were separated by methylene iodide. Zircon grains were hand-picked from the heavy fractions. The residual heavy fractions were cemented in a thin section for the analyses of monazite by EPMA at the National Museum of Nature and Science. The age method determined by EPMA for monazite was described in detail by Santosh *et al*. (2006), and the age method determined by Lazer Abla-

Table 1. Ages of granitoids and Tertiary volcanic rocks on Sado Island.

Cretaceous granitoids

rock type	locality	sample No.	mineral	method	age (Ma)
medium-grained granite	Kawabe area	SD03-1	monazite	EPMA	101.3 ± 3.4
medium-grained granite	Kawabe area	SD03-3	monazite	EPMA	101.3 ± 3.1
porphyritic granite	Kawabe area	SD03-2	zircon	LA-ICP-MS	103.1 ± 1.2
granodiorite	Washizaki area	SD04	zircon	LA-ICP-MS	105.2 ± 1.1

volcanics in the Tertiary sequence (N.F.- Nyukawa F., A.F.-Aikawa F.)

andesite (N.F.)	Washizaki area	SD17	zircon	LA-ICP-MS	26.4 ± 0.5 Ma
andesite (A.F.)	Kawabe area	SD12-1	zircon	LA-ICP-MS	27.5 ± 0.6 Ma

tion Inductively Coupled Mass Spectrometer (LA-ICP-MS) for zircon was described by Tsutsumi *et al*. (2012). The ages of both monazite and zircon are represented as probability diagrams in Figs. 2, 3, and 4. The age results of granitoids and volcanic rocks are listed in Table 1.

Sandstones: Among the many samples collected from Sado Island, only one sample, SD09, from the Akadomari area contains detrital monazite. The age pattern shows a bimodal pattern with peaks at 490 Ma and 1850 Ma (Fig. 2). There is no younger age than 450 Ma. On the other hand, the age pattern for detrital zircon has the strongest peak at around 250 Ma with subordinate peaks at 500 Ma and 1850 Ma (Fig. 3). The youngest and oldest zircon ages are 216 Ma and 2740 Ma, respectively.

In the Washizaki area, detrital zircons from the sample, SD16, were analyzed. The age pattern shows only one peak at around 250 Ma (Fig. 3). The youngest and oldest ages are 229 Ma and 2700 Ma, respectively. Zircon with ages older than 300 Ma are rare and sporadic. It is noteworthy that zircon with an age of around 1850 Ma is absent, which is different from the sample SD09 from the Akadomari area.

Lower Triassic sandstones from the Abrek Bay area, south Primorye Territory, were reported by Yokoyama *et al*. (2009). Their age patterns have one major peak at 508 Ma. Newly collected sam-

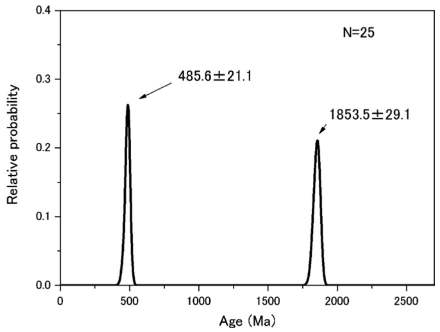

Fig. 2. Probability distribution of ages of detrital monazites from the sandstone, SD09, on Sado Island. Numerical value (n) denotes the number of analyzed monazite grains.

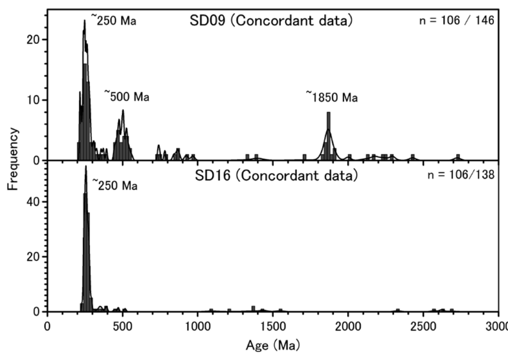

Fig. 3. Frequencies and probability distributions of concordant zircon ages from the samples, SD09 and SD16. Numerical value (n) denotes the number of analyzed zircon grains and concordant grains.

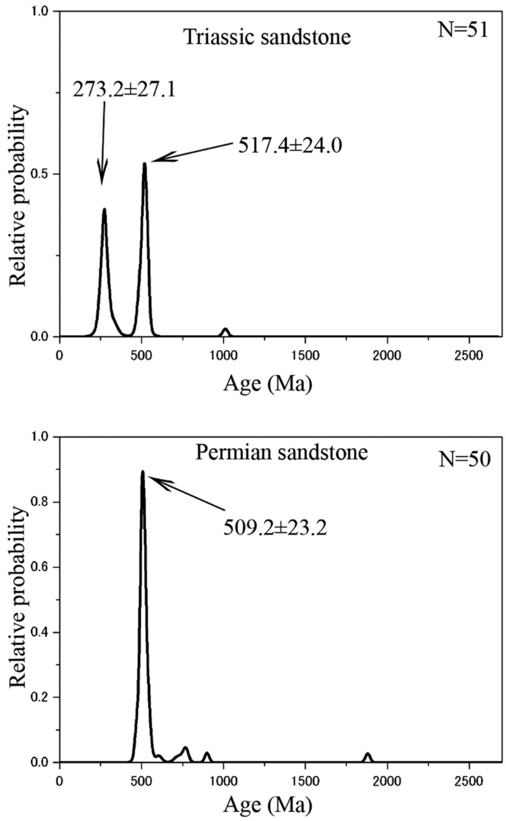

Fig. 4. Probability distribution of ages of detrital monazites from the Triassic and Permian sandstones from Vladiostok, south Primorye. Numerical value (n) denotes the number of analyzed monazite grains.

ples from Vladivostok are Lower Triassic and Permian sandstones. Only detrital monazites were analyzed in the samples. The age pattern of the Permian sandstone in Fig. 4 has only one peak at around 509 Ma, whereas Lower Triassic sandstone has two major peaks at 273 Ma and 517 Ma.

Granitoids and volcanic rocks: As listed in Table 1, the ages of four granitic rocks were obtained. The granitoid body in the Washizaki area is a few Ma older than granite blocks in the Kawabe conglomerate layer. They are in a narrow range from 101 Ma to 105 Ma, which is roughly consistent with K–Ar ages of 95–103 Ma for the four small granitoid bodies reported for Sado Island by MITI (1994).

The Tertiary volcanic sequence is widespread along the Sea of Japan. On Sado Island, the oldest Tertiary formation is the Nyukawa Formation that was succeeded by the Aikawa Formation. Many ages of the volcanic rocks in the Tertiary formations were obtained by K–Ar and the fission track method (e.g. Ganzawa, 1982: MITI, 1994). Their results show a wide range from 18 Ma to 31 Ma for the Nyukawa and Aikawa formations. It is commonly referred to that the younger results were due to later stage thermal events, and the present results by the LA-ICP-MS method for zircon will be the most reliable age data for the Sado Tertiary sequence. Ages from the Nyukawa and Aikawa formations are 26.4 Ma and 27.5 Ma, respectively. They are Oligocene in age and show no clear difference.

Discussion

Basement rocks on Sado Island are widely covered by thick Tertiary volcanic and sedimentary sequences and occur locally in the northern and southern parts of Sado Island (Fig. 1). Fossils, rarely reported from the basement rocks, are from the Permian to Early Jurassic. Some of them were found in the limestone blocks isolated from the sequence. In this study, monazite and zircon ages were obtained from the sandstone samples in both the Akadomari and Washizaki areas. The age result will contribute not only to provenance analyses but also to the depositional ages.

The sample, SD09, from the Akadomari area shows an age pattern of monazite with a strong peak at 500 Ma. This pattern is rare in the pre-Tertiary sandstones in the Japanese Islands (Yokoyama, 2016). The pattern was found in the Triassic sandstones from the Nabae and Yakuno groups in the Maizuru Belt and from Triassic and Permian sandstones in the south Primorye, Russia. As discussed by Yokoyama *et al.* (2009), provenances for these kinds of sandstones include the Khanka and Jiamusi blocks or their equivalent terrane. The sample has a peak at 1850 Ma that is characteristic of the North China Craton including the Korean Peninsula. As well as the Triassic sandstones in the Nabae Group (Yokoyama *et al*., 2009), it is concluded that the constituents of the sandstone were derived from both the North China Craton and Khanka-Jiamusi blocks, after amalgamation of the craton and blocks during the Early Triassic.

Zircons from the same sample, SD09, show a different age pattern from the monazite mentioned above. The zircon pattern is composed of a major peak at 250 Ma with subordinate peaks at 500 and 1850–1900 Ma. The difference is due to the constituent members in the provenance. Monazite is generally derived from granitoid and high-temperature metamorphic rocks, whereas zircon is derived from volcanic rock in addition to granitoid and high-grade metamorphic rock. The difference between zircon and monazite patterns is explained by the abundant volcanic rocks with an age of 250 Ma in the provenance.

The sandstone sample, SD16, from the Washizaki area has a zircon pattern with almost one peak at 250 Ma (Fig. 3). Zircons older than 300 Ma are rare in the sample. It shows that the provenance for the sandstone was widely covered by volcanic rock with an age of around 250 Ma. The youngest zircon for the sandstone from the Washizaki area is 226 Ma, which is slightly older that the sample from the Akadomari area of 216 Ma. Assuming that the volcanic eruption continued during the Triassic, depositional ages of both the sandstones were Triassic. Although the age should be reconfirmed by more age analyses of sandstone or tuff layer in each area, the Triassic result is consistent with the Late Triassic radiolarians reported from a mudstone sequence with intercalation of a thin sandstone layer by Itasaka *et al*. (1994).

Ages of three granitic blocks from the Kawabe conglomerate layer in the Aikawa Formation are well concentrated in a range from 101 to 103 Ma. The age is far older than the fission track age, 43 Ma, by Ganzawa (1982). Three granitic bodies from the Akadomari area and one grannodiorite body from the Washizaki area were 95 to 103 Ma determined by the K–Ar method (MITI, 1994). Our result for the granodiorite sample from the Washizaki area was 105 Ma. All these data from Sado Island are concentrated in a narrow range, showing granitoids with an age of around 100 Ma that occur widely under the Tertiary sequence in the island. Granite blocks in the Kawabe conglomerate layer has been treated as gravel. In addition to the narrow range of granite age, the occurrence of huge granite blocks up to 2 m in diameter and a small amount of volcanic matrix suggest that the Kawabe conglomerate layer was formed by the intrusion of volcanic rocks into the granitic region, rather than deposition as gravel brought by a river.

Komatsu *et al*. (1985) suggested that Sado Island was a northeastern extension of the Maizuru Belt through the Joetsu Belt (Fig. 1). Ichida *et al*. (2010) selected the basement rocks on Sado Island as a probable member of the Maizuru Belt or ultra-Tanba Belt. Tsutsumi *et al*. (2014) concluded that the granitoids in the Maizuru Belt are correlated in age with the granitoids in Vlagiostock, south Primorye. The rapid opening of the Sea of Japan started at around 15 Ma (Otofuji & Matsuda, 1983). Before the opening, Sado Island was probably close to the Primorye. Our data is not enough to conclude the close connection with the rocks in south Primorye, but the sandstones data indicate the correlation with the coastal zone of south Primorye. This will be supported by age correlation of granitoids from Sado Island and south Primorye. Granitic rocks along the Sea of Japan in the Niigata Prefecture, very close to the Sado Island, have well concentrated ages of 65–68 Ma (Yokoyama *et al*., 2016). They are different from the granitoids on Sado Island. Whereas, the granitoids with an age around 100 Ma occur along the coastal area of the Sea of Japan in south Primorye (Khanchuk *et al*., 2008). More detailed analyses of granitic rocks in both Sado Island and south Primorye, Russia, have been left as future areas of study.

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佐渡の白亜紀花崗岩と三畳紀砂岩の岩石学的研究

横 山 一 己・谷　健一郎・堤　之 恭

佐渡の花崗岩質岩4資料の年代測定と2資料の砂岩中の鉱物の年代測定を行った．花崗岩質岩の年代は，100–105 Maの狭い範囲に入り，佐渡の他地域の年代測定も同様で，佐渡の地下には，100 Ma前後の花崗岩が広く分布しているものと推定される．三畳紀砂岩の砕屑性鉱物の年代分布は，舞鶴帯の難波江層群や夜久野層群と同様に500 Maにピークがあるもので，ロシアのKhanka・Jiamusi帯を含む地帯が供給源と考えられる．しかし，この三畳紀砂岩の供給源には，250 Ma前後の火山岩が広い分布していることも明らかにされた．