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Provenance Study of Eocene–Miocene Sandstones in the Northern Kyushu and Western Chugoku Provinces, Western Japan

Kazumi Yokoyama*[1], Yukiyasu Tsutsumi[1], Shouichi Kiyokawa[2], Sergey A. Kasatkin[3] and Vladimir V. Golozoubov[3]

[1] Department of Geology and Paleontology, National Museum of Nature and Science,
4–1–1 Amakubo, Tsukuba, Ibaraki 305–0005, Japan
[2] Earth and Planetary Science, Kyushu University,
744 Motooka Nishiku Fukuoka 819–0395, Japan
[3] Far East Geological Institute, Russian Academy of Science,
159 Prospekt 100-letiya Vladivostok 690022, Russia
* E-mail: yokoyama@kahaku.go.jp

Abstract. Eocene–Miocene formations are present sporadically in the northern Kyushu and western Chugoku provinces. Eocene to Oligocene formations in the provinces are composed mainly of fluvial or lacustrine sediments, whereas Miocene formations are marine sediments. Possible provenances for the sediments are the Korean Peninsula, China Craton and basement rocks of the Kyushu and Chugoku provinces. In order to elucidate provenances of the Eocene–Miocene sediments, we obtained ages of detrital monazites and compared them with age distributions of present sand samples from major rivers in East Asia. More than 4500 monazite grains were analyzed in this study. Studied areas are the Tsushima Islands (Early to Middle Miocene), the Goto Islands (Early to Middle Miocene), the Sasebo area (Late Eocene to Middle Miocene) and the Nagato area (Late Oligocene to Middle Miocene).

Late Oligocene to Middle Miocene sandstones are rich in detrital monazite. Age data of the Late Oligocene to Middle Miocene usually show complex distribution pattern: major peaks at 100–300 Ma and 1800–1900 Ma with a subordinate peak at 410–450 Ma and a broad peak at 700–1000 Ma. Monazite with 2500 Ma is usually minor, but present in most of the sandstones. Such an age distribution pattern is similar to that of Paleogene sandstones from the western part of the Shimanto belt, indicating that the provenance of the sandstones includes the drainage basin of the present Yangtze River and Korean Peninsula. These results will contribute to the reconstruction of the tectonic framework at the Middle Miocene opening of the Sea of Japan.

Key words: monazite age, Tertiary, sandstone, Kyushu

Introduction

According to the reconstruction model of the Japanese Islands, the Sea of Japan formed in a continental arc setting in mid-Tertiary. At first, extension occurred at the continental margin followed by back-arc spreading and subsidence. In the early stage, non-marine sediments were deposited at the continental margin and then southwest Japan was rotated clockwise at Miocene in age. The Sea of Japan was opened widely during the Middle Miocene. Rapid subsidence to bathyal water depths occurred in early Middle Miocene (e.g. Kitazato, 1979; Matoba, 1983; Iijima & Tada, 1990). Around the Tsushima basin, the subsidence occurred during early Miocene (Chough & Barg, 1987). According to the more detailed tectonics summarized by Ingle (1992), initial rifting and extension in the Sea of Japan region occurred in late Oligocene time (ca. 32–25 Ma) followed by accelerating subsidence in the early Miocene (ca. 24–23 Ma) and then middle Miocene rotaion. The warm current, paleo-Tsushima, entered into the Sea of Japan providing warm water to form subtropical bivalves. Present days, the Tsushima Current enters into the Sea of Japan through the straight between the Japanese Islands and Korean Peninsula, but the straight was once closed and then cool conditions were appeared in the sea.

In this study, we collected Tertiary sandstones from the northern Kyushu and western Chugoku provinces to deduce the provenance of the sediments. This study will provide a clue how the sediment supply was made during the Late Eocene to Middle Miocene. The conventional approach to provenance studies of sandstones is based on determination of paleo-current trends, the nature and modal proportion of the constituent rock and mineral clasts, and chemical analyses of the heavy minerals in the sandstones. The development of analytical techniques that allow age determinations to be made on individual mineral grains has provided a powerful tool for use in provenance studies. Many age dating methods have been applied to provenance studies of zircon, as for example SHRIMP (Ireland, 1991; Tsutsumi *et al*., 2003), fission-track (Garver *et al*., 1999), and ICPMS (Wyck & Norman, 2004; Evans *et al*., 2001), and of monazite by EPMA (Suzuki *et al*., 1991; Fan *et al*., 2004).

To deduce the provenance for the Tertiary sandstones from the northern Kyushu and western Chugoku provinces (Fig. 1), we have analyzed more than 4500 grains of detrital monazites in the sandstones. The age of monazite is calculated from its chemical composition, measured by EPMA, which provides important information about the provenance as has been discussed in many papers (e.g. Suzuki *et al*., 1991; Fan *et al*., 2004; Yokoyama *et al*., 2015).

Brief geology and samples

Basement rocks in the northern Kyushu and western Chugoku provinces are composed mainly of the Sangun and Nagasaki high-pressure metamorphic rocks, Cretaceous granitic rocks and Triassic to Cretaceous sedimentary rocks. Tertiary formations, mainly overlying on these basement rocks, occur sporadically in the provinces. Paleogene formations are characterized by the presence of a thick coal layer. They are mostly non-marine sediments. As a continuous succession from the Late Eocene to Middle Miocene is scarce in these areas, sandstone sam-

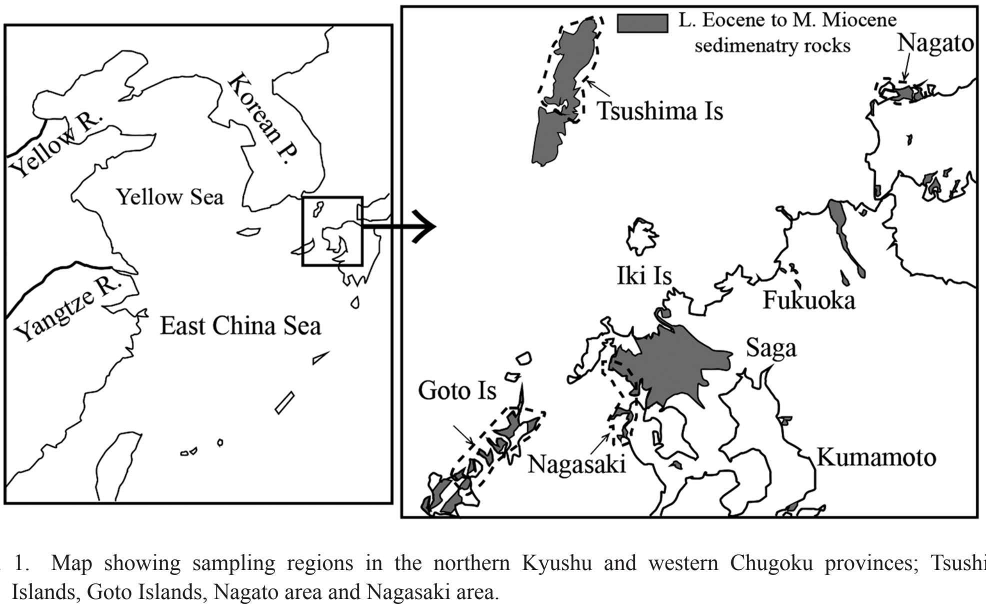

Fig. 1. Map showing sampling regions in the northern Kyushu and western Chugoku provinces; Tsushima Islands, Goto Islands, Nagato area and Nagasaki area.

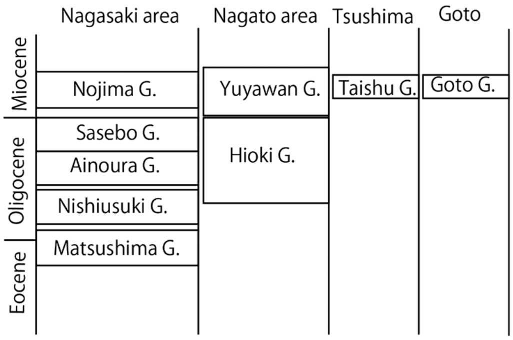

Fig. 2. Simplified stratigraphy of the studied Tertiary sandstones in the northern Kyushu and western Chugoku provinces.

ples are collected from four areas shown in Fig. 1. The simplified stratigraphy of the four areas is shown in Fig. 2.

In both the Tsushima and Goto islands, Early to Middle Miocene bathyal sediments develop associated with post-intrusive volcanic and granitic rocks. The Taishu Group in the Tsushima Islands is divided into three formations: upper, middle and lower (e.g. Nakajo *et al*., 2006; Ninomiya, 2012). The depositional age was determined through SHRIMP analyses of zircons in the intercalated tuffs. The age is 18–16 Ma (Ninomiya *et al*., 2014), probably similar to that of the Goto Islands. Sandstones were collected from the three formations.

In the Nagato area, Tertiary sediments are divided into the Late Oligocene Hioki Group and the Early to Middle Miocene Yukawan Group. They are mostly fluvial to marine sediments. The Hioki Group is composed of four formations: Juraku, Kiwado, Taoyama and Hitomaru from bottom to top. Sandstones were collected from the three formations except for the Juraku Formation. The Yukawan Group is divided into the Igami and Kawajiri formations. The Hioki Group and the Igami Formation are considered to be mostly non- or shallow-marine sediments (Ozaki *et al*., 2006), whereas the Kawajiri Formaion is composed of bathyal sediments.

In the Nagasaki area, sandstones were collected from the Late Eocene Matsushima Group to Early to Middle Miocene Nojima Group. The Nishiusuki, Ainoura and Sasebo groups belong to the Oligocene in age. Most of the sandstones are non-marine or shallow-marine sediment. Only sandstones from upper part of the Nojima Goup are bathyal sediments (Matsui *et al*., 1988). Conglomerates develop locally in the Eocene to Early Oligocene formation. Metamorphic and granitic clasts are common in the conglomerates, showing that they were derived from the nearby sources.

Tertiary sediments along the Sea of Japan consist mostly of volcanic sequences. In four areas mentioned above, tuff layers are intercalated sporadically in the sequence, but volcanic rocks are not so common as those in northern Japan. Several samples collected are tuffaceous sandstones. They are collected from the Taoyama Formation of the Hioki Group and the lower Oshima Formation of the Nishiusuki Group.

Heavy minerals and Age determination method of monazite

All the collected sandstones were crushed under the stainless steel vessel. The separation method of heavy fraction was presented by Yokoyama *et al*. (1990). In all the sandstones, detrital monazites are well preserved and are more or less present. Fifteen mineral species were observed in the heavy fractions. Among them, zircon and TiO_2 polymorphs are common and ultrastable minerals. Garnet is occasionally abundant. Monazite is one of the ultrastable detrital minerals. It is usually small in amount, occasionally more than a few percent in the heavy fraction (Table 1). The monazite grains are mostly rounded or sub-rounded suggesting a detrital origin. Euhedral grains are found in the tuffaceous sandstones, possibly showing a phenocryst in tuff (Fig. 3).

Monazite contains radiogenic elements. Monazite age has been determined on the basis of amounts of the radiogenic elements. The detailed age determination methods used for this study were shown by Santosh *et al*. (2006). As age dis-

Table 1. Heavy minerals in the sandstones from the northern Kyushu and western Chugoku provinces. Numerical values listed above show a number of grain of each mineral counted in heavy fraction. Mineral abbreviation: gar = garnet, gro = grossular-andradite, epid = epidote, Ti = TiO_2 polymorphs, zir = zircon, tit = titanite, apa = apatite, tou = tourmaline, all = allanite, ilm = ilmenite, spi = spinel, mon = monazite, xen = xenotime, flo = florencite, cht = chloritoid.

	samples	gar	gro	epi	Ti	zir	tit	apa	tou	all	ilm	spi	mon	xen	Flo	cht
Tsutsuma Is	TS-5				39	87		9	11			3	3			
	TSM-05				23	61		4	11			2	1	1		
	TS-7				42	64		1	8			7	5		4	
	TS-9				27	55		3	8			1	1		1	
	TSM-03				36	67		1	4			2	8	2	1	
	TS-8				40	67		4	4			8	3		4	
	TSM-08				30	71		2	2				1	1	1	1
	TSM-10				28	98		4	8			3	2	2	2	1
Goto Is.	No-1	57	1		24	42	29	2	4			1				
	No-2	96			7	25	14	1	1			2				
	No-3	51			13	100		2				3	8			
	No-4	5			20	145		7				5	1			
	Ta-2			7	29	60	21	3			32	2				
	Ta-6				10	79	12			22	50	2				
	Ta-8				22	127						10	4			
	Ta-9			73	11	8	40	4		1	14	1				
Nagato	YG-13	44			16	73		1				2	3			
	YG-14	3			43	62			7			3	2			
	YG-15	5			26	84				2	1	4	5			1
	YG-16	22			32	63			2			1	3			3
	YG-17	12			9	24				1	53	1	2			
	YG-18				26	74						3	18	1		
	YG-20	32			33	51					4	2	11		1	
	YG-21			9		11					32					
	YG-6	11	2	32		7	4	1	1	1	52		1			
Nagasaki	SB-12	34			20	43		2	1			2	4		1	2
	SB-14	2			30	80			4			4	12			1
	SB-16	1			53	51			9			1	4		1	
	SB-17				37	59			6			3	11	1	1	
	SB-18	71			12	28			4			1	5			
	SB-19	9			29	62		4	1			4	5	1		
	SB-21	60			13	38			1				3			1
	SB-22	32			25	34		7	5			1	7	1		
	SB-23	70			11	24		1	3				1			
	Sb-11	15			23	80		8			2	1	3			
	SB-10	3			36	82					1	5	4			
	SB-08	25			11	69		3	2		2	2	11			
	SB-09	19			16	72		4	2			4	7			
	SB-07	10			14	83		6	1			2	2			
	SB-06	90			2	1		1	38		1					
	SB-05	68			9	6		7	19			1				
	SB-04				39	72		2					10			
	SB-03	1			25	77		2	1		2	2	1		2	
	SB-02	2	3	42	5	21	11	3			18					

tributions of the probable provenance areas have been presented already by Yokoyama *et al.* (2007), monazite age is one of the powerful methods for the provenance study. If we can obtain enough age data for the sandstones, we can discuss the provenance of the sandstones simply comparing their age data with those of East Asia.

Age results

All the analytical points were selected from

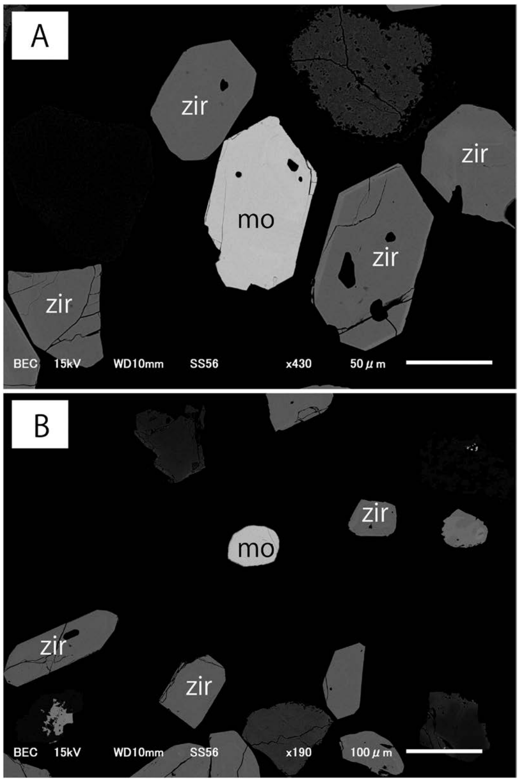

Fig. 3. Back-scattered electron images of detrital monazite grains in the tuffaceous sample (SB-10) from he Nishiusuki Group. A: a euhedral monazite with volcanic glass inclusions, mo = monazite, zir = zircon. B: a rounded detrital monazite.

back-scattered electron images and metamictised areas/zones were avoided. The standard deviation of ages within a single grain is mostly less than a few percent in old monazites (>ca. 300 Ma) or less than 25 Ma in younger monazites (< ca. 300 Ma). More than 4500 grains have been analyzed from the sandstones in the northern Kyushu and western Chugoku provinces. Age data are listed in Table 2. Ages of monazites are presented as frequency and probability diagrams in Figs. 4 to 6. Probability distributions for monazite ages were calculated with a multi-peak Gauss fitting method (Williams, 1998). The age data obtained from sandstones of the same formation are summarized in the same diagram as either sufficient age data was not obtained or the samples show a similar age distribution. The monazite ages range from ca. 0 Ma to 2600 Ma with strong populations at 100–300 Ma, 400–500 Ma and 1800–2000 Ma. In some samples, a small broad peak occurs between 700 and 900 Ma. Monazite with age around 2500 Ma is observed in almost all the samples. In the tuffaceous samples from the Hioki Group in the Nagato area and the Nishiusuki Group in the Nagasaki area, strong peaks at less than 50 Ma are observed. Such young monazites are euhedral in form and include a volcanic glass as shown in Fig. 3. It is reasonable to conclude that they were derived from a foregoing volcanic eruption. The peak ages, 32 Ma and 27 Ma, are similar to the depositional age: Oligocene. However, standard deviations of the peaks are too large to compare the EPMA age with depositional age. As these two samples are not so diagnostic for provenance study, the age results have not been discussed in the following sections.

In the Taishu Group from the Tsushima Islands, the distribution patterns of monazite ages from lower, middle and upper formations are similar each other (Fig. 4). The age patterns are composed of strong peaks at 200–250 Ma and 1850–1910 Ma with subordinate peaks at 150–200 Ma and 420–450 Ma. A small broad peak occurs at 800–900 Ma. Monazites with around 2500 Ma are present in all the formations. The sandstones from the Goto Islands has also similar age pattern to those from the Tsushima Islands, but the peak at 400–500 Ma is lower than those from the Tsushima Islands. As the depositional ages and bathyal conditions are similar in the Tsushima and Goto islands, it is probable that the sediments from both the islands were derived from the similar provenance.

In the Nagato area, sandstones from the Late Oligocene Kiwado Formation of the Hioki Group have a similar age pattern as the Miocene sandstones from both the Tsushima and Goto islands (Fig. 5). The difference is a strong peak at around 70 Ma in the Kiwado Formation. A similar Cretaceous peak is found in the Middle Miocene Kawajiri Formation. The sandstones from both

Table 2. Age data of detrital monazites in the sandstones from the northern Kyushu and western Chugoku provinces. Each column shows the number of analyzed monazite grains. Age in this table shows a range of age, *i.e.* 0 ranging from 0 Ma to 25 Ma and 5 ranging 500 Ma to 525 Ma.

	Tsushima Taishu Group			Goto G.	Nojima	Sasebo	Aino-ura	Nishi-sonogi	Nishi-sonogi	Matsu-shima	Yuya-wan	Yuya-wan	Hioki G	Hioki G	Hioki G
Age	Upper	Middle	Lower					Oshima U.	Oshima L.	Ichigo-shima	Kawa-jiri	Igam	Hito-maru F.	Taoyama F.	Kiwado
0	0	0	0	0	0	0	15	32	16	0	8	13	1	20	0
0.25	2	0	0	0	0	1	5	31	23	0	9	6	2	15	5
0.5	0	0	1	0	1	1	1	14	14	0	19	2	2	4	20
0.75	1	3	6	0	6	2	3	7	1	1	15	4	2	0	16
1	6	11	8	6	14	8	1	0	0	1	7	4	5	0	3
1.25	4	12	22	8	30	10	1	3	3	3	2	17	16	0	4
1.5	20	37	10	19	29	16	7	6	16	4	10	8	28	2	5
1.75	26	23	35	24	59	14	3	2	7	8	25	11	15	2	5
2	25	34	20	14	34	20	6	1	13	7	25	29	30	1	5
2.25	37	45	3	38	41	25	7	2	3	10	21	11	14	0	11
2.5	28	27	0	19	19	0	4	1	0	3	6	2	0	0	3
2.75	0	1	2	1	3	0	1	0	0	0	0	0	0	0	2
3	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3.25	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0
3.5	0	0	0	1	1	1	0	0	0	0	0	0	2	0	2
3.75	0	1	16	1	17	2	2	0	0	0	1	0	1	0	2
4	9	16	11	4	15	12	2	0	0	2	7	6	3	0	6
4.25	12	17	1	9	10	4	3	0	0	2	3	2	5	0	4
4.5	12	7	0	4	4	1	1	0	0	0	1	1	1	0	1
4.75	8	3	0	2	2	2	0	0	1	0	2	1	1	0	2
5	1	1	1	0	1	0	2	1	0	0	0	0	0	0	0
5.25	0	1	1	1	2	0	0	0	0	0	0	0	0	0	0
5.5	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
5.75	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
6	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1
6.25	0	0	2	0	2	0	0	0	0	0	0	0	0	0	0
6.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6.75	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
7.25	0	1	0	1	1	0	0	0	0	0	0	0	0	0	1
7.5	0	0	4	0	4	0	1	0	0	0	0	0	0	0	0
7.75	0	3	5	0	5	0	2	0	1	1	1	0	1	0	1
8	2	3	1	4	5	3	0	0	0	0	1	0	0	0	2
8.25	3	4	1	2	3	1	0	0	1	1	0	0	0	0	0
8.5	5	6	1	1	2	0	0	0	0	0	0	0	0	0	0
8.75	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
9	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9.25	2	1	2	0	2	0	0	0	0	1	0	0	0	0	0
9.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9.75	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
10	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
10.25	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
10.5	0	0	0	1	1	2	0	0	0	0	0	0	0	0	0
10.75	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0
11.25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11.5	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
11.75	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12.25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12.75	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13.25	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
13.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13.75	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14.25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14.75	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15.25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 2. Continued.

	Tsushima Taishu Group			Goto G.	Nojima	Sasebo	Aino-ura	Nishi-sonogi	Nishi-sonogi	Matsu-shima	Yuya-wan	Yuya-wan	Hioki G	Hioki G	Hioki G
Age	Upper	Middle	Lower					Oshima U.	Oshima L.	Ichigo-shima	Kawa-jiri	Igam	Hito-maru F.	Taoyama F.	Kiwado
15.75	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0
16	1	0	0	1	1	0	0	0	0	0	0	0	1	0	0
16.25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16.5	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
16.75	0	0	0	0	0	2	0	0	0	0	1	0	0	1	0
17	0	0	1	0	1	0	0	0	0	0	0	1	1	0	0
17.25	1	0	2	2	4	1	0	1	0	0	0	2	0	0	0
17.5	0	2	1	1	2	2	0	0	2	0	1	1	1	1	0
17.75	6	1	3	4	7	2	0	0	3	0	2	3	2	0	1
18	5	14	35	3	38	23	6	4	12	2	5	4	9	0	4
18.25	10	36	56	46	102	49	11	6	36	5	15	15	29	1	13
18.5	22	62	44	64	108	60	21	2	33	14	38	34	50	1	16
18.75	45	56	12	80	92	53	24	3	20	14	25	48	61	2	14
19	38	22	5	56	61	41	8	0	8	8	12	39	32	1	12
19.25	30	14	2	29	31	34	9	0	2	1	5	16	10	0	6
19.5	7	1	3	12	15	11	9	0	1	2	2	6	4	0	4
19.75	6	1	0	5	5	4	2	0	0	0	0	6	1	0	3
20	1	0	1	0	1	0	0	0	0	0	1	0	0	0	0
20.25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20.75	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
21.25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21.75	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22.25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22.75	0	0	0	1	1	0	0	0	0	0	0	1	0	0	0
23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23.25	0	0	0	1	1	0	0	0	0	2	0	0	1	0	0
23.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23.75	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	2	1	0	0	0	0	0	0	0	1
24.25	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0
24.5	0	1	0	0	0	1	0	0	0	0	0	0	0	0	1
24.75	0	1	1	1	2	0	0	0	0	0	0	0	0	0	0
25	0	0	0	1	1	0	0	0	0	0	0	1	1	0	0
25.25	1	1	0	1	1	0	0	0	0	0	1	4	1	0	0
25.5	1	0	0	0	0	0	0	0	0	0	0	1	1	0	0
25.75	1	1	0	0	0	0	0	0	0	0	0	0	1	0	0
26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
total	382	475	319	471	790	414	158	116	218	94	272	303	337	51	177

the Hitomaru Formation of the Hioki Group and the Igami and Kawajiri formations of the Yuya-wan Group have a smaller peak at 400–450 Ma than those from the Tsushima Islands.

In the Nagasaki area, some Eocene to Early Oligocene sandstones are poor in monazite. Age of monazite is mostly Cretaceous or younger. Referring to the rock fragments such as metamorphic and granitic rocks, it is reasonable to conclude that the detrital minerals were derived from nearby terrane: northern Kyushu. On the other hand, the monazite-rich sandstones from Late Eocene to middle Miocene are similar each other (Fig. 6). Although peak positions are similar to those from the Tsushima and Goto islands, a peak at 400–450 Ma is usually small, similar to those from the Yuyawan Group in the Nagato area. Similarly, monazite older than 2000 Ma is far less recognizable.

Discussion

The drainage systems of rivers in East Asia have changed with geological time as evidenced

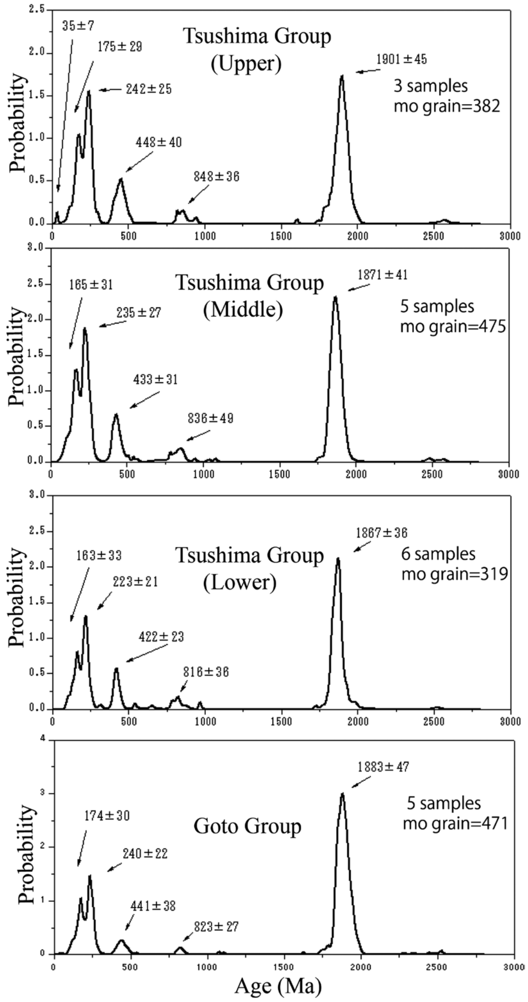

Fig. 4. Relative probability distribution diagrams of monazite ages of the sandstones from the Tsushima and Goto islands.

by the occurrence of young monazites sourced in the Himalayan region which were supplied into the paleo-Yangtze River from the Early Pleistocene and small drifts of peaks suggesting a similar origin occurring since Late Tertiary (Fan *et al.*, 2004). This fact needs to be taken into account when comparing the monazites from the modern rivers with those in the sandstones of the northern Kyushu and western Chugoku provinces. The East Asian continent has been stable at least since the end of Cretaceous (cf. Lee & Lawver, 1994) and most of the Tertiary sediments have been derived from the Asian continent. The present Japanese Islands is also possible provenance. In northern Kyushu and western Chugoku provinces, possible monazite sources are Cretaceous granite and Triassic to Cretaceous sandstones in the western Chugoku Provinces (Yokoyama, 1998; Yokoyama *et al.*, 1998). The age patterns of the pre-Tertiary sandstones have the same age pattern as that of the Korean Peninsula (Yokoyama *et al.*, 2007). However, the distributions of the pre-Tertiary sediments are too local to produce the monazite pattern of the Tertiary sediments treated in this study. Thus it is reasonable to consider distribution pattern of monazite age from modern major river systems as an analogue for those in the Tertiary sandstones in the northern Kyushu and western Chugoku provinces before the opening of the Sea of Japan.

Age patterns of monazite from the Korean Peninsula, and Yellow and Yangtze rivers are shown in Fig. 7. As represented by Yokoyama *et al.* (2007), the bimodal pattern with peaks at 100–300 Ma and 1800–1900 Ma is found from the Korean Peninsula. One the other hand, a 400–450 Ma peak is observed in both the Yellow and Yangtze rivers. A broad peak at 700–900 Ma is characterized by the pattern of the South China Craton where is included in a drainage basin of the Yangtze River. The peak at 2500 Ma is not observed from the rivers in the Korean Peninsula, but is present in both the Yangtze and Yellow rivers.

The Miocene sandstones from the Tsushima Islands have a moderate peak at 400–450 Ma and a broad peak at 700–900 Ma, in addition to the strong peaks at 100–300 Ma and 1800–1900 Ma. The comparison with age data from East Asia shows that a drainage basin of the Yangtze River is included in the provenance of the sandstones from the Tsushima Islands. A peak at 420–450 Ma is a major peak in the Yangtze River, but it is a subordinate peak at the sandstones from the Tsushima Islands. Hence, it is considered that the provenance of the Tertiary sandstones includes both the Korean Peninsula and drainage basin of

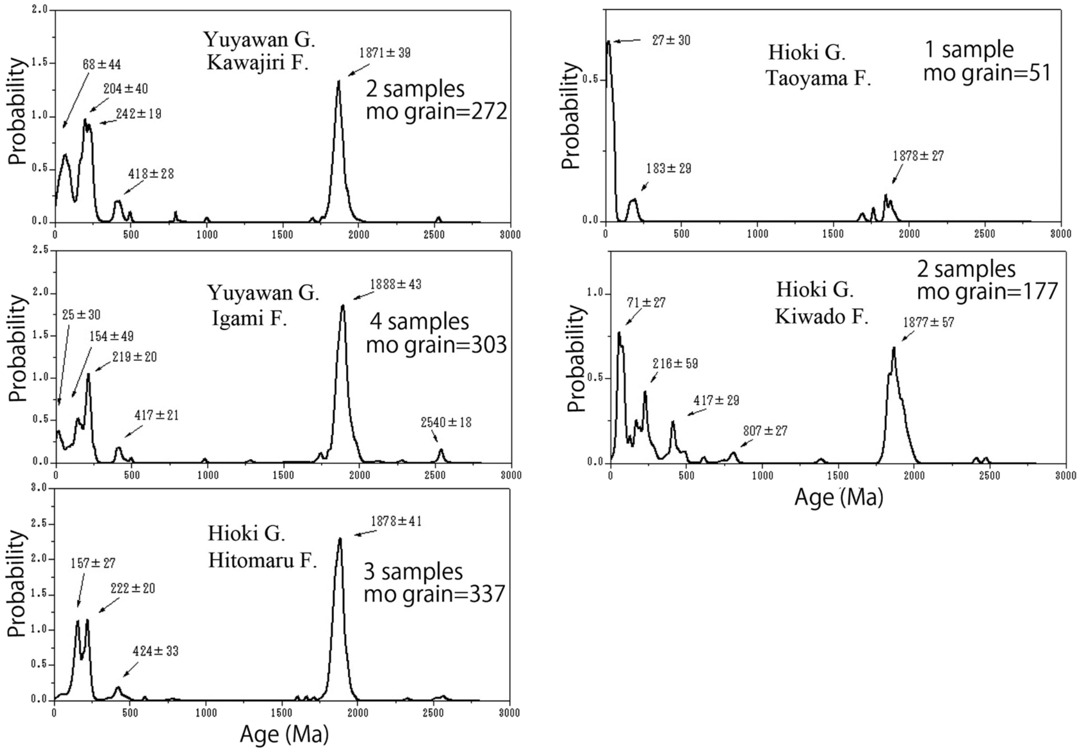

Fig. 5. Relative probability distribution diagrams of monazite ages of the sandstones from the Nagato area.

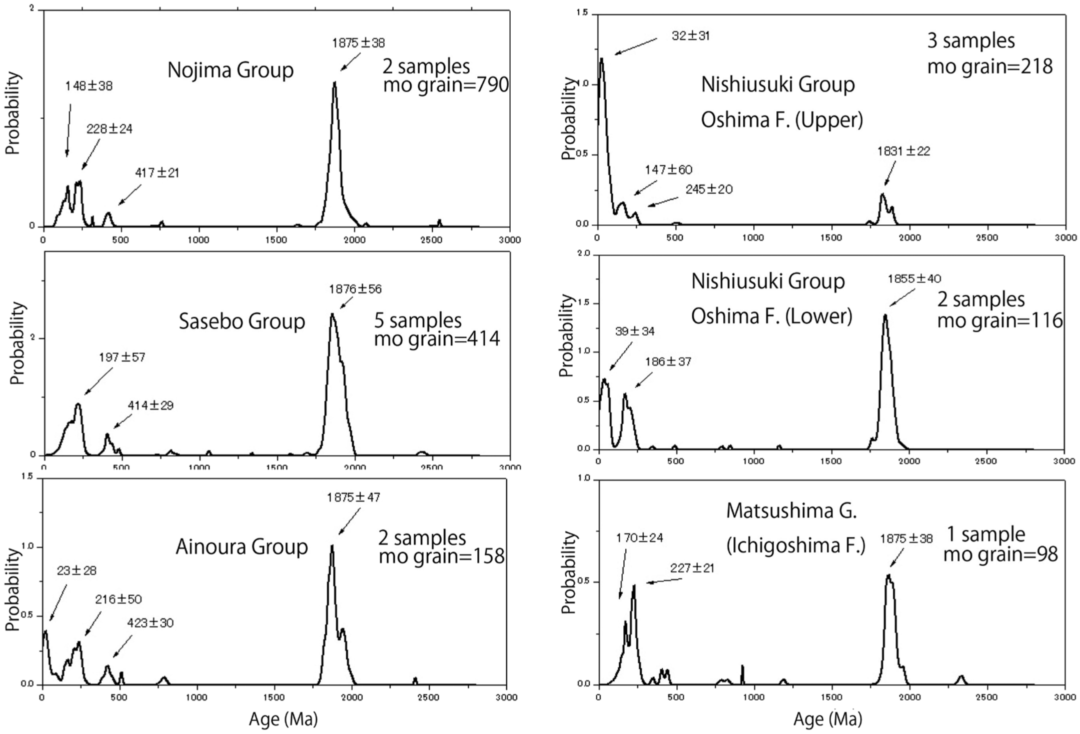

Fig. 6. Relative probability distribution diagrams of monazite ages of the sandstones from the Nagasaki area.

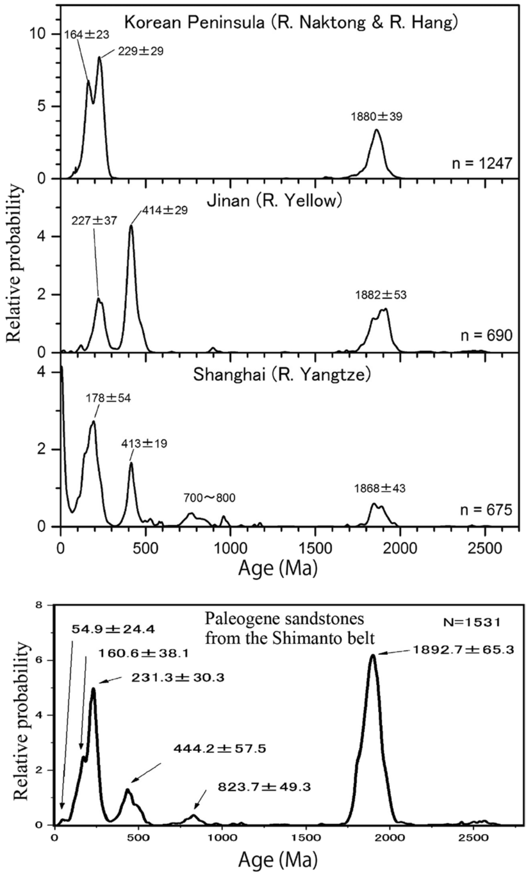

Fig. 7. Relative probability distribution diagrams of monazite ages of the sands from the Korean Peninsula, Yellow and Yangtze rivers (after Yokoyama *et al*., 2007). The probability diagram for the Paleogene sandstones from the Shimanto Belt is from Yokoyama (2016).

the Yangtze River. The drainage basin of the Yellow River is also a probable provenance. The river is now passing through the narrow straight between the Shandong and Liaodong peninsulas. In the earlier age, it is probable that the paleo-Yangtze River had a huge drainage basin including both the basins of the present Yangtze and Yellow rivers (Wang, 1985). It is important that the constituents of the Miocene sandstones in the Tsushima Islands were derived more or less from the drainage basin of the present Yangtze River.

It is noteworthy that the peak positions in the Miocene sandstones from the Tsushima Islands and the Paleogene sandstones from the Shimanto Belt are coincident even in detail as shown in Figs. 4 and 7. The close coincidence suggests that the drainage system for the sandstones has not ben changed significantly since Paleogene. Yokoyama (2016) concluded that the Paleogene sediments from the Shimanto Belt were derived from a huge drainage basin including a part of present basins of Yangtze and Yellow rivers and also Korean Peninsula. According to the paleogeographic map for the Late Tertiary of China compiled by Wang (1985), a drainage basin was developed in the lower parts of the Yellow and Yangtze rivers and the Ordos basin existed in the upper reaches of the Yellow River. Thus, it seems probable that no sediment was transported from drainage basins in the upper sections of the present Yangtze and Yellow rivers. Furthermore, the paleogeographic map suggests that the paleo-Yellow River ran through the Shanghai area towards the East China Sea rather than into the Yellow Sea, as did the paleo-Yangtze River. The coincidence of the patterns from the Tsushima Islands and Shimanto Belt suggests that the provenance of the Miocene sandstones are the same as that of the Paleogene sandstones in the Shimanto Belt, indicating that the paleo-Yangtze River had kept the similar drainage basin from Paleogene to Middle Miocene. If the Tsushima Islands had been kept at the present position after the Early Miocene, sediment supply to the Tsushima Islands from the paleo-Yangtze River was an eastern branch of a huge fan. As an alternative idea, it is possible that the Tsushima Islands were located at more western side and was moved by a transcurrent movement to the present position. The position of the Tsushima Islands at Early to middle Miocene is one of the most important keys for future reconstruction model around the islands. As the Miocene sandstones from the Goto Islands have age pattern similar to those of the Tsushima Islands, they were formed under the similar conditions to those of the Tsushima Islands.

The Miocene sandstones in the Nagato area have a peak at 400–450 Ma which is lower than that of the Tsushima Islands. In addition, monazite with age around 800 Ma is rare. These differences show that the provenance for the sandstones from the Nagato area was mainly from the Korean Peninsula and contributions from the paleo-Yangtze River is smaller than those for the sandstones from the Tsushima and Goto islands. A strong peak at around 70 Ma was observed from the Miocene Kawajiri Formation and Oligocene Kiwado Formation. The age shows the supply from the Upper Cretaceous granitoid region which widely develops at the southern part of the Korean Peninsula (Lee, 1987).

Except for the tuffaceous sandstones, age patterns of the sandstones in the Nagasaki area are similar to those from the Nagato area: a weak peak at 400–450 Ma and rare monazite with around 800 Ma. It is noteworthy that age pattern from the Late Eocene Ichigoshima Formation is also similar to that from the Middle Miocene Nojima Group. Probable major provenance is the Korean Peninsula with a small contribution from the paleo-Yangtze River during late Eocene to Middle Miocene.

In all the sandstones studied, provenances for sandstones were more or less the Korean Peninsula and a drainage basin of the paleo-Yangtze River. A notably different age pattern is not observed from Late Eocene to Middle Miocene sandstones from the northern Kyushu and western Chugoku provinces. It is reasonable to conclude that, with the exception of tuffaceous sandstones, the Late Eocene to Middle Miocene age patterns could be formed by mixing of sands from the Korean Peninsula and a drainage basin of the paleo-Yangtze River. Although we have failed to present a reconstruction model around the northern Kyushu and western Chugoku provinces from the Late Eocene to Middle Miocene, our data will place important constraints on any tectonic model for the East Asia region.

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九州北部・中国地方西部に分布する
始新世〜中新世の砂岩の供給源について

横山一己・堤　之恭・清川昌一・S. A. Kasatkin・V. V. Golozoubov

北九州と中国西部の砂岩中のモナズ石の年代分布から，始新世から中新世の時代の砂の供給源が研究された．殆どの砂は，古揚子江や韓半島を起源とするものであった．対馬の中新世の砂岩の供給源が四万十帯の古第三系と同じで，長い時間に渡って供給源が同じであったことが示された．