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Provenance Study of Accretionary Complexes in Primorye, Far East Russia, using Ages and Compositions of Detrital Minerals

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Abstract. Jurassic to Early Cretaceous accretionary complexes exist in Primorye, Far East Russia: Samarka and Taukha belts. The Samarka Belt, which is a Jurassic accretionary complex, is thought to be the northern extension of the Mino–Tanba and/or Chichibu belts, Japan. In this study, we try to determine the continuity of accretionary complexes in the Japanese Islands and Primorye, Far East Russia, using dating of detrital zircon and monazite, and the chemical composition of detrital spinel. The age distributions of detrital zircon and monazite from the main part of the Samarka Belt show a 500 Ma peak, whereas the coastal part of the Samarka Belt in addition to the Taukha Belt shows a definite >1800 Ma component without a peak at 500 Ma. Provenance for the main part of the Samarka Belt is the Khanka massif or its equivalents. Furthermore, the other parts were from the Korean Peninsula or its equivalents. Cretaceous non- or shallow marine sequences in the Zhuravlevka and Taukha belts, as well as in the coastal part of the Samarka Belt, show a bimodal age pattern. Detrital spinel from the main part of the Samarka Belt has very high TiO_2 content, which contrasts with the very low TiO_2 content in the other belts. Such a high TiO_2 spinel occurs only in the Plateau Basalt in Siberia. These results are in agreement with the provenance study that relies on zircon and monazite ages.
Key words: Age, Zircon, Monazite, Spinel, Samarka, Taukha

Introduction

The Japanese Islands were situated at a continental margin of East Asian until the opening of the Sea of Japan. The paleomagnetic and age data of Neogene volcanics in Japan demonstrated that the Miocene opening of the Sea of Japan was multi-axis back arc basin spreading (e.g. Otofuji & Matsuda, 1983). Although this theory has been mostly accepted, there are some reconstruction models about the paleogeographic location of the Japanese Islands before the opening (e.g. Otofuji *et al*., 1985; Golozoubov *et al*., 1999). The Samarka Belt in Primorye, Far East Russia, is a Jurassic accretionary complex (Kojima *et al*., 2000). It is considered that the Samarka Belt continues to the Chichibu and/or Mino–Tanba belts in Japan. Some researchers tried to compare the geologic belts in Southwest Japan and Primorye, Far East Russia (e.g. Yamakita & Otoh, 2000; Kojima *et al*., 2000; Ishiwatari & Tsujimori, 2003).

Detrital zircon and monazite age data are important to estimate the provenances of sediments (e.g. Nakama *et al*., 2012; Yokoyama *et al*., 2015). Although many age data of detrital zircon and monazite are obtained from all over the Japanese Islands, there are still few for Primorye. To reconfirm the simultaneity of geology in Japan and Primorye, we attempted to obtain U–Pb ages of detrital zircon and the U–Th–Pb chemical age of detrital monazite from Primorye.

Additionally, the chemical composition of detrital spinel was obtained. We also reflect on the origin of the rocks in the supply sources (Kamentsky *et al*., 2001).

Geological settings and samples

Primorye, Far East Russia, is roughly subdivided into the Khanka–Jiamusi Massif, the Sergeevka Belt, the Samarka Belt, the Taukha Belt, and the Zhuravlevka Belt (Fig. 1; Khanchuk *et al*., 1996). The Khanka–Jiamusi Massif is a Precambrian basement with overlain sequences that occurred after the Cambrian. The Sergeevka Belt is an ophiolite containing various ages of rocks that are mainly Paleozoic in age. The Samarka and Taukha belts are accretionary complexes that are dated to the Jurassic and Early Cretaceous, respectively. The Zhuravlevka Belt is an Early Cretaceous turbidite sequence. In the coastal zone of southern Primorye, the Samarka Belt occurs as a narrow zone between two major strike-slip faults: the Central Sikhote-Alin fault and the Arseniev fault. The Samarka Belt between the two faults is divided into two parts, the main and the coastal part. The Sergeevka Belt exists between the two parts of the Samarka Belt. We collected more than ten samples from both the main and coastal parts of the Samarka Belt. In the other belts, we collected many sandstone samples. The sample locality and measured minerals are listed in Table 1.

Heavy minerals in the sandstones were separated by the same method described by Yokoyama *et al*. (1990). Representative heavy minerals are listed in Table 2. Among the heavy minerals, zircon and monazite are the most important for elucidating the provenance of the sandstones. The zircons and monazites are mostly small or scarce in quantity. Especially, monazite makes up less than a few percent of the heavy fraction in most of the sandstones (Table

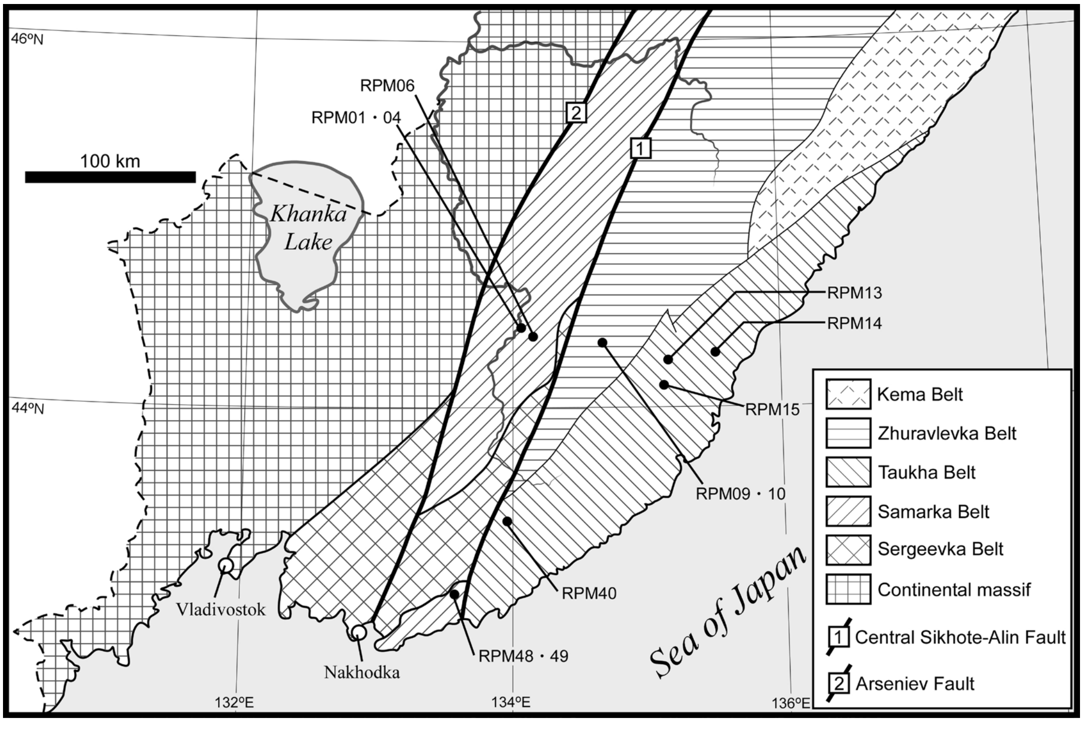

Fig. 1. Tectonic division map of the southern part of Primorye, Far East Russia, and sample localities (modified after Khanchuk *et al*., 1996).

2). Monazite grains are rounded or sub-rounded suggesting a detrital origin. Zircon is an ultrastable mineral and is observed in all the sandstones collected.

The sample, RPM06, which is from the main part of the Samarka Belt, contains detrital zircon and monazite, whereas RPM47 and 48 come from the coastal part and contain only detrital zircon because the two samples are weakly metamorphosed. From the Zhuravlevka Belt, RPM09 and 10 contain detrital monazite. From the Taukha Belt, detrital zircon and monazite are obtained only from sample RPM40. RPM13, 15, and 16, which are non- or shallow- marine sandstones in the Taukha Belt, contain sufficient amount of detrital monazite for dating.

Spinel is abundant in the heavy fractions of some sandstones. The chemical composition of spinel is measured for samples RPM01, 04, and 06, which are from the main part of the Samarka Belt, and RPM40 is from the Taukha Belt, while RPM47 and 48 are from the coastal part of the Samarka Belt.

Table 1. Information of the samples.

Label	Localities	Analyzed minerals		
		Zrn	Mnz	Spl
Main Samarka				
RPM06	N44°24′19.4″ E134°10′46.3″	○	○	○
RPM01	N44°26′37.7″ E134°04′21.4″			○
RPM04	N44°27′36.5″ E134°04′03.0″			○
Coastal Samarka				
RPM48	N42°59′44.5″ E133°34′43.1″	○		○
RPM49	N42°59′16.8″ E133°35′55.6″	○		○
Zhuravlevka				
RPM09	N44°21′17.1″ E134°40′40.3″		○	
RPM10	N44°20′45.5″ E134°41′28.6″		○	
Taukha (CS)				
RPM13	N44°14′40.1″ E135°09′50.0″		○	
RPM15	N44°07′05.0″ E135°07′43.8″		○	
RPM16	N44°07′11.6″ E135°07′37.8″		○	
Taukha (AC)				
RPM40	N43°23′17.1″ E133°57′39.6″	○	○	○

CS: coherent sequence, AC: accretionary complex.

Analytical methods and results

U–Pb dating of zircon

The zircon grains for Laser Ablation Inductively Coupled Plasma Mass Spectrometry (LA-ICP-MS) analysis were handpicked from heavy fractions. Zircon grains from the samples, the zircon standard FC1 ($^{206}Pb/^{238}U = 0.1859$; Paces & Miller, 1993), and the glass standard NIST SRM610 were mounted in an epoxy resin and polished until the surface was flattened with the center of the embedded grains exposed. Both the backscattered electron and cathodoluminescence images were used to select the sites for analysis. U–Pb dating of these samples was carried out using the LA-ICP-MS that was assembled by NWR213 (Electro Scientific Industries) and Agilent 7700x (Agilent Technologies) installed at the National Museum of Nature and Science, Japan. The experimental conditions and the procedures followed for the measurements were based on Tsutsumi *et al*. (2012). The spot size of the laser

Table 2. Heavy minerals in the sandstones collected from Primorye, Far East Russia.

	Samarka Belt						Zhuravlevka Belt and Taukha Belt						
	RPM-01	RPM-03	RPM-04	RPM-05	RPM-06	RPM-07	RPM-09	RPM-10	RPM-11	RPM-13	RPM-15	RPM-16	RPM-20
garnet	3	15						39		92	17		12
epidote										22			
TiO_2	1	12	13	40	26	8	30	13		10	30	17	15
zircon	43	71	51	71	63	108	131	123	7	70	103	142	82
titanite		2						1		10			
apatite	3	1	3		3	2	17	13		3	16	7	3
tourmaline			1		6		13	15	18	4	10	5	
allanite										3			
ilmenite			1				1		1				
spinel	63	3	42	3	8	3	1			1	11	11	36
monazite				p	1		15	5	1	4	16	24	
xenotime										1		2	
total	113	104	111	114	107	121	208	209	27	220	203	208	148

was approximately 25 μm. A correction for common Pb was made on the basis of the measured ^{208}Pb and Th/U ratio (e.g. Williams, 1998) and the model for common Pb compositions proposed by Stacey & Kramers (1975).

We obtained detrital zircon ages from four samples: RPM06, RPM48, and RPM49 from the Samarka Belt, and RPM40 from the Taukha Belt. Because the age distribution of RPM48 and 49 have the same feature, the age data of the two samples are plotted together. The age distribution of the sample from the main part of the Samarka Belt has peaks at around 160, 190, 255, 355, and 500 Ma. Zircon with Precambrian age is rare (Fig. 2a), and the age of the youngest peak and grain ages are 157 ± 14 Ma and 145 ± 5 Ma, respectively. The age distributions for samples RPM48 and 49 have peaks around 190, 250, and 1870 Ma. Several zircons are over 2000 Ma in age (Fig. 2b). The ages of the youngest peak and the youngest grain are 189 ± 15 Ma and 168 ± 3 Ma, respectively. The age distribution of sample RPM40 has peaks around 175, 220, 255, 295, and 1880 Ma. A moderate number of zircons

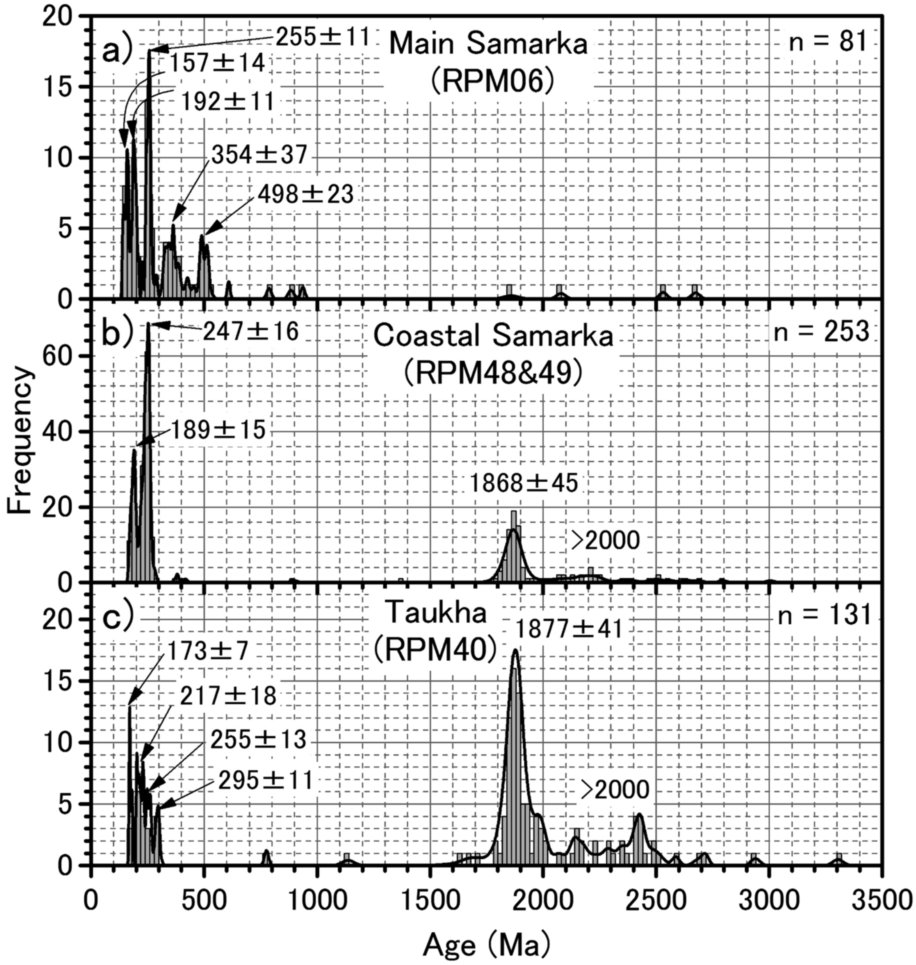

Fig. 2. Probability distribution diagrams of zircon ages from the samples RPM06 from the main Samarka Belt (a), RPM48 and 49 from the coastal Samarka Belt (b) and RPM40 from the Taukha Belt (c). As considering propagation of error, in the diagrams, ^{238}U–^{206}Pb*ages and ^{207}Pb*/^{206}Pb*ages are applied for younger (< 1000 Ma) and older (≥1000 Ma) age data respectively (e.g. Mattinson, 1987).

are over 2000 Ma (Fig. 2c). The ages of the youngest peak and youngest grain are 173 ± 7 Ma and 170 ± 2 Ma, respectively.

U–Th–Pb chemical dating of monazite

The theoretical basis for the monazite U–Th–Pb chemical age calculation is essentially the same as that developed by Suzuki *et al*. (1991). Monazites were analyzed by the electron micro probe fitted with a Wavelength Dispersive Spectrometer (WDS), JXA-8230 (JEOL) situated in the National Museum of Nature and Science, Japan. The analytical conditions used have been described by Santosh *et al*. (2003). The age cali-

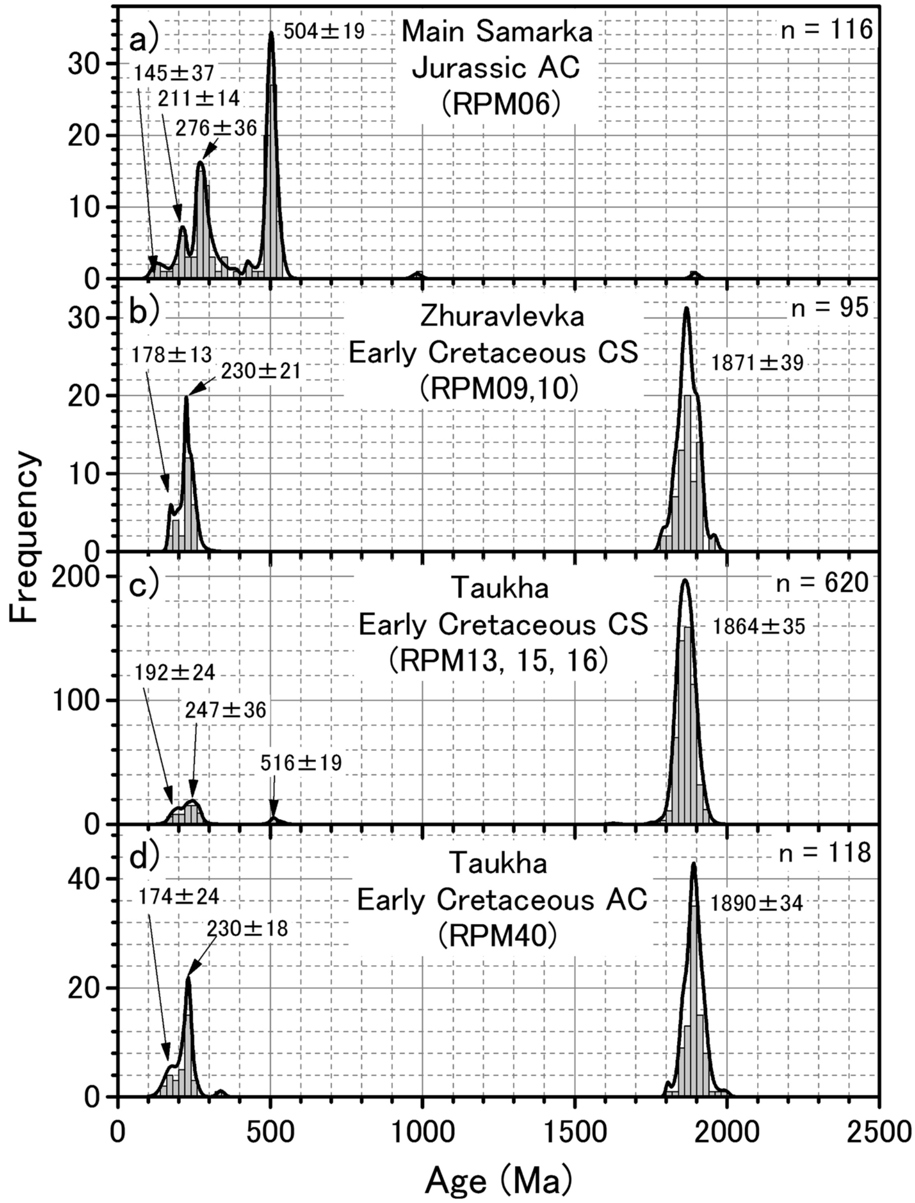

Fig. 3. Probability distribution diagrams of monazite ages from the samples RPM06 from the main Samarka Belt (a), RPM09 and 10 from the Zhuravlevka Belt (b) and RPM13, 14, 15 and 40 from the Taukha Belt (c). CS: coherent sequence, AC: accretionary complex.

brations were carefully performed by comparing data obtained by Electron Probe Micro Analyzer (EPMA) dating with those acquired by the Secondary Ionization Mass Spectrometer (SIMS) technique (e.g. Santosh, *et al*., 2006). The standard deviation of the age obtained depends mostly on the PbO content of the monazite. The errors for the age are within a few percent for most of the analyzed monazites that were rich in ThO_2.

We obtained detrital monazite ages from six samples. RPM06 is from the main part of the Samarka Belt. RPM09 and 10 are from the Zhuravlevka Belt. RPM13, 15, and 16 are from the Early Cretaceous coherent sequences on the Taukha Belt. RPM 40 is from the accretionary complex of the Taukha Belt. The age distribution of the sample from the main part of the Samarka Belt has peaks around 145, 210, 255, 275, and 505 Ma (Fig. 3). A peak at 505 Ma is the strongest among the peaks. Monazites with Precambrian age are rare. In the other samples, all the age distributions show essentially a bimodal pattern with peaks at 150–250 Ma and 1850–1900 Ma. Monazite around 500 Ma is scarce. Only samples from the non- or shallow-marine sequence in the Taukha Belt show a weak peak at 500 Ma.

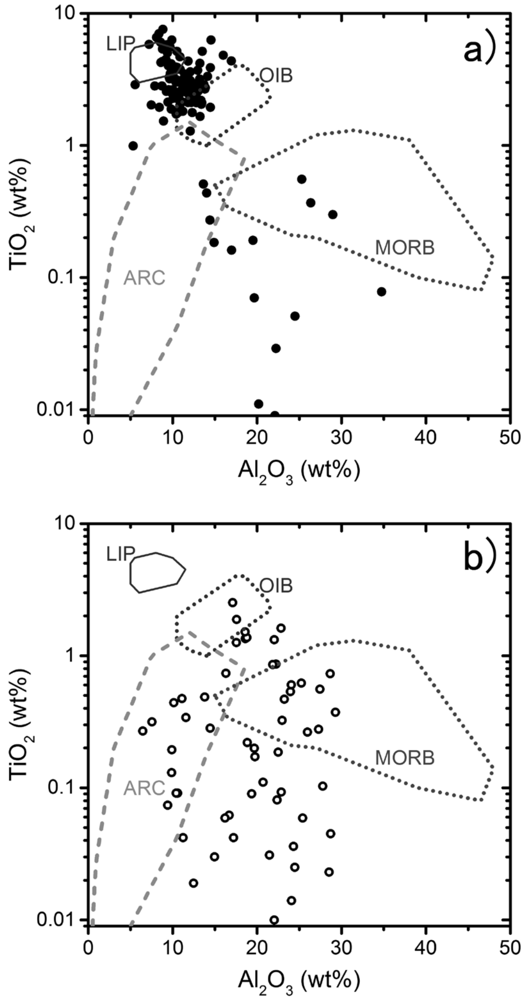

Fig. 4. Al_2O_3 vs. TiO_2 compositional relationships of detrital spinels from (a) main part of the Samarka Belt (RPM01, 04 and 06), and (b) the coastal part of the Samarka Belt and Taukha Belt (RPM40, 47, 48). The discriminations made from the mid-ocean ridge basalt (MORB), ocean-island basalt (OIB), large igneous province (LIP) and island-arc margins (ARC) are after Kamenetsky *et al.* (2001)

Chemical composition of spinel

Spinel is abundant in the heavy fractions from some sandstones. The chemical composition is obtained by EPMA. Spinel is one of source diagnostic minerals and has been well summarized by Kamenetsky *et al*., (2001). Spinel is derived from various rock types such as basalt, gabbro, and peridotite. In Fig. 4, the chemical composition of spinel was plotted in the TiO_2–MgO diagram of Kamenetsky *et al*. (2001). Spinels from the sandstones in the main part of the Samarka Belt are characterized by high TiO_2 content and are plotted in an area for the LIPs (large igneous provinces) and ocean-island basalt (Fig. 4). On the other hand, spinels in the sandstones from the Zhuravlevka and Taukha belts are low in TiO_2 showing that they are mostly derived from peridotite and/ or serpentinite.

Discussion

The present Japanese Islands were located at the continental margin of East Asia and were separated at the time of the opening of the Sea of Japan during the Miocene (e.g. Otofuji & Matsuda, 1983). Many authors tried to reconstruct the paleogeographic map before the opening. Kojima *et al*. (2000) found the Jurassic microfossils in the Samarka Belt and concluded that the Samarka Belt in Primorye, Far East Russia, was a Jurassic subduction complex continuing to the Mino Belt in Japan. Golozoubov *et al*. (1999) divided the Cretaceous formations in both Russia and Japan on the basis of plant fossils. The plant fossils in the Taukha Belt are similar to those occurring along the Kurosegawa Tectonic Line in the Chichibu Belt. According to their reconstruction, the Taukha Belt was formed on the south side of the Korean Peninsula and was moved to the northeast by strike-slip movement. The present results of zircon and monazite ages and chemical compositions of spinel will give important clues for the reconstruction of the Primorye and Japanese Islands.

From the same sample, RPM06, from the main Samarka Belt, both zircon and monazite ages were obtained. Strictly speaking, the age patterns are different from each other (Figs. 2 and 3). It is because the monazite was derived from restricted rock-types such as granitoid and high-grade metamorphic rocks, whereas zircon was derived from many rock-types including volcanic rocks and low-grade metamorphic rocks. Even though zircon and monazite ages of the main Samarka Belt have a strong peak at 500 Ma (Figs. 2 and 3), Precambrian age data are rare in the belt. On the other hand, major clusters from the other belts and the coastal part of the Samarka Belt are 150–250 Ma and 1850–1900 Ma, showing an almost bimodal age pattern. Provenance for the 500 Ma monazite from the main Samarka Belt is the Khanka and Jiamushi blocks and its equivalent in Russia as well as the Triassic sandstones in the Khanka Block (Yokoyama *et al*., 2009). Here, we tentatively conclude that the provenance for the sandstones in the main Samarka Belt was the Khanka and Jiamushi blocks and its equivalent. The other bimodal pattern of monazite age was found in the sandstones from the Jurassic subduction complex in the Japanese Islands (Yokoyama *et al*., 2016). Yokoyama *et al*. (2016) concluded that the provenance with bimodal pattern with peaks at 150–250 Ma and 1850–1900 Ma was the Korean Peninsula and the coastal area of China. If the sediments from the Zhuravlevka and Taukha belts and the coastal zone of the Samarka Belt were formed around the present positions, monazite with an age of 500 Ma should be common in the age pattern. The absence of such a peak shows that the rocks from the belts were formed near the Korean Peninsula or from the more southern side as concluded by Golozoubov *et al*. (1999). Even though the microfossils are similar on both the main and coastal blocks of the Samarka Belt, sediments in the coastal zone were derived similar to those in the Zhuravlevka and Taukha belts.

In the narrow zone between the Central Sikhote-Alin and Arseniev faults (Fig. 1), the Sergeevka Belt divides the main Samarka and coastal Samarka belts. The coastal Samarka Belt, as well as the Zhuravlevka and Taukha belts, was formed far to the southwest, which is different from the main Samarka Belt. The Central Sikhote-Alin Fault may run along the boundary between the Sergeevka Belt and the coastal Samarka Belt.

Spinel composition gives us important information about the provenance. Spinel in the main Samarka Belt is very high in TiO_2 content, showing the probable provenance as the Siberia Plateau Basalt. Whereas, spinel in the other belts is TiO_2-poor, derived from peridotite and/or serpentinite. The difference shows clearly that only sediments from the main Samarka Belt were derived from the Khanka and Jiamusi blocks and from the Siberian Plateau.

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極東ロシアの砂岩中の重鉱物の年代測定と供給源の研究

堤　之恭・横山一己・Sergey A. Kasatkin・Vladimir. V. Golozoubov

極東ロシアの地質帯は，日本のジュラ紀の付加帯や白亜紀の地層が分布すると考えられていた．これらは，南西にあったものが横ずれで現在の位置に動いたものと思われていた．今回の研究では，ジュラ紀から前期白亜紀の付加帯及び前期白亜紀の陸生又は浅海性の砂岩について，ICPでジルコン，EPMAでモナズ石の年代測定を行なった．その結果，殆どの砂岩は，日本の美濃帯と同じく2つのピークを持っているが，サマルカ帯の主体の砂岩は，5億年のピークをもち，現在の極東またはそれ相当の地帯からもたらされたことが判明した．スピネルの分析からは，シベリアの玄武岩台地からもたらされたことを示す結果が得られ，サカルカ帯主体は，ほぼ現在の位置での堆積環境にあったことが示された．