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Age Distribution of Monazites in Sands Collected from the Most Important Rivers in Asia

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Abstract. Age distributions of monazites in sands collected from some of the most important rivers in Asia were determined. The drainage basins of the rivers cover about half the area of Asia. Major populations are in the ranges of 2400–2600 Ma, 1800–2000 Ma, 400–600 Ma, 100–300 Ma and less than 30 Ma. Peaks at 2500 Ma are found in the samples from the Amur and Liao rivers whose drainage basins include the oldest part of the Sino-Korean Craton. Monazites from 1800 to 2000 Ma are common in the samples from the several rivers which traverse the Sino-Korean and Yangtze cratons. Monazites with age from 700 to 1100 Ma are rare in the rivers except for the Yangtze and Zhu rivers cutting through the Yangtze Craton. Monazites from 400 to 600 Ma are common in most of the rivers. Although peak positions are similar between adjacent rivers, at least four periods are observed as major thermal events: 500–600 Ma for the Indian subcontinent, around 500 Ma for the northeast China and Siberia areas, 450 Ma in Indochina and around 420 Ma in China. Monazites with age from 200 to 300 Ma are the most common, corresponding to collision and amalgamation events after the breakup of the Pangaea. The youngest monazites <30 Ma are found around the Himalaya Mountains.

Key words : monazite, age, thermal event, Asia.

Introduction

Voluminous quantities of age data have been obtained in Asia by various methods. Most of the ages were obtained through minerals separated from rocks and are concentrated in specific regions such as the oldest craton, collision belt and shear zone. As far as we know, the most densely analyzed regions are Archean terrane of the Sino-Korean Craton (*e.g.* Biao *et al.*, 1996), the Korean Peninsula (Zhai *et al.*, 2007), the suture zone between the Sino–Korean and Yangtze cratons, around the Red River Fault (Tapponnier *et al.*, 1990; Liang *et al.*, 2007), Himalaya Mountains and South India (Santosh *et al.*, 2003). Since the number of age data determined for a region or country depend on the presence of the necessary scientific expertise and equipment in each country, data have not been obtained equally from all regions of Asia. Although these ages are not summarized here, there are many regions in which fewer age data are available than the regions mentioned above.

In this paper, we summarize the age data of monazites collected from the major rivers and some other important rivers in Asia. The closure temperature of the monazite is less than that of zircon. Hence, in a region where the parental thermal event was “overprinted” by later high temperature event, the monazite age shows only the age of that later stage. Although we can neither clearly identify early parental events in such a region nor assign a source area for each monazite, age data of the detrital monazites in the sands does reveal the outstanding characteristics of age distribution in Asia.

Previous works and newly collected samples

In previous projects of the National Museum of Nature and Science, age distributions of river sands have been obtained in some areas of Asia: China and Korea (Yokoyama *et al*., 2007), Amur River (Yokoyama *et al*., 2009), southeast Asia (Yokoyama and Tsutsumi, 2008). These studies were carried out to identify provenance of the local sandstones in Asia and, as a further goal, to elucidate the provenance of the sandstones in the Japanese Islands. In this paper, we collected sands from the Ganges and Brahmaputra rivers of the Indian subcontinent. Both the rivers cover vast areas of the regions related to the Himalaya Orogeny. The drainage basins of the rivers are shown in Fig. 1, together with those of the other eight major rivers in Asia. The basins of the ten rivers cover almost half of Asia. Age distributions of the smaller rivers have already presented in the previous papers (Yokoyama *et al*., 2007; Yokoyama & Tsutsumi, 2008), or this volume for Vietnam. Unfortunately, we could not collect any sands from two rivers in Myanmar. These rivers have also huge drainage basins between the Brahmaputra and Mekong rivers.

Analytical procedures

Procedures for the separation of heavy minerals from the sand samples and their subsequent analysis for monazite are the same as those described by Yokoyama *et al*. (1990, 2007), Yokoyama & Tsutsumi (2008) and Santosh *et al*.

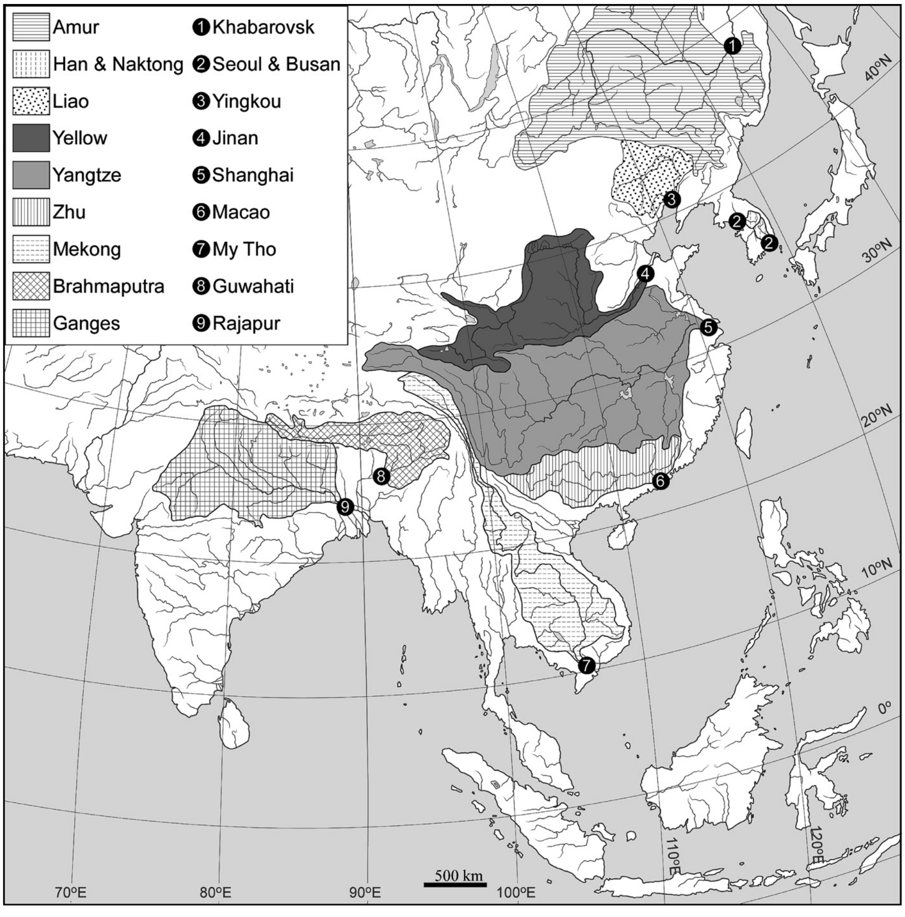

Fig. 1. Sampling localities (with site number) for the drainage basins of the Asian rivers studied in this work.

(2006). The theoretical basis for monazite age calculation is essentially the same as that developed by Suzuki *et al*. (1991).

Monazites were analyzed with an electron probe micro-analyzer (EPMA) fitted with a Wavelength Dispersive Spectrometer (WDS), JXA-8800 situated in the National Museum of Nature and Science, Tokyo. Analytical conditions are the same as those described by Santosh *et al.* (2006). Age calibrations were carefully performed by comparing data obtained by EPMA dating with those acquired by the SHRIMP technique. Apart from minor shifts due to machine drift and variation in standard conditions, the ages obtained from both techniques were found to have good consistency. Monazites with ages of 3020 Ma and 64 Ma, obtained from SHRIMP and K–Ar methods, respectively, were used as internal standards for age calibrations. The standard deviation of the obtained ages depends mainly on the PbO content of the monazite, and age errors are within a few percent for most of the analyzed monazites that were rich in ThO_2.

In the younger (<50 Ma) monazite, belonging to the Himalaya Orogeny, it is hard to separate events within the range. More detailed analyses of the younger age may have to be carried out using another method such as Ar–Ar method, the SHRIMP method or by using other radiogenic minerals such as thorite for the Red River Fault (Yokoyama *et al*., 2010).

Results of Ganges and Brahmaputra rivers

The heavy fraction of sand from the Ganges River is composed mainly of amphibole, garnet and epidote with subordinate amounts of ilmenite, titanite and clinopyroxene. The heavy fraction from the Brahmaputra River has similar heavy mineral assemblage to that of the Ganges. Although monazite grains are rare, less than 0.5%, in the heavy fractions from both the rivers, more than 1000 grains were analyzed in this study. Monazite ages of the rivers are represented as frequency diagrams in Fig. 2 and are listed in Table 1 together with those of the other Asian rivers studied. Each age datum has a more or less moderate standard deviation. All data are represented in the same diagram (Fig. 2) by a probability distribution diagram calculated with a multi-peak Gauss fitting method (Williams, 1998).

The age of monazite from the Ganges River ranges from ca. 0 to 2000 Ma with a strong peak at less than 30 Ma. Small populations appear at ranges from 450 to 600 Ma and from 900 to 1100 Ma. Twenty two monazite grains, about 0.4%, are in a range from 1700 to 1950 Ma (Table 1). The Brahmaputra River as well as the Ganges River also has the strongest peak at <30 Ma. The main differences between the two rivers are the presences of a subordinate peak at 500 Ma and a population around 200 Ma in the Brahmaputra River. Only one grain among 483 grains is older than 1700 Ma in the Brahmaputra River.

The drainage basin of the Ganges River covers a southern flank of the Himalaya Mountains and northern area of the Indian subcontinent, whereas the Brahmaputra River covers northern flank of the Himalaya Mountains. Monazites less than 30 Ma in both rivers were clearly derived from the Himalaya Mountains where Tertiary metamorphic and igneous rocks crop out. Monazite with 450–600 and 800–1100 Ma in both rivers are probably derived from the Paleozoic to Mesozoic sedimentary rocks, occurring in the mountains, which were parentally formed as marginal sediments of the Indian subcontinent or super continent “Pangaea”. The Paleozoic to Mesozoic sandstones in the western part of the Himalaya Mountains have clear peaks at 500 and 900 Ma (Fig. 3). Although these sandstones were collected from a drainage basin of the Indus River, the small populations at 500–600 Ma and 800–1100 Ma will be derived from the Paleozoic to Mesozoic rocks in the mountains belonging to the drainage basins of the Ganges and Brahmaputra rivers. It is hard to attribute the provenance of the old monazite (>1500 Ma) in the Ganges River. One possible provenance will be an occurrence of 1700 Ma granite and gneiss in the Delhi region

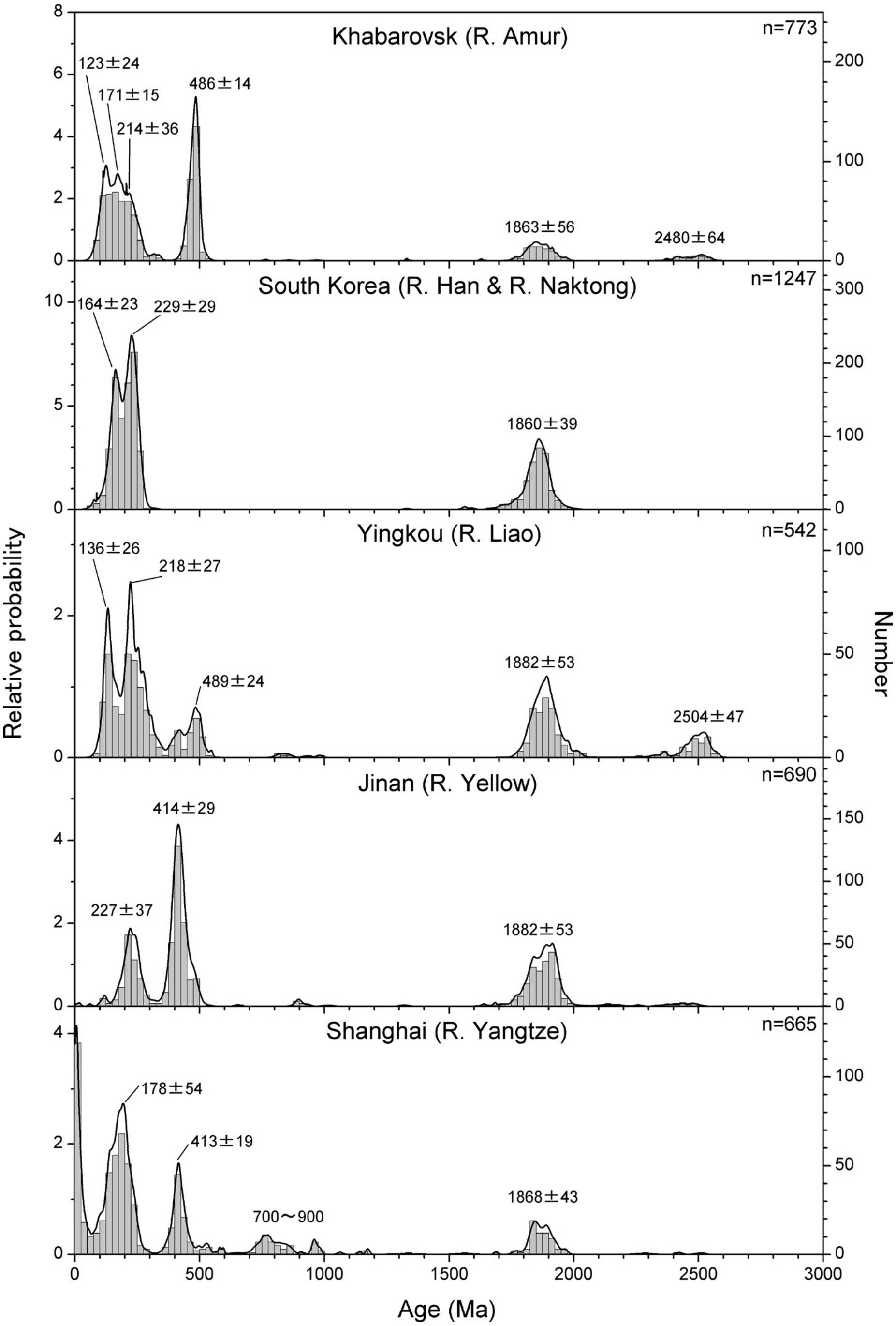

Fig. 2. Histograms of monazite ages determined in this study. Smooth curves show frequency distribution diagrams of monazite ages. Numerical value (n) denotes the number of analyzed monazite grains.

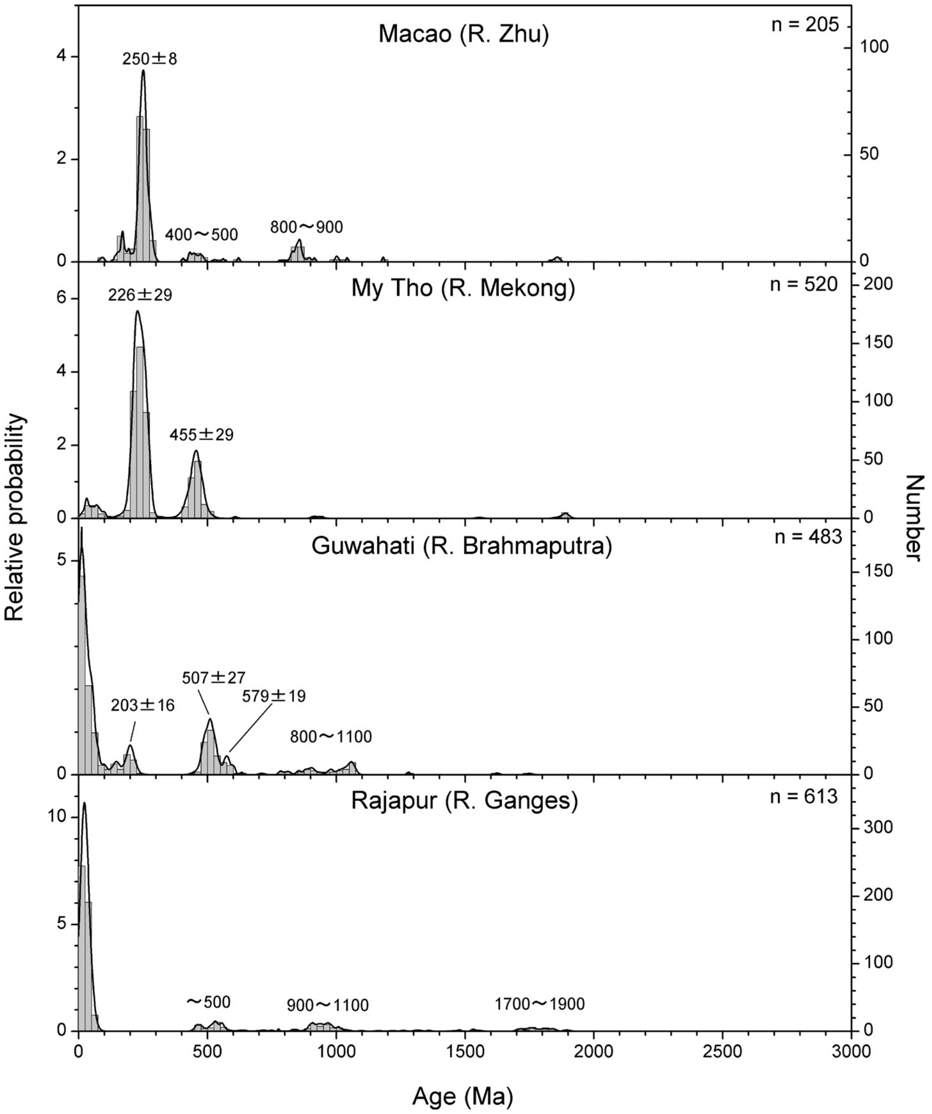

Fig. 2 (Continued).

in northern part of the Indian subcontinent (Biju *et al*., 2002). Absence of such old monazite in the Brahmaputra River supports that their provenance was at the southern part of the mountains. The Brahmaputra River has a small population at 200 Ma. The absence of the monazite from 400 to 100 Ma in the Ganges River shows that the monazites around 200 Ma were derived from a region close to the drainage basins of the Yangtze and Mekong rivers which have a major peak at around 200 Ma.

Discussions

Age analyses of detrital monazites in sand provide us information about geological event in the drainage basins. Age data are especially important in the area as well as time frames encompassing the collision and amalgamation of continental or microcontinental blocks. Adding the age data from the Ganges and Brahmaputra rivers, the monazite age data cover half of Asia (Fig. 1). Monazite occurs as an accessory mineral in the granitic rock and high-temperature

Table 1. Age data of detrital monazites in the river sands from Asia. Each column shows the number of analysed monazite grains.

Age (Ma)	1	2	3	4	5	6	7	8	9
−75–−50								4	
−50–−25								4	1
−25–0								50	26
0–25				2	119		4	147	245
25–50					18		11	66	191
50–75		5		1	10		11	31	24
75–100	21	8	2		12	2	4	7	
100–125	66	19	27	6	19		2	4	
125–150	67	83	50	2	46	1	1	8	
150–175	69	180	25	5	56	12	2	4	
175–200	60	125	21	15	68	4	7	15	
200–225	60	173	50	57	51	6	109	11	
225–250	46	215	47	37	28	68	147	1	
250–275	21	80	34	22	5	62	91		
275–300	4	1	23	9	3	10	5		
300–325	5	1	11	2		1			
325–350	3		5	2					
350–375			1	11	4		1		
375–400	1		6	51	15		1		
400–425	2		13	128	45	1	10		
425–450	15		4	67	21	4	35	1	1
450–475	82		12	21	7	4	49	2	9
475–500	135		19	22	2	2	12	24	4
500–525	9		10		3		6	33	5
525–550	2		1	1	4	1		14	13
550–575					1	1		9	6
575–600					3			7	1
600–625						1	1	1	1
625–650					1			1	1
650–675				1	1				
675–700									1
700–725					1			1	1
725–750					7				1
750–775	1				11				
775–800					7	1		2	1
800–825			2		5	1		2	
825–850			1		3	7			3
850–875	1		1		5	7		2	
875–900				4		2		4	4
900–925				2	1	1	1	3	11
925–950			1	1			2	2	7
950–975	1				7			2	10
975–1000			1		2	1		2	5
1000–1025				1		1		3	5
1025–1050						1		4	2
1050–1075					1			9	
1075–1100									1
1100–1125									
1125–1150					1				
1150–1175					2				1
1175–1200						1			
1200–1225									1
1225–1250									
1250–1275									1
1275–1300								1	
1300–1325				1					2
1325–1350	1	1			1				
1350–1375									1
1375–1400									
1400–1425									
1425–1450									
1450–1475									1
1475–1500									1
1500–1525									
1525–1550									2
1550–1575		3			1		1		1
1575–1600		2							
1600–1625								1	
1625–1650	1			1					
1650–1675		2		1					
1675–1700		1		1	1				
1700–1725		7		2					4
1725–1750		5						1	2
1750–1775	3	13		5	2				6
1775–1800	2	13	3	8	1				
1800–1825	13	39	7	18	3				5
1825–1850	14	65	24	31	19	1			3
1850–1875	14	84	22	28	12	2	1		
1875–1900	12	76	29	36	12		5		1
1900–1925	10	26	24	43	9				1
1925–1950	5	12	11	22	3				
1950–1975	3	5	6	6	3				
1975–2000		2	2	2					
2000–2025		1	3	1					
2025–2050			2						
2050–2075									
2075–2100									
2100–2125				1					
2125–2150				2					
2150–2175									
2175–2200				1					
2200–2225									
2225–2250									
2250–2275			1	1					
2275–2300					1				
2300–2325									
2325–2350			1	1					
2350–2375	1		3						
2375–2400	1			1					
2400–2425	4		1	1	1				
2425–2450	3		5	3					
2450–2475	2		3	1					
2475–2500	5		9	2					
2500–2525	4		7		1				
2525–2550	3		10						
2550–2575	1		2						
2575–2600									
analyzed grains	773	1247	542	690	665	205	520	483	613

1 Amur River
2 Han & Naktong rivers (Korea)
3 Liao River
4 Yellow River
5 Yangtze River
6 Zhu River
7 Mekong River
8 Brahmaputrra River
9 Ganges River

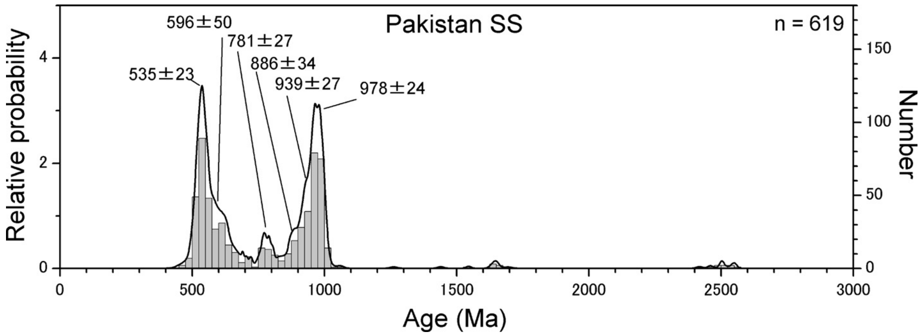

Fig. 3. Histograms of monazite ages of the Permo-Triassic sandstones occurring in the western part of the Himalaya Mountains. Analysed samples are from the stocked specimen of National Museum of Nature and Science. Smooth curves show frequency distribution diagrams of monazite ages. Numerical value (n) denotes the number of analysed monazite grains.

metamorphic rocks. In addition to the igneous and metamorphic rocks, monazite is derived from sedimentary rocks such as sandstone and conglomerate. Although there is much age data available on the granitic rocks and gneiss, there is only scarce age data for detrital monazites in the sedimentary rocks. In spite of the difficulty of assigning the source rocks for the monazite, the age data of monazites in sands should contribute to confirmation of the geological event within the drainage basins of the rivers studied.

A: monazite older than 1100 Ma

Well-documented Archean terranes in Asia are found in the Sino–Korean Craton and Indian subcontinent. The former is mainly in the drainage basins of the Liao River and a tributary of the Amur River. The later is in the central part of Indian subcontinent where no sand has yet been collected. Monazite with Archean age is indicated by a subordinate peak of the Liao River and a small peak from the Amur River (Fig. 2). Archean monazites are rarely found in the Yellow and Yangtze rivers. It is hard to trace their source rocks in the basins because of very small populations in both the Yellow and Yangtze rivers. In the Sino–Korean Craton, the oldest rocks are determined as 3800 Ma obtained from zircon by SHRIMP method (*e.g.* Biao *et al.*, 1996). Such old ages have not been detected in the detrital monazite in the basins. Even if Archean rock occurs sporadically as a basement rock in Asia (in Korea, Zhai *et al.*, 2007: in Vietnam, Lan *et al.*, 2001), it is hard to elucidate through monazite age determination, because the monazite age has been reset by later high-grade metamorphism which have occurred commonly in Asia.

After a hiatus in the age distributions from 2100 Ma to 2400 Ma, monazite has a subordinate peak at around 1900 Ma in five sand samples from the Amur River to the north of the Yangtze rivers. In the south of the Yangtze River, there is no visible peak or population around 1900 Ma. The peak positions are within a narrow range from 1863 to 1882 Ma (Fig. 2), indicating that their source rocks were formed by the same orogenic event. As the drainage basin of the Amur River includes the Khanka and Jiamusi blocks and part of the Siberian Craton which were mainly formed at around 500 Ma, the probable provenance for the monazite with 1900 Ma will be in the Sino–Korean and Yangtze cratons. There is a large hiatus in monazite age from 1700 to 1100 Ma. As far as we know, geological events within this range were scarce in the world. It is notable that there is almost no age datum from 1700 to 300 Ma in the sample from the Korean Peninsula.

B: monazite from 1100 Ma to 300 Ma

In the age range from 1100 Ma to 300 Ma, geological events have been classified as using terminology into many stages or orogenies:

Grenville (ca. 1000–900 Ma), Chenjiang (China, ca. 700–800 Ma), Pan-African (600–500 Ma), Caledonian (ca. 500–400 Ma) and Hercynian (ca. 300–400 Ma). Strong peaks occur in a range from 400 to 600 Ma, corresponding to the Pan-African and Caledonian orogenies. Although a clear peak has not been observed in the range from 1100 to 600 Ma, small populations were found in this range in the samples from the Yangtze, Zhu, Ganges and Brahmaputra rivers. The populations are different from river to river: ca. 750 Ma for Yangtze, ca. 850 Ma for Zhu, 1050 Ma for Brahmaputra and ca. 950 Ma for Ganges. Differences of the ages show that there is no correlation among orogenic events in the drainage basins. On the other hand, there are some correlations of peaks at a range from 400 to 600 Ma. The strongest peak from the Amur River is 486 Ma which is the same as a subordinate peak at 489 Ma from the Liao River. The Amur River cuts through the Northeast China Block (Jiamusi and Songliao-Zhangguangcao blocks), the Khanka Block and Siberian Craton. All these blocks or cratons have age data around 500 Ma (Velde *et al*., 2003; Salnikova *et al*., 1998). The contribution from the craton and blocks is represented by the peaks at 486 and 489 Ma.

Wilde *et al*. (2003) pointed out that the Jiamusi Block in the drainage basin of the Amur River was located along the northern margin of the Australian Block, based on the presence of the late Pan-African magmatic event at <500 Ma. The age distribution of the Pan-African Orogeny at around 500 Ma is shown by the data of the Permo-Triassic sandstones in Pakistan (Fig. 3). Their peak positions and population are different from those of the Amur River. Hence, it is premature to discuss tectonic reconstruction because of the lack of sufficient age data for the comparison of the tectonic events.

The strongest peak, at 414 Ma, from the Yellow River is the same as a subordinate peak at 413 Ma from the Yangtze River. The coincidence indicates that both drainage basins include a block suffered from the same tectonic event. As noted in the previous section, the subordinate population at 500–600 Ma from the Brahmaputra River corresponds to the Pan-African Orogeny. On the other hand, the Mekong River has a subordinate peak at 455 Ma clearly different from the peaks from the other rivers. The Mekong River cuts mainly through the Indochina Block. Hence, it is probable that the orogenic event in the block was different from the other cratons or blocks. In most of the samples, monazite with age from 300 to 400 Ma is scarce. Such monazite is rarely observed in the samples from the Liao, Yellow, and Yangtze rivers.

C: monazite from 300 Ma to 60 Ma

Ages from 300 to 60 Ma correspond to Latest Paleozoic (Permian) to Cretaceous. The cratons in East and Southeast Asia have suffered from drastic events in Permian to Triassic: separation from super-continent "Pangaea", collision and amalgamation of Sino–Korea and Yangtze cratons and Indochina and Khanka blocks. The collision was completed by the Late Triassic to form the huge continent that is essentially the Eurasian continent of today. Although major populations in most of the samples appear in this range, the age distribution in the range is characterized by double or triple peaks or broad peaks. A younger peak, 100–200 Ma, after the collisions is probably due to Jurassic to Cretaceous igneous activity induced by subductions of oceanic plates. In the Indian subcontinent, there is either no or only a rare population in the range from 500 to 60 Ma, indicating no thermal activity to produce or effect the monazite age after the Pan-African Event.

D: monazite younger than 60 Ma

Monazite younger than 60 Ma is found as a major population in the samples from the Brahmaputra, Ganges and Yangtze rivers. The monazites of both the Brahmaputra and Ganges rivers are clearly from the Himalaya Mountains where Tertiary granite and metamorphic rock crops out widely as a result of the collision of the Indian subcontinent and Tibetan Plateau. The collision induced shear faults around the region.

One well-known shear zone is the Red River Fault which is 1000 km in length running through China and Vietnam (*e.g.* Tapponnier *et al.*, 1990). The drainage basin of the Red River consists of Tertiary granitic and high-grade metamorphic rocks. The ages of the rocks are concentrated in a range of 35–17 Ma (Liang *et al.*, 2007). The sand sample from the Red River has the strongest peak at less than 30 Ma (Yokoyama *et al.*, 2010). In the northwest part of the drainage basin of the Yangtze River, Tertiary granites occur. They were probably also formed during the shear heating along a fault induced by the collision as were also those from the Red River Fault. Younger monazite was not recognized in the other samples, indicating a weak contribution from the collision event and also absence of late Tertiary plutonic activity in the drainage basins.

Conclusions

Although the drainage basin of a river is not coincident with a region of craton or block, the overall age distribution in Asia will be expected to be reflected in the age distribution of monazites in the sands collected from the vast rivers of Asia. The age data will be summarized as follows.

1) The oldest age in Asia was obtained from zircon analyses by SHRIMP and was 3800 Ma from the Sino–Korea Craton. As far as the monazite age is concerned, no age older than 2700 Ma has been recognized, indicating that later stage thermal events obliterated evidence of the older age.

2) Monazite older than 1700 Ma is common in samples from several rivers cutting through the Sino-Korean and Yangtze cratons. In the other areas, such an aged old monazite is negligible.

3) Monazite aged from 700 to 1100 Ma is rare in the rivers except for the Yangtze and Zhu rivers cutting thorough the South China Block.

4) Monazite ages from 400 to 600 Ma are common in several rivers. The peak position is similar between the adjacent rivers, but at least four periods can be recognized as major thermal events: 500–600 Ma for Indian subcontinent, around 500 Ma for the North China and Siberia, 450 Ma in the Indochina and ca. 420 Ma in China.

5) Monazite from 200 to 300 Ma is the most common in many samples, corresponding to the collision and amalgamation events after the breakup of the Pangaea.

6) The youngest monazite (<30 Ma) is found in the Himalaya region and in the drainage basin of the Yangtze River. This age corresponds to the collision of the Indian subcontinent with the Tibetan Plateau.

Most of the major geological events known to have occurred in the Earth's history are more or less well represented in Asia. Further detailed age analyses of sands including those from tributaries of the rivers will allow a more complete and accurate tectonic reconstruction of the events in Asia to be elucidated. These age data will hopefully contribute to the basic information necessary for comprehensive studies of the amalgamation of the continent and the provenance of the sandstones.

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アジアの河川から求められたモナズ石年代の総括

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アジアの10本の河川から採集された砂中のモナズ石の年代分布が求められた。これらの河川の後背地は、アジアのほぼ半分の地域を占めるもので、ほぼアジアの年代が求められたものと考えられる。アジア最古の年代は38億年であるが後の高温変成作用によりモナズ石が若い年代にレセットされ、モナズ石の最も古い年代は27億年である。アジアの年代分布は、24–26億年、18–20億年、4–6億年、2億年前後と３千万年以下にピークがある。7–11億年のモナズ石は揚子江地塊やヒマラヤ周辺に見られるが、他の年代頻度に比べると少ない。近接した河川の年代ピークには共通性が見られるが、一般的には河川ごとに年代ピークが異なる。年代を岩石から分離して求めることは重要であるが、アジアや世界の河川の鉱物から大量の年代を求めることにより、地球の活動の変遷をひもとく基礎データが得られるものと思われる。