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Reconnaissance Study of Monazite Age from Southeast Asia

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Abstract. Southeast Asia has a complex tectonic framework. The old craton, Indochina craton, is surrounded by Cenozoic accretional zone and magmatic arc. Many age data have been presented from the craton, though they have not been determined in a regional scale. We analyzed detrital monazites in the sands from the rivers cutting through the craton and surrounding younger terranes. Peaks in the age distribution of monazites from the Mekong and Sap Rivers are in ranges of 200–300 Ma and 400–500 Ma. In the other areas, major peaks are less than 300 Ma. A small peak with 500–600 Ma was recognized from the river running through Thailand. Such an old monazite is thought to be derived from the nearby sub-Indian continent at the time of Pangaea age. Monazite with 110 Ma or younger peaks is due to the Cenozoic magmatic event at the time of subduction. The Triassic age, around 240 Ma, is attributed to the breakup of the Pangaea or events related to the collision of Yangtze and North China cratons. The oldest peak, 450 Ma, is a key age which should be present before the breakup event of the Pangaea. The age is not correlated with the age data of the India subcontinent, but is similar to that in the southern part of the Yangtze craton, suggesting that the Indochina craton was parentally formed with a part of the Yangtze craton.
Key words : EPMA age, detrital monazite, drainage system, Indochina.

Introduction

Present continents were present as one super continent, Pangaea, at Permian in age. After major breakup of the Pangaea at around 200 Ma, each craton moves to different direction. Some cratons were collided to form a large craton like Eurasia continent. Movements of the cratons are presented through Plate Tectonic Theory (e.g. Lawver *et al.*, 2002). Most of the present continents have cores which are older than 1000 Ma; Yangtze craton (1900 Ma), North China craton (>2500 Ma), India sub-continent (>2500 Ma). As far as huge continents are concerned, movements of the cratons have been reconstructed up to 1000 Ma ago.

In East and Southeast Asia, the biggest event was collision of Yangtze and North China cratons at around 230 Ma. Both cratons and surrounding small cratons including the Indochina were separated from Pangaea before the major breakup of the Pangaea at 200 Ma. The India sub-continent collided to the Eurasia continent at the early Tertiary; 45 Ma. According to the reconstruction model by Lawver *et al.* (2002), the Indochina craton was located between the India craton and Yangtze craton at around 400 Ma. The Yangtze craton was separated from the supercontinent at the earliest breakup of the supercontinent Pangaea, around 300 Ma, soon after followed by separation of the Indochina craton. After collision of the Yangtze and North China cratons, the Indochina craton was attached with the Yangtze craton. The Sammua Depression zone between northern Vietnam and southwestern China represents the boundary of the Yangtze and Indochina cratons (e.g., Trung, *et al.*, 2007). Even in Tertiary in age, the Indonesian craton and surrounding area have complex tectonic history including collision of microcontinents and opening of sea (Lee & Lawver, 1994).

The Indochina craton had been thought to contain Precambrian block, >540 Ma (Hutchison, 1989). However, recent age data do not show any evidence of Precambrian block in the craton. The most common ages are around 240 Ma and 100 Ma (e.g. Owada, *et al.*, 2006; Trung, *et al.*, 2007). As the age data were obtained mostly by isotopic age of minerals separated from rocks, they are restricted in number or local. In this study, we analyzed age of detrital monazite from the rivers cutting through the craton. More than 600 age dada were obtained from the monazites. It will be representative of the craton. The correlation between the Indochina and the other cratons will be discussed by the age data.

This geological study is a part of the project "Biodiversity inventory in the Western Pacific region". Reconstruction of geotectonic history, especially collision or separation of continents and islands, is important as basic information for biodiversity.

Samples and Analytical Procedures

Nine sand samples were collected mainly at riverbeds from the rivers including Mekong and Chao Phraya (Fig. 1). Two samples from Singapore were collected from beaches, in assumption that sand grains were derived from the nearby lands. Two samples from placer gold and diamond mines were given by mine workers from Sampit and Martapura, respectively. As heavy minerals in the samples had been well separated by panning in local, the minerals observed in the samples are restricted as described later. Procedures for the separation of heavy minerals and their subsequent identification are the same as have been described by Yokoyama *et al.* (1990). Carbonate and micaceous minerals were not subjected to examination, and magnetic fractions were removed prior to the separation of the heavy minerals. Modal proportions of heavy minerals are listed in Table 1.

The theoretical basis for monazite age calculation is essentially the same as that developed by Suzuki *et al.* (1991). Monazites were analyzed by the electron probe micro-analyzer fitted with a Wavelength Dispersive Spectrometer (WDS), JXA-8800 situated in the National Museum of Nature and Science, Tokyo. Analytical conditions used have been described by Santosh *et al.* (2003). Age calibrations were carefully performed by comparing data obtained by EPMA dating with those acquired by the SHRIMP technique (e.g. Santosh, *et al.*, 2006). Apart from minor shifts due to machine drift and variations in standard conditions, the ages obtained from both techniques were found to have good consistency. Monazites with ages of 3020 Ma and 64 Ma, that were obtained by SHRIMP and K-Ar methods, respectively, have been used as internal standards for age calibrations. The standard deviation of the age obtained depends mostly on the PbO content of the monazite. The errors for the ages are within a few percent for most of the analyzed monazites that were rich in ThO_2. If the age error exceeded 25 Ma for Mesozoic to Cenozoic monazites and/or 50 Ma for older monazites, these data were excluded from the figures and further discussion.

Heavy Minerals and age of monazite

Twenty three mineral species were observed in the heavy fractions. Abundance of each of the mineral species has been listed in Table 1. There are a variety of heavy minerals species in the sands from the river, but a restricted number of species in the sands from beaches and mines due to the local drainage and well-panning procedure in local, respectively. The heavy minerals have been used for provenance study (Morton, 1984, & 1991). Among them, monazite and zircon have been used for age analyses (Ireland, 1991; Suzuki *et al.* 1991; Tsutsumi *et al.* 2003). Monazite analyzed here is usually minor in the heavy fraction. It is from 1% to 7% in the Indochina and Singapore samples, but is far less than 1% in the samples from Kalimantan (Table 1).

All the analytical positions of monazite grains were selected from back-scattered electron images and metamictised areas/zones were avoided. The standard deviations 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

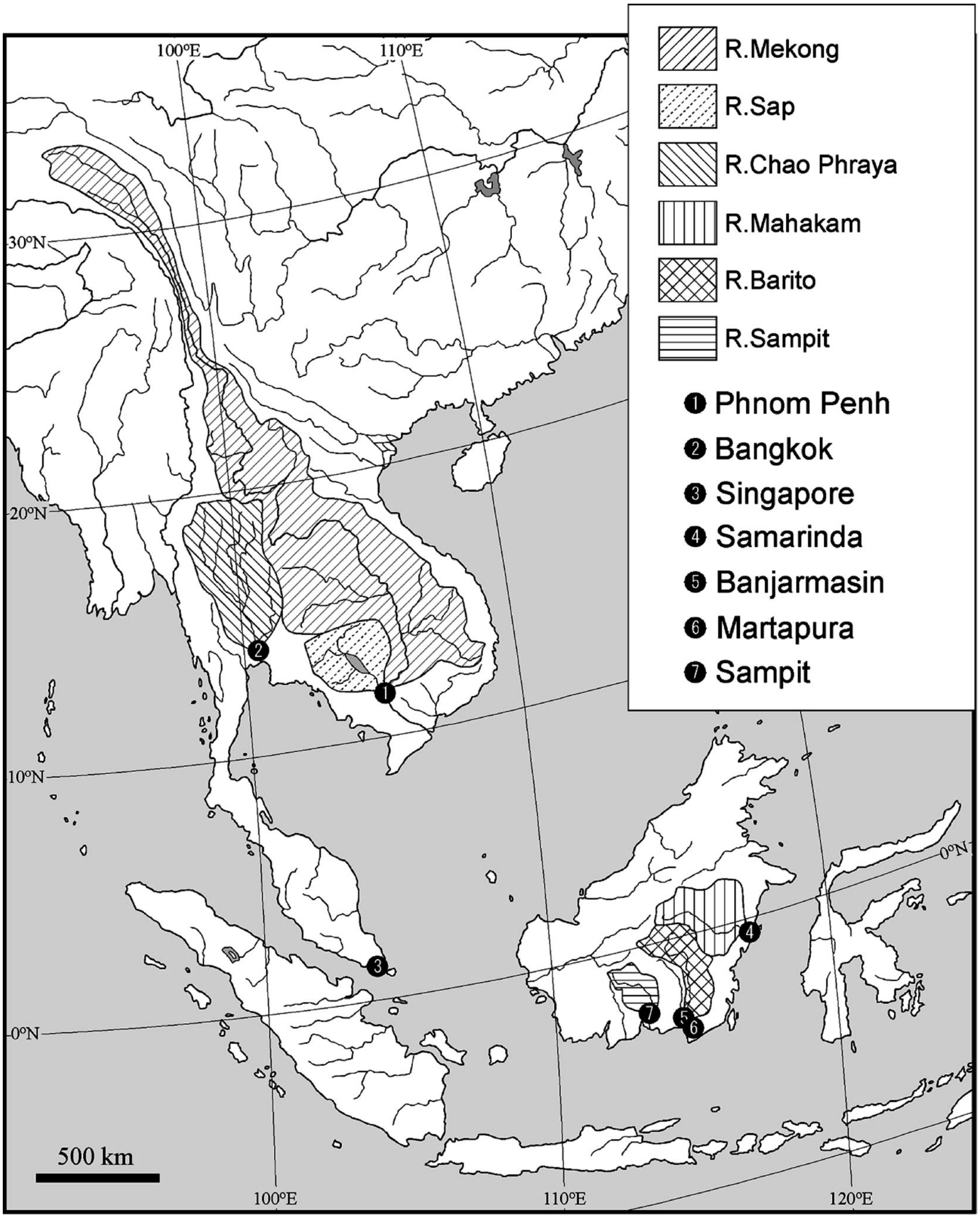

Fig. 1. Drainage systems of rivers running through Southeast Asia and sampling localities of sand samples.

younger monazites (<ca. 300 Ma). One representative age has been selected from each grain. More than 600 grains have been analyzed from the sands in Indochina and surrounding area.

All the age data are summarized in Table 2. As the ages have different standard deviation each other, they are presented as frequency and probability diagrams in Fig. 2 & Fig. 3. Probability distributions for monazite ages were calculated with a multi-peak Gauss fitting method

Table 1. Modal proportions of heavy minerals in the sands collected from Southeast Asia.

River or site City	Mekong R. Phnom Penh	Tonle Sap R. Phnom Penh	Chao Phraya R. Bangkok	Changi Singapore	Sentosa Singapore	Mahakam R. Samarinda	Barito R. Bandjermasin	Marutapura Marutapura	Sampit Sampit
orthopyroxene	1					38	1		
clinopyroxene	4	12				42	4		
Ca-amphibole	11	26	1			18	38		
garnet	1	7	10			1	2		
gr-And	2		4			1			
epidote	33	60	8			85	64		
rutile	18	9	30	24	10	8	31	4	17
zircon	44	18	57	32	109	7	35	1	244
titanite		4	3			4	2		
apatite	2	6	1						
tourmaline	3	5	41		13	2	3		
allanite		2							
ilmenite	51	38	46	134	29	35	35	41	3
spinel	2		2			8	1	110	3
monazite	10	4	16	2	14	p	p	p	p
staurolite				4	2		1		
chloritoid		1							
sillimanite	2	1	3	1	2				
thorite			1		1				
xenotime			4		6				
flourencite	1	1					2		1
cassiterite			6		4				
glaucophane							6		

p; present

Table 2. Age data of monazite in the sands from Southeast Asia. Each number shows a monazite grain analyzed.

Age (Ma)	1	2	3	4	5	6	7	8	9
0–25									
25–50	1		7						
50–75			17		17			5	
75–100	2	1	17		17	5	10	2	5
100–125	1		2		2	8	14	4	13
125–150					1	3	13	7	5
150–175		1	1		1		10	6	1
175–200	5	1	13	1	1		3	4	2
200–225	29	9	44	32	7	1		1	
225–250	36	13	11	16	18	3	1	7	
250–275	24	6		1	18	1		4	
275–300	2				5		1	3	
300–325		1			3				
325–350					1				4
350–375						2			3
375–400						1		3	2
400–425	4	1						1	1
425–450	12	5							
450–475	16					1		1	3
475–500	3	2							
500–525			3					1	1
525–550			1						
550–575			1						
575–600			1						
600–625					1			1	
625–650									
650–675									
675–700								1	
700–725									
725–750									
750–775									
775–800									
800–825								1	
825–850									
850–875									
875–900									
900–925									
925–950			1			1			
950–975								2	
975–1000			1						
1000–1025									
1025–1050								1	
1050–1075									
1075–1100									
1100–1125									
1125–1150									
1150–1175								1	
1175–1200									
1200–1225									
1225–1250									
1250–1275									
1275–1300									
1300–1325									
1325–1350									
1350–1375									
1375–1400									

Table 2. (Continued)

Age (Ma)	1	2	3	4	5	6	7	8	9
1400–1425									
1425–1450									1
1450–1475									
1475–1500									
1500–1525									
1525–1500									
1550–1575	1								
1575–1600									
1600–1625									
1625–1650									
1650–1675			1						
1675–1700									
1700–1725									
1725–1750									
1750–1775									
1775–1800									
1800–1825									
1825–1850									
1850–1875	1								
1875–1900									1
1900–1925								2	
1925–1950									
1950–1975									
1975–2000									
2000–2025									
2025–2050									
2050–2075									
2075–2100									
2100–2125									
2125–2150									
2150–2175									
2175–2200									
2200–2225									
2225–2250			1						
2250–2275									
2275–2300									
analysed gr.	137	40	122	50	92	26	52	58	

1; R. Mecong, Phnonm Penh, 2; R. Sap, Phnonm Penh, 3; R. Chao Phraya, Bangkok, 4; Southern beach, Singapore, 5; Northern beach, Singapore, 6; R. Mahakam, Samarinda, 7; R.Sanpit, Sampit, 8; R. Barito, Banjarmasin, 9; fan deposit, Martapura

(Williams, 1998). The monazite ages in the Mekong River range from ca. 25 Ma to 1900 Ma with strong populations at 200–300 Ma and 400–500 Ma. Monazite older than 500 Ma is scarce. The monazite age from the Sap River, a tributary of the Mekong River, are similar in peak age to those from the Mekong River. The Chao Phraya River has different age pattern from those mentioned above. Major peaks are 50 Ma, 80 Ma and 210 Ma. Small peak is present at 500–600 Ma.

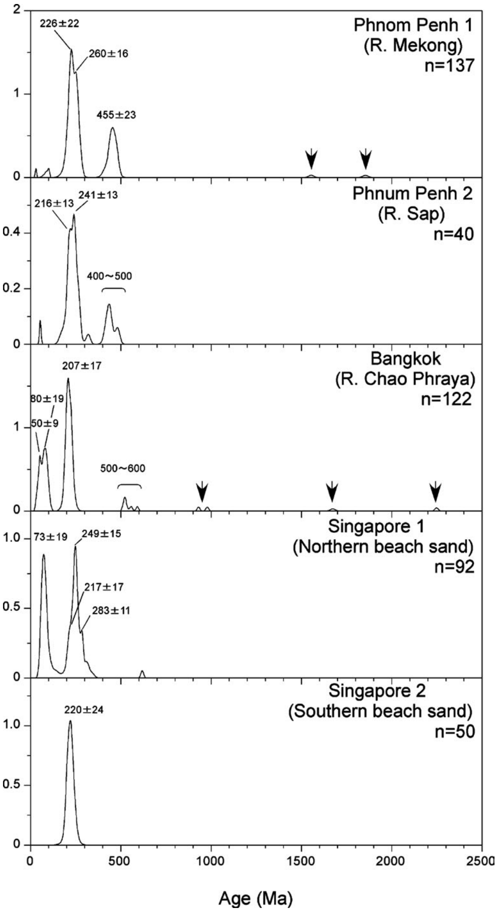

Fig. 2. Frequency and probability distribution diagrams of monazite ages from the sands from the Indochina Peninsula. Numerical value (n) denotes the number of analyzed monazite grains. Arrows point up small peaks.

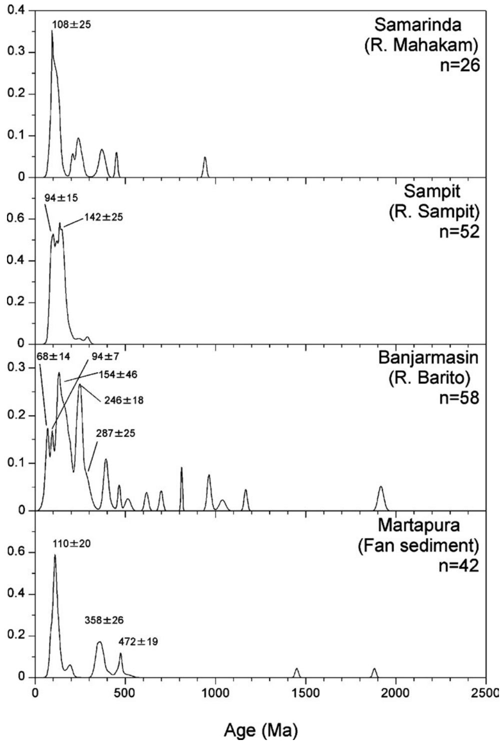

Fig. 3. Frequency and probability distribution diagrams of monazite ages in the sands from Kalimantan. Numerical value (n) denotes the number of analyzed monazite grains.

Major peaks from the northern beach sands from Singapore are younger than 300 Ma; 70 Ma and 250 Ma, whereas a single peak, 220 Ma, is observed at the southern beach.

In the Kalimantan, analyzed monazite grains are restricted in all the samples, though complex age distributions were observed. The Mahakam River has a major peak at 110 Ma with small peaks at 200–300 Ma and 300–400 Ma. On the other hand, the Barito River has several peaks between 50 Ma to 300 Ma and negligible peaks from 350 Ma to 1200 Ma. The sand from diamond mine at Martapura has a similar age distribution pattern with a strong peak at 110 Ma with a subordinate peak at 300–400 Ma to that from the Mahakam River. The sand from placer gold mine at Sampit has a narrow range in monazite age; from 50 Ma to 200 Ma.

Discussion

Monazite is formed at high temperature conditions and is found in granitic and gneissose rocks which are major constituents of continental crust. In addition to the rocks, monazite in sand is derived also from sandstones as a result of reworking. Monazite ages in the recent sands collected from eight localities in Southeast Asia are shown in Fig. 2 & Fig. 3. Each sample has its distinct age distribution characteristics, reflecting the different rocks within their drainage basins. The restricted range of monazite age or single peak

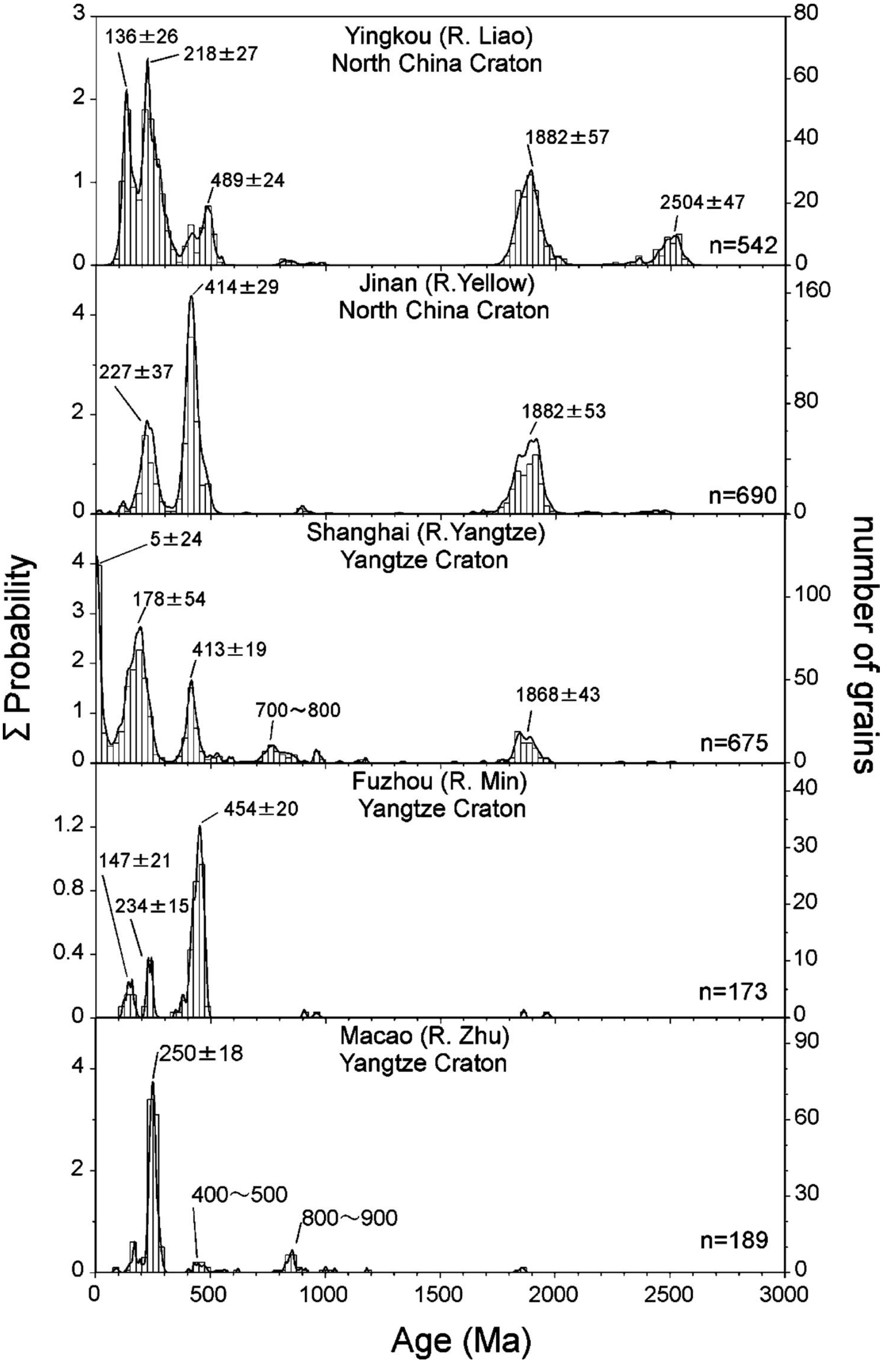

Fig. 4. Frequency and probability distribution diagrams of monazite ages in the sands from the East Asia continental margin (Yokoyama *et al.*, 2007). Numerical value (n) denotes the number of analyzed monazite grains.

were observed in sands from the southern beach of Singapore and from Sampit, probably due to the basin being small. The most common peaks are found between 50 Ma to 300 Ma. The peak ages at 200–300 Ma are observed in most of the samples and are related to the breakup event of Pangaea supercontinent or collision event of Yangtze and North China cratons (e.g. Lawver *et al.*, 2002), whereas age around 100 Ma are related to the subduction event at the periphery of the Southeast Asia block (e.g. Parkinson *et al.*, 1998). These young ages are commonly observed in the monazite age data from the rivers cutting through East Asia; Yangtze and North China cratons (Fan *et al.*, 2004; Yokoyama *et al.*, 2007).

Precambrian Monazite, i.e. more than 540 Ma, is scarce in all the samples. As no clear peak has been recognized in all the sand samples, it is probable that the rare Precambrian monazites were reworked from old sandstones which included monazites derived from the other continents at the time of Pangaea age. Although it is probable that a small Precambrian block occurs locally in the Indochina Peninsula, they are tentatively excluded from consideration in age studies of the cratons in Southeast Asia.

The age distribution from the Mekong River has a subordinate peak at 450 Ma. Such a peak is recognized in the Sap River, tributary of the Mekong River. According to the Plate Tectonic reconstruction (Lawver *et al.*, 2002), the cratons in Southeast Asia were located between or near the Yangtze and India cratons. The youngest event in the India craton was Pan-African event at 500–600 Ma (Santosh *et al.*, 2003). On the other hand, Yangtze craton has many event, 180 Ma, 410 Ma, 700–800 Ma and 1900 Ma at the drainage basin of Yangtze River, 230 Ma and 450 Ma at the Min River and 250 Ma, 400–500 Ma and 8001–900 Ma at Zhu River (Fig. 4). Compared with these data, the monazite data with 450 Ma Peak from the Mekong River are similar to those of the Min River which is cutting through the southern part of the Yangtze craton. At least in East Asia, there is no other candidate fitting to the age data. Hence it is probable that the craton in the drainage basin of the Mekong River was formed as one block as the southern part of the Yangtze craton.

In the age distribution from the Chao Phraya River, a small peak is present at 500–600 Ma. The age is a typical age of Pan-African event developed in the India and Antarctica cratons. As the river has a small drainage basin (Fig. 1), it is probable that the small peak is due to reworking from sandstones formed at the Pangaea age rather than presence of block with 500–600 Ma in the basin.

Monazites with age older than 300 Ma are sporadically present in the Kalimantan samples. Although most of the peaks are too small to compare with the data in the other continent, it is noted that a small peak around 350 Ma is observed in three samples from Samarinda, Banjarmasin and Martapura. The age will be corresponding to the Hercynian event which is common in Europe. However, there is no such peak in the Asian region including East Asia (Fig. 4) and India continent. This may mean that the monazites were not derived from old sandstone by reworking, but directly from granitic rock or gneiss with 300–400 Ma in Kalimantan.

Summary

Age analyses based on more than 600 monazites from Southeast Asia have led us to the following conclusions:

Major peak ages are observed in the range from 50 Ma to 300 Ma. Age around 240 Ma is corresponding to the breakup event of Pangaea super continent or collision events of Yangtze and North China cratons, whereas age around 100 Ma is due to the Cretaceous subduction event. Precambrian rock has not been confirmed in the Indochina area. The oldest peak age will be around 450 Ma, similar to that in the southern part of the Yangtze craton. Weak peak at 300–400 Ma is observed in Kalimantan. As the peak has not been reported from the adjacent continents, it is probable that a small block is present in the island.

This reconnaissance study was followed by the age analyses in East Asia. Although, for the comparison of age, analyses of the other continents such as Australia and India are important, the other areas in Southeast Asia have been still left for the age analyses of monazite, e.g. Vietnam and Myanmar. To confirm whether the Precambrian terrane is present in the Indonesia area or not, we will continue the analyses in Vietnam and Myanmar as a next target.

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モナザイトによる東南アジアの年代分布の予察的研究

横山一己・堤　之恭

東南アジアの河川や海岸から採集した砂からモナザイトが分離され，600以上の年代が求められた．年代の殆どは，3億年より若く，パンゲアの分裂，揚子江地塊と北中国地塊の衝突，白亜紀のプレート潜り込みに伴う火山活動に対応するものである．3億年以上の古い年代分布からは，先カンブリア紀の地帯はないものと推定され，古い年代として4億5千万年前後にピークがある．この年代は，近辺の大陸の年代分布の中では揚子江地塊の南部に見られるもので，パンゲアの分裂前にインドネシアの古い地塊は揚子江地塊の南部と同時に形成されたものと推論できる．