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Age Distribution of Monazites from the Nine Rivers of Vietnam

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Abstract. More than 2500 age determinations were carried out on monazite and thorite grains sampled from rivers cutting through Vietnam. Monazite ages ranged up to 2600 Ma, but ages >540 Ma are rare or absent. In northern Vietnam, monazite has major peaks at 30 Ma and 260 Ma, whereas in the southern part, 240 Ma and 450 Ma are those mainly represented. These ages, except for 30 Ma, are the most common ages in the Indochina and Yangtze cratons. The detailed age distributions for young monazite was clarified by analyses of thorites. In the Red River, the thorite age varies from 24 Ma to 55 Ma with major peak at 26 Ma. The peak age varies from river to river: 34 Ma for the Black River, 30 Ma for the Ma River and 24 Ma for the Ca River. These youngest ages are due to thermal event during shearing and left-lateral displacement along the rivers. A small peak at 50 Ma was found from the Red and Black rivers. Such an age has not been previously described from the areas along the rivers. Although the 240–260 Ma age is related to the breakup of Pangaea or collision of the continents, other peaks has been recognized. Cretaceous and Tertiary ages were obtained from the Dong Nai River. Ages of ca. 350 Ma probably corresponding to the Hercynian event were noted in samples from the Da Rang River. Small peaks of 500–600 Ma and 900–1000 Ma were recognized from the White River running through northern Vietnam and China. The ages correspond to the Pan-African and Grenville events, respectively.

Key words: monazite, thorite, Vietnam, age, drainage basin.

Introduction

The Indochina block is thought to contain Precambrian terrane, >540 Ma. Vietnam, belonging mostly to the Indochina block, has been considered to have a long history of geological development from Archean to Quaternary (Hutchison, 1989: Bien, 2005). Although Vietnam has lacked reliable radiometric data (Nam, 1995), much age data were obtained by various methods, especially for plutonic and metamorphic rocks along the Red River (Tapponnier *et al*., 1990; Lan *et al*., 2001; Leloup *et al*., 2001; Gilley *et al*., 2003; Liang *et al*., 2007). The ages of the rocks are concentrated between 17–36 Ma. Many papers have clearly documented that the age was correlated to the shearing during the left-lateral displacement of the Red River Fault and the opening of the South China Sea, parentally induced by the collision of India with Asia. Except for gneisses with 2.8–2.5 Ga from the Cavinh complex in the north Vietnam (Lan *et al*., 2001), recent age data do not show any evidence of an Archean block in Vietnam. The most common ages are around 250 Ma corresponding to the Indochinian orogeny (Lepvrier *et al*., 1997; Owada, *et al*., 2006; Trung, *et al*., 2007). As the age data were mostly obtained by isotopic analyses of minerals separated from rocks, they were restricted in number.

In this study, we obtained ages of detrital monazites from the nine rivers cutting through Vietnam. More than 2400 monazite age and 100 thorite age dada were obtained from sand samples. Although these age data do not allow the direct assignment of their source rocks in the drainage basin, they will provide a basis for further research on the ages of rocks in Vietnam.

Samples and Analytical Procedures

Nine sand samples were collected at riverbeds from some rivers in Vietnam. In the northern area, they are the White (Song Lo), Red (Song Hong), Black (Song Da), Ma and Ca rivers (Fig. 1). In the southern area, they are the Thu Bon, Da Rang, Dong Nai and Mekong rivers. Heavy minerals in the samples had been previously roughly separated by panning in the field. Procedures for the further separation of heavy minerals and their subsequent identification are the same as have been described by Yokoyama *et al*. (1990). Magnetic fractions were removed prior to separation of the heavy minerals. Twenty mineral species were observed in around 200 grains from the heavy fractions of the sand samples. The abundance of each of the mineral species is listed in Table 1. The heavy minerals were used for a provenance study (Morton, 1991; Yokoyama *et al*., 1990). Among these, monazite and zircon have been commonly used for age analyses (*e.g*. Ireland, 1991; Suzuki *et al*. 1991; Tsutsumi *et al*., 2003; Wyck *et al*., 2004). Although monazite in the rivers is usually minor in the heavy fraction, around 200 grains were analyzed in the heavy fraction from each river (Table 2).

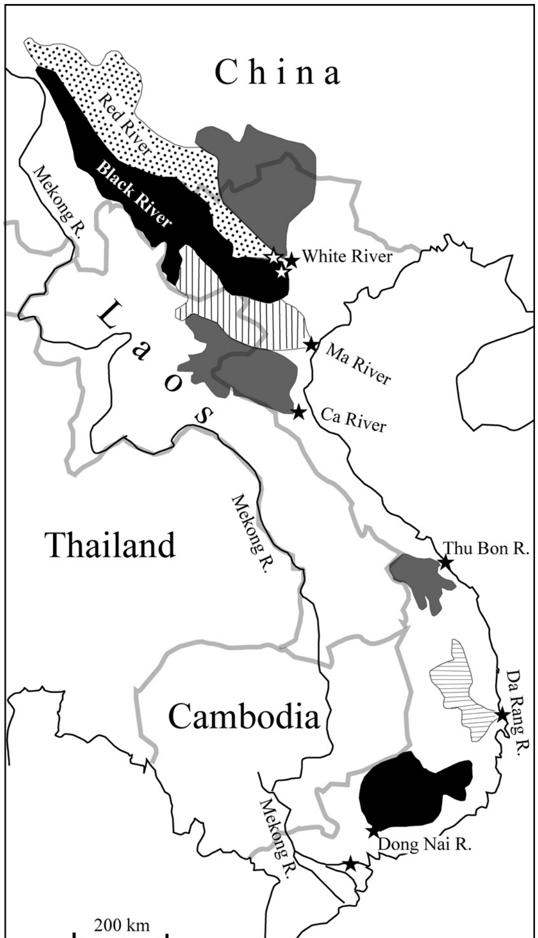

Fig. 1. Drainage systems of rivers running through Vietnam and sampling localities of sand samples.

According to the geological map of Vietnam (Bien, 2005), the drainage basin of the White River in Vietnam is composed mainly of Devonian sedimentary rocks with subordinate amounts of Paleozoic granitic rocks and Cambrian–Silurian sedimentary rocks. The granitic rock and sedimentary rocks are various in types: granite, granodiorite and tonalite or sandstone, mudstone and limestone. They are tentatively called simply “granite” and “sediment” here. The basin of the Red River is composed mainly of Precambrian metamorphics with subordinate amounts of Precambrian and Paleozoic granite. The basin of the Black River is composed of Precambrian–Early Paleozoic metamorphics, Mesozoic sediments and granite and Early Paleozoic sediment. The basin of the Ma River is composed mainly of Triassic to Jurassic sediments with subordinate amounts of Cretaceous granite, Early to Middle Paleozoic granite and Precambrian to Early Paleozoic sediments. The basin of the Ca River is composed of Early Paleozoic metamorphic rocks, Paleozoic and Mesozoic sediments and Triassic granite with a small amount of the Late Mesozoic granite. In Vietnam, it had often been considered that metamorphic rocks of granulite facies are Archean in age and rocks of amphibolite facies are Proterozoic in age. Most of complex related to Early Paleozoic deposits are metamorphic rocks of green schist facies or non-metamorphic rocks.

In Southern Vietnam, the basin of the Thu Bon River is composed of Precambrian to Early Pale-

Table 1. Heavy mineral species and modal proportions in the sands collected from the nine rivers in Vietnam. Abbreviations for rare minerals: apa-apatite, ala-allanite, ctd-chloritoid, xen-xenotime and flo-flourencite.

	White R.	Red R.	Black R.	Ma R.	Ca R.	Thu Bon R.	Da Rang R.	Dong Nai R.	Mekong R.
Orthopyroxene	0	1	1	0	0	6	1	4	1
Clinopyroxene	15	16	4	0	0	30	3	0	14
Amphibole	9	97	8	5	11	186	15	5	36
Garnet	6	11	5	15	5	24	18	1	13
Ca-rich garnet	13	1	2	3	1	4	0	0	9
Epidote	14	14	20	9	20	46	20	3	81
TiO_2 polymorph	18	6	7	7	19	6	6	8	19
Zircon	44	6	12	8	29	1	4	25	14
Titanite	5	8	3	0	1	7	7	0	4
Tourmaline	2	2	1	1	6	7	1	1	11
Ilmenite	83	33	79	169	117	17	104	146	49
Spinel	0	0	4	6	1	0	1	0	2
Monazite	8	4	2	4	6	1	3	6	2
Staurolite	0	0	2	1	0	3	0	1	0
Sillimanite	0	2	0	1	2	9	5	2	1
Others	apa(1)	apa(2), ala(2)			ctd(1), ala(1)		xen(1)	xen(1)	flo(1), apa(6)

ozoic metamorphics, Permian granite with subordinate amounts of Precambrian granite and Mesozoic sediment. The basin of the Da Rang River is composed of Precambrian granite and metamorphics, Triassic to Jurassic sediment and Triassic granite with small amounts of Cretaceous granite and Archean metamorphics. The basin of the Dong Nai River is composed of Tertiary to Quaternary volcanics and Jurassic sediments with a subordinate amount of Late Mesozoic and Cenozoic intrusions. The Mekong River has a huge drainage basin including areas of Vietnam, Cambodia, Laos and China.

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. The analytical conditions used have been previously 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 (*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 internal consistency. Monazites with ages of 3020 Ma and 64 Ma, that were obtained by SHRIMP and K–Ar methods, respectively, were 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 age 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, the data were excluded from the figures and further discussion.

Ages of monazite

All the analytical positions of monazite grains were selected from 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). One representative age was selected from each grain. More than 2400 monazite grains have been analyzed from the sands in Vietnam. All the monazite age data are summarized in Table 2. As the obtained

Table 2. Age data of Vietnamese monazites.

range (Ma)	White	Red	Black	Ma	Ca	Thu Bon	Da Rang	Dong Nai	Me-kong
0–25		17	6	4	16			5	4
25–50	8	126	50	57	96			11	10
50–75	5	27		10	29			5	10
75–100	15	16		5	3			13	2
100–125	10	3						11	1
125–150		4						6	1
150–175	3	4						2	1
175–200	1						1	1	1
200–225	5	1	1			12	19	30	71
225–250	49	3	21	21	8	113	104	41	98
250–275	102	5	123	93	53	112	79	26	61
275–300	15	2	22	11	13	8	5	8	3
300–325			3	1				1	2
325–350							2		
350–375			1				6		1
375–400	1					1	4		1
400–425			1	1		8	8	4	5
425–450	3		4		2	30	6	5	18
450–475			7	4	1	21	11	3	33
475–500			2	2		9	8	8	7
500–525			1			5		3	6
525–550	6		5			1		1	
550–575	10		3		1				
575–600	5								
600–625	1								1
625–650	6		1						
650–675	1								
675–700	2								
700–725									
725–750					1				
750–775			1		1				
775–800				1					
800–825			1						
825–850		2							
850–875		2	1						
875–900		1	1						
900–925					1				1
925–950	1		2						2
950–975	5	1	1	1					
975–1000	1		2	1					
1000–1025	4								
1025–1050	2								
1050–1075	1								
1075–1100									
1100–1125									
1125–1150	1			1					
1150–1175									
1175–1200									
1200–1225									
1225–1250									
1250–1275			1						
1275–1300									
1300–1325									
1325–1350									
1350–1375									
1375–1400									
1400–1425									

Table 2. Continued.

range (Ma)	White	Red	Black	Ma	Ca	Thu Bon	Da Rang	Dong Nai	Me-kong
1425–1450									
1450–1475									
1475–1500									
1500–1525									
1525–1550									
1550–1575									
1575–1600									
1600–1625									
1625–1650									
1650–1675									
1675–1700									
1700–1725									
1725–1750									
1750–1775									
1775–1800									
1800–1825									1
1825–1850			2						
1850-1875									1
1875–1900	1	2	6				1	1	5
1900–1925	1		7						
1925–1950		1	5				1	2	
1950–1975			1						
1975–2000		1							
2000–2025									
2025–2050			1						
2050–2075									
2075–2100									
2100–2125									
2125–2150									
2150–2175									
2175–2200									
2200–2225									
2225–2250									
2250–2275									
2275–2300									
2300–2325									
2325–2350									
2350–2375									
2375–2400									
2400–2425									
2425–2450									
2450–2475	1								
2475–2500									
2500–2525				1					
2525–2550									
2550–2575									
2575–2600			1						
2600–2625									

age have different standard deviation, they are presented as frequency and probability diagrams in Figs. 2, 3 and 4. Probability distributions for monazite ages <700 Ma were calculated with a multi-peak Gauss fitting method (Williams, 1998).

Monazite ages from the rivers in Vietnam range up to 2600 Ma (Figs. 2–4, Table 2). Precambrian monazite, i.e. older than 540 Ma, is rare in all the samples. Small populations at 1900 Ma are observed in the Black and Dong Nai rivers. The samples, except for those from the Red River, show their strongest peak at 240–260 Ma. The major peaks in the northern rivers are 256 Ma to 266 Ma, whereas those from 236 Ma to 249 Ma dominate in the southern rivers. In northern Vietnam, four of the rivers, except for White River, have a clear peak at around 30 Ma. On the other hand, in the White River, weak populations appear at around 550 Ma and 950 Ma. Such peaks are not recognized in the other rivers. In the southern rivers, a peak or, at least, relatively high population of monazite appears at around 450 Ma. In the Thu Bong and Da Rang rivers,

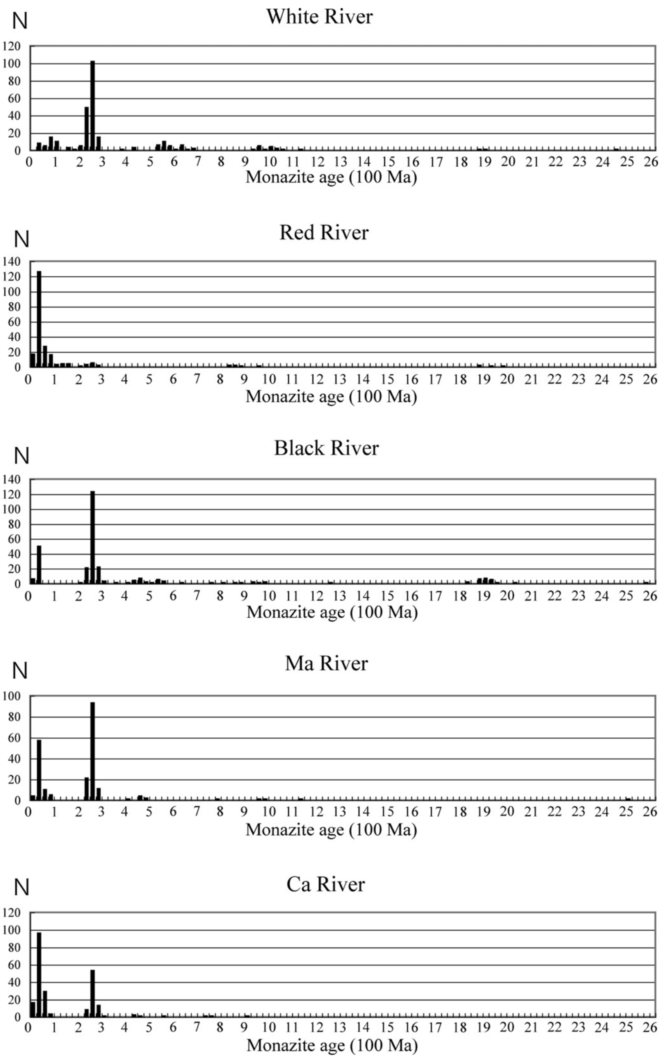

Fig. 2. Frequency distribution diagrams of monazite ages from sands sampled in northern Vietnam. Numerical values (n) denote the number of analyzed monazite grains.

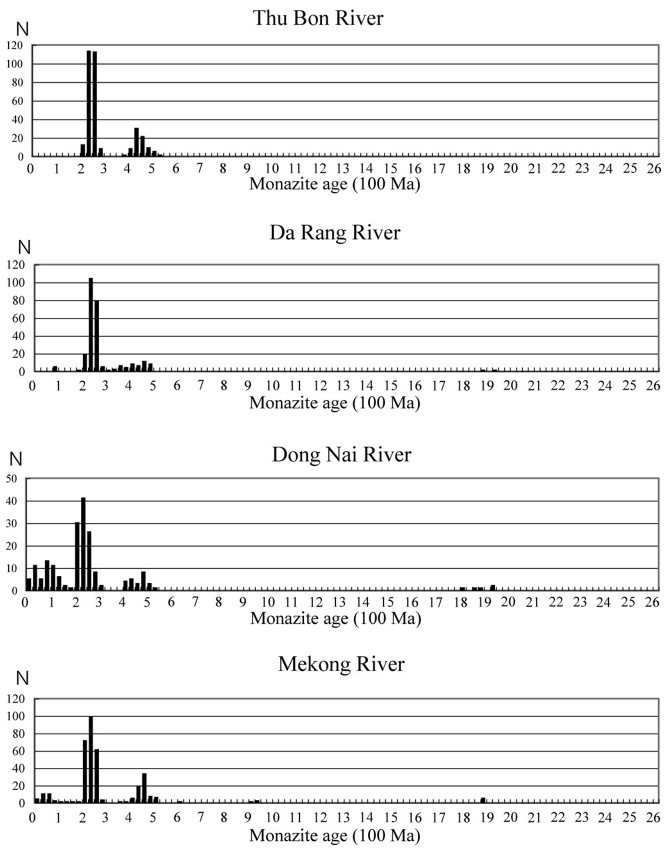

Fig. 3. Frequency distribution diagrams of monazite ages from sands sampled in southern Vietnam. Numerical values (n) denote the number of analyzed monazite grains.

monazite ages are restricted from 200 Ma to 550 Ma, whereas the Dong Nai River has younger monazites of Cretaceous and Tertiary age. Three grains from the Dong Nai River showing Tertiary age were analyzed in detail to reconfirm the age. They are 18±10 Ma, 33±6 Ma and 32±4 Ma. The monazite ages in the Mekong River range from ca. 25 Ma to 1900 Ma with a strong population at 240 Ma and a subordinate population at 400–500 Ma. Monazite older than 500 Ma is scarce.

Age of thorite

Thorite is not correctly represented as a heavy mineral in the category of those listed in Table 1, because it is a very rare mineral. It is mostly found in the northern rivers. In total 119 grains were found in the heavy fractions from the four rivers: Red River (36 grains), Black River (22), Ma River (25) and Ca River (36). A few grains of thorite were found in the southern rivers. One uraninite grain was found from the Red River (Fig. 5D), and one thorianite grain from the Ca River (Fig. 5C). The age of these radiogenic minerals is obtained using the same method as for the monazite. Age calibration was done by thorites with 1.5 Ma and 115 Ma which were acquired by the SHRIMP technique. As the radiogenic Pb of thorite is enough to reduce the standard deviation of age to <2 Ma, it is applicable even to the Tertiary rock (Fig. 5).

Thorite age from the Red River shows a wide range from 22 Ma to 54 Ma (Fig. 6). A strong peak was at 26 Ma and a weak one at 50 Ma. The age from the Black River is mostly concentrated

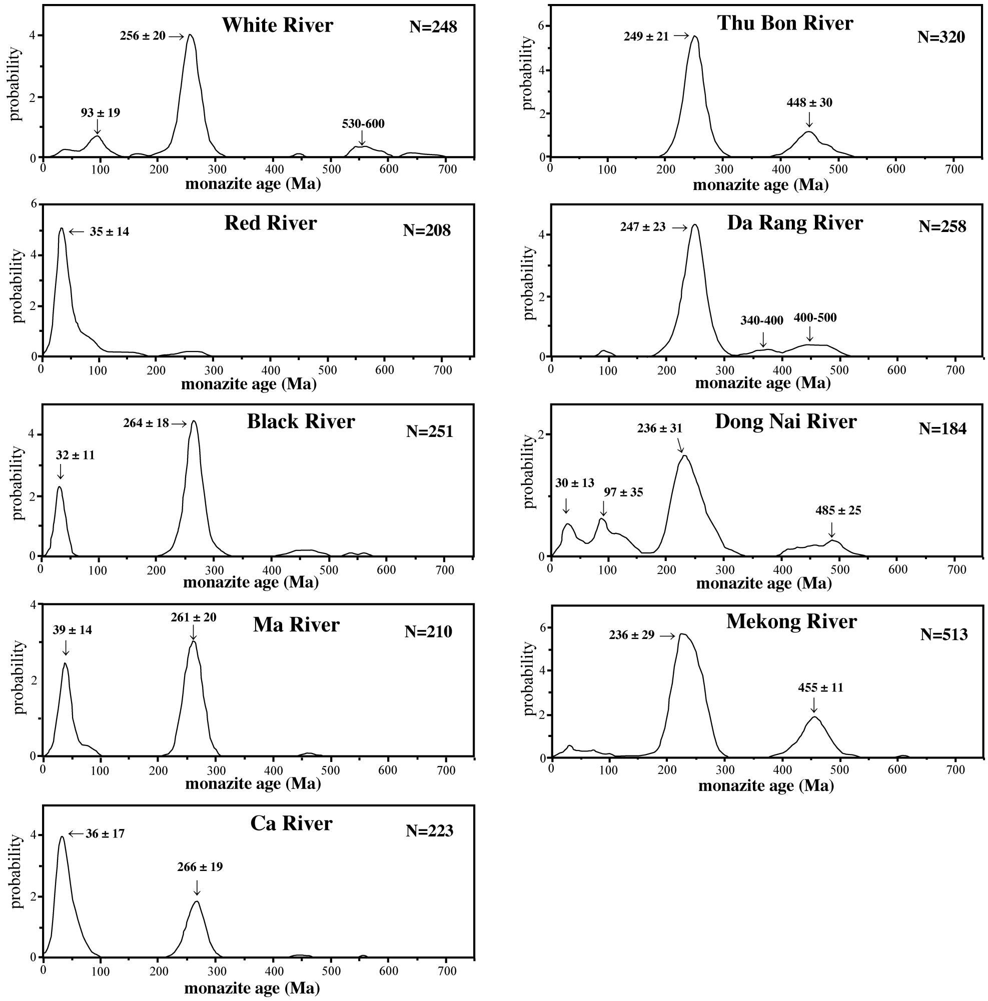

Fig. 4 Probability distribution diagrams of monazite ages <700 Ma.

in a narrow range from 26Ma to 36 Ma and an age peak is found at 34 Ma. Three grains in the Black River have 50 Ma, corresponding to a weak peak from the Red River. Both the Ma and Ca rivers have a narrow range in thorite age from 22 Ma to 32 Ma. Peak positions, however, are different: 30 Ma for Ma River and 24 Ma for Ca River. One thorianite grain from the Ca River is far older −244 Ma. It is important to note that the peak age is different from the river to river.

In the other rivers, ages obtained by thorite are older than 90 Ma, but there is not enough data to make a histogram. Thorite, uraninite and thorianite were not found in the heavy fraction from the Dong Nai River where Tertiary monazites are moderately developed.

Discussion

Monazite and thorite are formed at high temperature conditions and are found in granite and gneiss which are the major constituents of continental crust. In addition to these rocks, monazite is derived from sandstones as a result of reworking. On the other hand, thorite has not been found in the sandstone because of its less resistant nature after deposition. More than 2400 monazite and 100 thorite age determinations

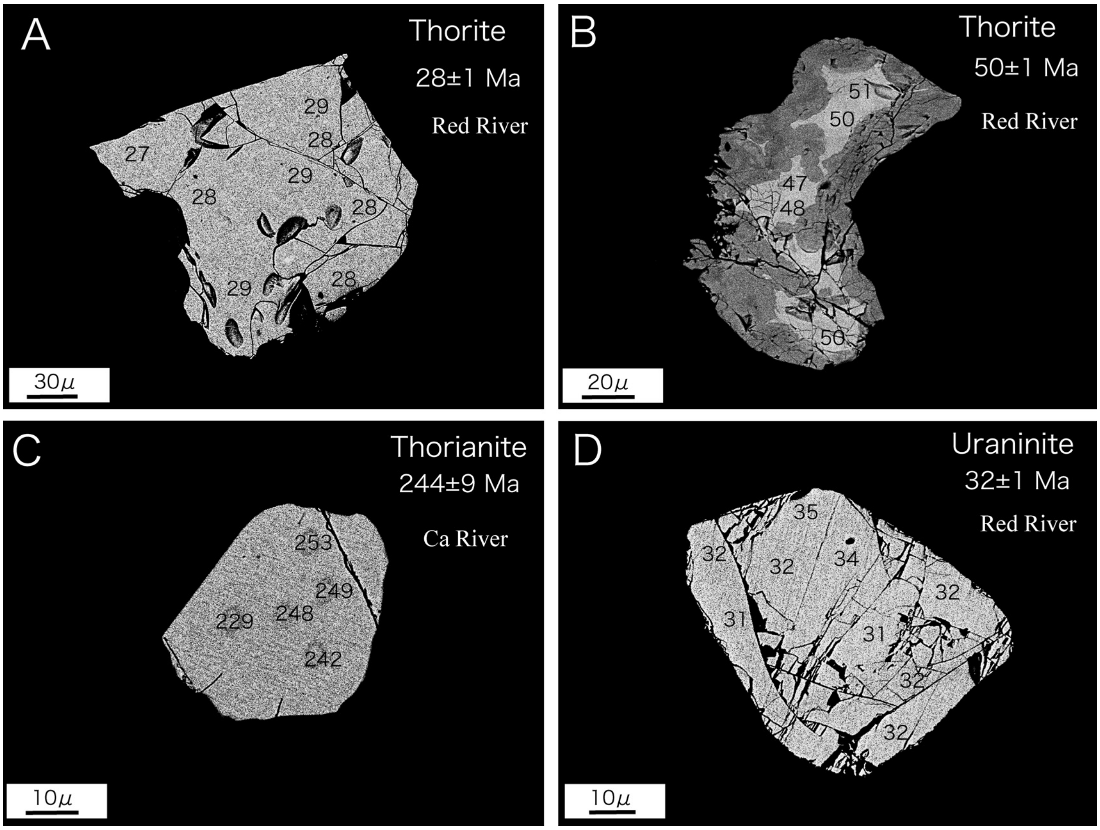

Fig. 5 Back-scattered electron image of thorite, uraninite and thorianite, and age variation in the grains. Thorite grain in B is highly replaced by hydrous thorite.

from recent sands collected from nine localities in the Vietnam were obtained in this study. Although each age is not directly assigned to the source rock, the age distributions will show the characteristics of the drainage basins of the rivers.

The presence of Archean blocks has been indicated in the central part of Vietnam (Bien, 2005). According to the geological map, Precambrian rock is one of the major constituents in central and northern Vietnam. Recent age analyses show that the oldest rocks (28–25 Ga) are from the drainage basins of the Red and Black rivers (Lan *et al*., 2001). Nam *et al*. (2001) studied the metamorphic rock in central Vietnam which has been described as Archean. They obtained a U-Pb zircon age of ca. 1.4 Ga for the Kontum Massif in central Vietnam. In the present analyses, only three grains were found of Archean age. Such scarce data indicate that they were probably derived, not from the Archean block, but from the sandstones of the Paleozoic to Mesozoic. In the drainage basin of the Da Rang River, Archean rocks develop moderately according to the geological map (Bien, 2005). No material of Archean age has been confirmed from river sources. A small population of monazite of ca.1900 Ma is found in the Black and Dong Nai rivers. In spite of the wide occurrence of Paleozoic to Mesozoic sediments in North Vietnam, monazites of this age are absent in the basins of the neighboring Ma and Ca rivers (Fig. 2). Hence, the monazite from the Black River indicates that the Early Proterozoic igneous or metamorphic rocks occur locally in the basin. On the other hand, there is probably no igneous or meta-

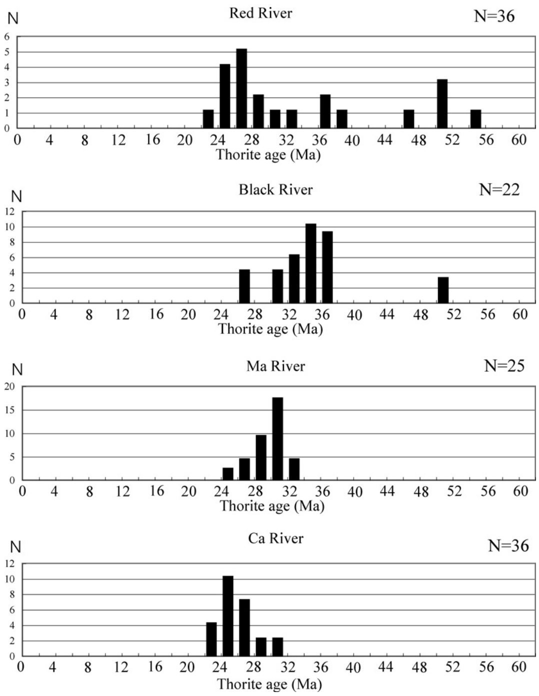

Fig. 6 Frequency distribution diagrams of thorite ages from sands in northern Vietnam.

morphic rock in the drainage basin of the Don Nai River. The latter may be explained by derivatives from the Mesozoic sandstones.

Monazite with 400–500 Ma is found as a small population in the southern rivers (Fig. 3). An age of 400–500 Ma is common in the Yangtze and Yellow rivers (Yokoyama *et al.*, 2007) and corresponds to the Caledonian orogeny or event. In central Vietnam, Roger *et al.* (2007) reported U-Pb zircon ages of ca. 430–470 Ma from the Kontum massif as a high temperature episode. So far it is hard to decide whether the monazites with 400–500 Ma were derived directly from metamorphic or igneous rock or from Paleozoic to Mesozoic sandstones.

On the other hand, monazite with ca. 250 Ma is abundant in the rivers except for the Red River. Granite and gneiss of a similar age have been reported from Vietnam by many authors (*e.g.* Lepvrier *et al.*, 1997; Owada, *et al.*, 2006; Trung, *et al.*, 2007). The monazite should be derived directly from the granite and gneiss in the basins of the rivers rather than the sandstones. The most common age, around 250 Ma, has been reported in East Asia and corresponds to the Indochinian orogeny. As far as the peak is concerned, the age peaks of the northern rivers are around 260 Ma, older than those of the southern rivers: ca 240 Ma. Owada *et al.* (2006) reported monazites with core age of ca. 260 Ma and rim age of ca. 240 Ma from granite and gneiss in central Vietnam. One possible explanation is that the difference in peak age between the northern and southern rivers might be attributed to late-stage thermal overprinting in southern Vietnam.

The other strong peak, around 30 Ma, is observed in the northern rivers. The standard deviation of monazite is too high to discuss Tertiary rocks in detail. The age population for such young monazites is discussed based on the thorite age as will be mentioned later. The other young monazite is of the Cretaceous to Tertiary age in the Don Nai River (Fig. 4). It is also difficult to designate their source rocks, but, as a possible source, there are Cenozoic Alkaline intrusions in the basin. So far the youngest monazite is Eocene to Miocene in age: 33 ± 6 Ma, 32 ± 4 Ma and 18 ± 10 Ma.

The White River has a different age distribution from the other rivers. There are small populations at 500–600 Ma and 900–1000 Ma which correspond to the Pan-African and Grenville orogenies, respectively. High population with such ages has not been described from the rivers cutting through China and the other rivers in Vietnam. The neighboring drainage basin of the White river is of the Zhu River. The age distribution of the Zhu River has weak peaks at 400–500 Ma and 800–900 Ma, clearly different from those of the White River (Yokoyama *et al.*, 2007). Along the Red River running south of the White River, a huge left-lateral displacement more than 500 km occurred in the Tertiary period. Hence, it is not so surprising that the age distribution of the White River is different from that of the other rivers in Vietnam. However, monazites of 500–600 Ma and 900–1000 Ma in the White River are puzzling because of absence of such peaks, at least in East Asia. Another puzzling of age data is 300–400 Ma from the Da Rang River. The age corresponds to the Hercynian orogeny. In East Asia, monazite with 300–400 Ma was reported from the Liao River, China, and from Kalimantan (Yokoyama *et al*., 2007, 2008). The absence of monazite aged 300–400 Ma in the other rivers indicates that they were derived not from the old sandstones by reworking, but directly from a granite or gneiss body with 300–400 Ma in the drainage basin of the Da Rang River.

Four rivers in the northern Vietnam have a strong peak at around 30 Ma in the age distribution of monazite (Fig. 2). The age distribution in the Tertiary is well documented by analyses of thorite. Detailed age analyses by several methods have been presented from granite and gneiss along the Red River. Isotope ages along the Red River range from 17 to 36 Ma (Tapponnier *et al*., 1990; Lan *et al*., 2001; Leloup *et al*., 2001; Gilley *et al*., 2003; Liang *et al*., 2007), in good agreement with the present data except for 50 Ma. The granite and gneiss were formed by shear heating during the left-lateral displacement. Shear zones run along the other three rivers: Black, Ma and Ca rivers. In the Ca River, 22 Ma was reported for a pegmatite (Lepvrier *et al*., 1997). Our present data revealed the different age distribution among the drainage basins of the four rivers: peak at 26 Ma from the Red River, 34 Ma from the Black River, 30 Ma for the Ma River and 24 Ma for the Ca River. The age variation of granite and gneiss along the Red River has been rationalized by assuming that they were formed at the time of the left-Lateral displacement. Assuming that age variations of the other three rivers were also as a result of the displacement, major shearing will be sifted in the age range from 24 to 34 Ma. As far as we know, rocks of age 50 Ma have not been reported from the basin of the Red River. They are found in the basin of the Black River. This coincidence of ages might indicate that an igneous or metamorphic block of around 50 Ma occurs astride both the basins of the Red and Black rivers. The age of 17–36 Ma was widely documented that it was correlated to the shearing during the left-lateral displacement parentally induced by the collision of India with Asia. Somehow, the age of 50 Ma appears to correspond to the start of collision of the India subcontinent.

Summary

Age analyses based on more than 2400 monazite and 100 thorite grains from the nine rivers in Vietnam have led us to the following conclusions:

Although monazite age varies up to 2600 Ma, the major peak ages are observed in the range from 10 Ma to 300 Ma. Subordinate peaks are found at 400–500 Ma from southern Vietnam. A low population at 1900 Ma was found from the Black and Dong Nai rivers. One major peak corresponds clearly to a thermal event in the drainage basin of each river. However, it is hard to conclude whether these subordinate or weak populations were produced by erosion of granite and gneiss in the basin of each river or by reworking of the Paleozoic and Mesozoic sediments. Major peaks of the northern rivers are around 260 Ma, whereas they are 240 Ma for the southern rivers. These ages are common in East Asia and correspond to the breakup of the Pangaea super continent or subsequent collision of the cratons.

Thorites of Tertiary age in northern Vietnam were derived directly from granites and gneisses formed by the shearing during the left-lateral displacement. The major shearing was shifted from basin to basin during 24–34 Ma. In the shear zones of northern Vietnam, the earliest thermal event in the Tertiary was 50 Ma ago. It can be observed in both the basins of the Red and Black rivers.

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ベトナムの河川から求められた鉱物年代の分布

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ベトナムの9本の河川から採集した砂からモナズ石やトール石が分離され、2400以上の年代が求められた。年代の殆どは、3億年より若く、240–260 Maにピークがあり、パンゲアの分裂や東アジアの小地塊の衝突によるものである。ベトナム北部の河川からは、トール石の年代として30 Ma前後にピークがあり、インドとの衝突により引き起こされた断層運動によるものである。北部のそれぞれの河川でトール石のピークの年代が異なり、断層活動がシフトしていたと推定される。また、今までに報告されていない50 Maの年代が2つの河川で確認された。