Rb-Sr Isochron and K-Ar ages of igneous rocks from the Samnua Depression Zone in Northern Vietnam

Nguyen Minh TRUNG^{*,**}, Nguyen Dieu NUONG^{*} and Tetsumaru ITAYA^{*}

^{*}*Research Institute of Natural Sciences, 1-1 Ridai-cho, Okayama University of Science, Okayama 700-0005, Japan*

^{**}*Research Institute of Geology and Mineral Resources, Thanhxuan, Hanoi, Vietnam*

The Samnua Depression Zone (SNDZ) extends NW-SE for more than 400 km from Northern Vietnam to Southwestern China. It represents the northern edge of the Indochina block and is separated from the South China block by the Songma fault. The zone is occupied mainly by Paleozoic sedimentary rocks and Mesozoic volcano-sedimentary successions that are intruded by Mesozoic intrusives and extrusives and by Cenozoic extrusives. Representative igneous rocks of the SNDZ were geochronologically investigated by the Rb-Sr whole rock and K-Ar biotite methods. The Rb-Sr ages obtained are 222 Ma for the Nuichua gabbros, 213 Ma for the Songma granitoid (SMG), 203 Ma for the Piabioc granitoid (PBG), 138 Ma for the Banmuong subvolcanic granite, 27 Ma for the Banchieng granitoid (BCG), 218 Ma for the Dongtrau felsic volcanics, 186 Ma for the Muonghinh felsic volcanics and 5.8 Ma for the Cenozoic basaltic rocks (CBR). The K-Ar methods give 252 Ma for the SMG, 237 Ma for the PBG and 24 Ma for the BCG. The groundmass fraction of the CBR yields an age of 1.9 Ma. Geochronological comparison and using fossil records suggest that the Rb-Sr ages of Mesozoic igneous rocks provide apparent young age, a pseudo isochron age. The major igneous activity of the SNDZ took place during Late Permian-Triassic time to form granitic and felsic volcanic rocks, which were related to the continental volcanic arc magmatism. Minor intraplate igneous activity occurred in the Paleogene. This suggests that the tectonic environment of the SNDZ changed from a convergent plate margin to a matured continental margin in the time span between the Triassic and Paleogene.

Keywords: Northern Vietnam, Samnua depression zone, Rb-Sr, K-Ar, Felsic igneous rocks, Basalts

INTRODUCTION

The structural unit “Samnua” in Northern Vietnam was mentioned first by Fromaget (1941) who called it “Samnua syncline” and described the relationship between it and other structural units such as Songca syncline and Phuhoat massif. In the “Geologic Map of Northern Vietnam”, Dovjikov et al., (1965) defined the Samnua structural unit as a depression within the Truongson fold region. Since 1965, Vietnamese geologists have adopted the same idea in a number of publications on the geology of Vietnam. Tran Van Tri and others (1977) have described the depression events base on the detailed geological studies. However, no geochronological studies have been performed on the igneous rocks that constitute main lithologies in the Samnua Depression Zone (SNDZ) though these studies are so important to understand the details of the Indosinian orogeny.

The SNDZ extends NW-SE for over than 400 km from Northern Vietnam to Southwestern China through Laos (Fig. 1). It represents the northern edge of Indochina block (ICB) and is separated from South China block (SCB) by the Songma fault (Tri et al., 1977; Minh and Hai, 1991; Bao and Luong, 1985; Than et al., 2000; Trung and Itaya, 2002, 2004). It is mainly composed of Paleozoic sedimentary rocks and Mesozoic volcano-sedimentary successions that are intruded by Mesozoic and Cenozoic granitic rocks. Mafic to ultramafic rocks and basaltic extrusives also occur in the zone. The diverse compositions and ages of these igneous activities are not investigated yet except for the Honvan serpentinite body by Trung et al. (2006). In this study, we carried out geochronological studies with the double methods at the Plural Laboratories. Both Rb-Sr whole rock isochron ages and K-Ar biotite ages of eight kinds of igneous rocks are presented and two types of ages for each rock type are compared to obtain the reasonable ages for these rocks. The Mesozoic igneous activity in relation to the continental

Figure 2. Map showing the locations of the samples analyzed in this study. Legend is the same as that in Figure 1. The symbols, star and cross show locations of the samples analyzed by Rb-Sr and K-Ar methods, respectively.

phy of these rocks.

SMG cover an area of 65 km² in the Muongsai area in the northwestern part of the SNDZ. They also occur as small bodies to the south of 217 Road fault. The SMG is composed mainly of hornblende biotite granodiorite and granophyric granite. The granodiorite is a grey to dark grey rock composed of plagioclase (25–40%), potassium feldspar (30–45%), quartz (25–40%), biotite (5–7%) and hornblende (1–5%). Common accessory minerals are zircon, apatite, sphene, epidote, and ore minerals. The granophyric granite is yellowish-gray in color and shows hypidiomorphic granular or granophyric texture. It is composed of plagioclase (25–40%), potassium feldspar (30–45%), quartz (25–40%), biotite (5–7%) and trace hornblende. Accessory minerals are zircon, apatite and iron ores.

PBG comprises Langbong massif and a series of massifs of different sizes, occurring between the Songma and 217 Road Faults. The main rocks are medium-grained biotite and two-mica granites that intruded into the HNF and DTF and formed contact aureoles in the formations. The two-mica granite is composed of quartz (30–60%), potassium feldspar (34–45%), plagioclase (23–

25%), biotite (3–45%) and muscovite (0.5–8%). Accessory minerals are ilmenite, zircon, apatite, tourmaline and magnetite. Concentration of heavy minerals by panning revealed the presence of monazite and fluorite.

BMSGV constitutes the Banmuong, Chiengkhaio, Bume and Cuadat subvolcanic formations that are genetically related to the rhyolitic rocks of MFV described below. It is composed of granophyric granite and porphyritic granite dissected by aplite and pegmatite veins. The phenocrysts are potassium feldspar and quartz set in a fine to medium-grained groundmass. The mineral compositions are 35–45% potassium feldspar (microcline), 15–20% plagioclase, 28–40% quartz and 7–15% biotite. Accessory minerals are apatite, zircon and sphene.

Songchu, Burinh, Bume and Phamay massifs belong to the BCG. The biggest Songchu massif covers an area of 100 km² at 20 km west of Baithuong. The massif is zoned and composed of granodiorite, alkali feldspar granite, biotite granite and quartz syenite that have veins of aplite and tourmaline-bearing pegmatite. Alkali feldspar granite and quartz syenite predominate in the massif that intruded the MFV and the BMSGV. Alkali feldspar granite is porphyritic and is composed of phenocrysts of

potassium feldspar (35–45%), plagioclase (20–25%), quartz (20–40%), biotite (5%), hornblende (1–2%) and little muscovite. Accessory minerals are apatite, zircon, topaz, fluorite and tourmaline. Quartz syenite has transitional contact with other rocks, and consists of potassium feldspar (6–80%), plagioclase (8–30%), quartz (6–20%), and little biotite and muscovite. Accessory minerals are apatite, zircon, topaz, fluorite and tourmaline. The vein rocks are very leucocratic and composed mainly of quartz, potassium feldspar, plagioclase and little biotite. Accessory minerals are apatite, zircon, topaz, fluorite and tourmaline.

Trinang gabbroic massif and a series of small-sized gabbro and gabbro-peridotite massifs distributed along Songam fault from Thuongxuan to Nameo belong to NCMUM. The NCMUM comprises fine-grained, massive, weakly laminated gabbro, gabbroic pegmatite, gabbroic diorite, gabbroic diabase, diabase, and some serpen-

tinized peridotite bodies. Trinang massif is a lenticular body covering an area of about 45 km² and is composed of plagioclase (40–42%), pyroxene (55–56%) and amphibole (1–2%). Accessory minerals are apatite, sphene, and ore minerals. Trung et al. (2006) represent the serpentinite body and its related gabbroic rocks as a remnant of paleo-oceanic lithosphere between the Indochina and South China blocks based on their petrological and geochemical studies.

DFV occurs usually interbedded with DTF marine sediments (Middle Triassic). The DFV-DTF sequence occupies almost all the area of the SNDZ. The DFV/DTF ratio in the sequence is about 0.2. The DFV is composed of porphyritic rhyolites, quartz-rhyodacite, dacite and light grey felsite. The volcanic rocks include acidic tuffs of up to 10 m thick. Weakly chloritized biotite and occasionally amphibole are present.

MFV is intruded by BMSVG and unconformably

Table 1. Rb-Sr isotopic data of the igneous rocks in the Samnua depression zone in Northern Vietnam

Rock	Sample No.	Rb (ppm)	Sr (ppm)	⁸⁷ Sr/ ⁸⁶ Sr	⁸⁷ Rb/ ⁸⁶ Sr (2 σ)	(⁸⁷ Sr/ ⁸⁶ Sr) _i	Ages (Ma)
Plutonic Rocks							
SMG	ML110	140.0195	264.8348	0.7179	2.0615 (1)	0.7121	213 ± 10
	ML2190	155.6407	225.603	0.7204	2.6901 (1)		
	ML3230/1	214.8743	251.8766	0.7221	3.3091 (1)		
	ML3221	180.0634	113.5616	0.7314	6.1654 (1)		
	ML3278/1	341.9849	81.2453	0.7615	16.386 (1)		
PBG	ML297/1	15.183	193.0115	0.7265	0.1792 (1)	0.7259	203 ± 5
	ML3434/8	17.8475	179.0286	0.7267	0.2322(1)		
	ML3829	26.065	223.2018	0.7268	0.2661(1)		
	ML2822/4	33.9615	196.0986	0.7269	0.3268(1)		
	ML3827/5A	47.6549	238.3305	0.7272	0.4102(1)		
BMSVG	ML187	150.5186	218.491	0.7309	2.6827 (1)	0.7257	138 ± 5
	ML2667	110.1601	149.079	0.7316	2.8774 (1)		
	ML2808	184.4866	197.5735	0.7331	3.6299 (1)		
	ML123	118.9507	118.4402	0.7335	3.9067 (1)		
	ML3591/1	222.4911	187.7435	0.7348	4.841 (1)		
	ML322	312.4447	132.9562	0.7438	9.1343 (1)		
NCMUM	ML5315	15.7428	340.7893	0.7067	0.0799 (1)	0.7065	222 ± 10
	ML5246	16.2583	243.094	0.707	0.1903 (1)		
	ML5320	6.5803	96.2418	0.7068	0.1114 (1)		
	ML5288	16.2096	193.4676	0.7067	0.0966 (1)		
	ML80	13.7292	133.5818	0.707	0.1815 (1)		
Volcanic Rocks							
DFV	ML2187	244.1427	129.293	0.7238	2.256 (1)	0.7151	218 ± 10
	ML24	342.7517	117.843	0.7357	6.6042 (1)		
	ML2345	134.2722	232.1675	0.7346	6.1842 (1)		
	ML340	198.3252	127.23	0.7376	7.3375 (1)		
	ML3251	264.7344	166.9842	0.7502	11.3364 (1)		
MFV	MX5288	218.8672	184.1266	0.7342	4.5734 (1)	0.7227	186 ± 5
	MX5286	216.678	127.0985	0.7411	6.6044 (1)		
	MX5289	237.0839	134.9514	0.7416	6.7753 (1)		
	MX5284	258.8811	99.5111	0.7481	10.1202 (1)		
	MX5328	337.1441	61.904	0.7791	21.1865 (1)		

The analyses were carried out at CGAEV (see text).

Figure 3. Rb-Sr isochron diagram of the igneous rocks from the Samnua depression zone in Northern Vietnam.

Table 2. K-Ar age data of biotites from the igneous rocks in the Samnua depression zone in Northern Vietnam

Rock	Sample No	Analysed sample	Potassium (wt%)	$^{40}\text{Ar}/^{40}\text{K}$ (atm.ratio)	K-Ar Age (Ma)(recalculated)
PBG	NT12/1	Biotite	5.73	0.0112	192
PBG	NT 2280/4	Biotite	6.38	0.0106	173
PBG	18851/1	Biotite	4.9	0.0115	187
BMSVG	AT7	Biotite	7.08	0.0106	173
BMSVG	BM542/2	Biotite	6.88	0.0103	168
BCG	BT26	Biotite	6.72	0.00194	33
BCG	8954/2	Biotite	4.66	0.0017	29
BCG	FL13	Biotite	4.32	0.0016	27

These rocks were dated at VSEGEI (see text).

overlies the rocks aged Triassic. Felsic effusives constitute 80–85% of MFV by volume, and alternate with conglomerate, sandstone, and siltstone layers in the MHF. In Sopsanh area, MFV occurs as a large mass that comprises massive dacites and rhyolites of greyish blue to pale grey color. Some effusive rhyolites are porphyritic and contain phenocrysts of quartz, K-feldspar, plagioclase and little biotite. Accessory minerals are zircon and magnetite.

CBR is exposed to the north of Nghiadan and Nongcong as a 30 to 50 m thick flat lava sheet. Dense fresh basalt of ash-grey color occurs in the lower part of the CBR. The upper part consists of porous frothy basalt, which has been weathered in the upper most part into laterite or spongy brown-grey basalt.

GEOCHRONOLOGY LABORATORIES AND THEIR ANALYTICAL METHODS

Rb and Sr elemental and isotope analyses of the rocks were performed with a mass spectrometer VG Sector with nine Faraday cups at the Center for Geological Analysis and Experiment of Vietnam (CGAEV). Rb-Sr isochron

age and initial Sr isotope ratios were calculated by the method of York (1966), using the decay constant of $\lambda^{87}\text{Rb} = 1.42 \times 10^{-11}/\text{y}$ (Steiger and Jäger, 1977). K-Ar analyses of minerals were carried out at two laboratories. One is All Russia Geological Research Institute (VSEGEI) of Ministry of Natural Resources of the Russian Federation and another is Research Institute of Natural Sciences (RINS) of Okayama University of Science in Japan. The rock samples were sent to the CGAEV for the Rb-Sr analysis and the mineral samples to the VSEGEI for K-Ar analyses. The K-Ar analytical method at RINS has been reported by Nagao et al. (1984) and Itaya et al. (1991, 1996) and then is described below.

The granitic rock samples (SMG, PBG and BCG) were crushed with a jaw crusher and then sieved. Biotites were separated from the 80–100 or 100–150 mesh size fractions of the samples. The basaltic rock (CBR) was cut with a diamond saw into thin (5 mm) slices, to check for freshness and to eliminate coarse-grained phenocrysts and any xenoliths and then ground with an agate mortar. The 60–100 and 100–200 mesh size fractions were separated using fresh nylon-sieve cloth, washed with distilled

Table 3. K-Ar age data of biotites from the igneous rocks in the Samnua depression zone in Northern Vietnam

Rock	Sample No	Analysed material	Size (mesh)	Potassium (wt%)	Radiogenic ^{40}Ar (10-8ccSTP/g)	K-Ar age (Ma)	Non-radiogenic Ar (%)
SMG	SMG100/150	Biotite	100-150	2.81 ± 0.06	2952.9 ± 28.4	252.6 ± 5.2	2.6
PBG	PBG100/150	Biotite	100-150	6.38 ± 0.13	6260.9 ± 59.7	236.6 ± 4.9	1.4
BCG	TRU04B6-8	Biotite	60-80	7.51 ± 0.15	709.6 ± 0.9	24.2 ± 0.6	9.8
BCG	TRU04B8-10	Biotite	80-100	7.30 ± 0.15	817.3 ± 0.9	24.7 ± 0.6	13.6
CBR	QBE120/200	nmf	120-200	0.65 ± 0.01	4.8 ± 0.2	1.88 ± 0.1	66.9
CBR	QBE60/100	nmf	60-100	0.66 ± 0.01	5.0 ± 0.2	1.95 ± 0.1	57.1

These rocks were dated at RINS (see text).

The analyzed material "nmf" of the CBR shows the nonmagnetic fraction from the basalts (see text).

Table 4. Compilation of ages of the igneous rocks from the Samnua depression zone in Northern Vietnam

	Rb-Sr age	K-Ar age (VSEGEI)	K-Ar age (RINS)	Fossil age
Plutonic Rocks				
SMG	213 ± 10		252.6 ± 5.2	
PBG	203 ± 5	173-192	236.6 ± 4.9	
BMSVG	138 ± 5	168-173		
BCG	$27 \pm 1^*$	27-33	24.5 ± 0.6	
NCMUM	222 ± 10			
Volcanic Rocks				
DFV	218 ± 10			Anisian Mollusca 240-233
MFV	186 ± 5			
CBR	5.8^{**}		1.92 ± 0.1	

Rb-Sr ages of BCG and CBR are after Minh et al. (1991) and Hoang (1996), respectively.

Fossil data are after Bach et al. (1996).

water, and oven dried. Magnetic materials were removed from the fractions using a Nd hand magnet and then the fractions free of magnetic material were used for the age dating.

Analyses of potassium and argon in the biotite separates and the fraction from basalt, and the calculations of ages and errors were carried out using the method described by Nagao et al. (1984) and Itaya et al. (1991). Potassium was analyzed by Atomic Absorption spectrometry using a 2000 ppm Cs buffer. The method has an analytical error within 2% at 2-sigma confidence level. Argon was analyzed on a 15 cm radius sector-type mass spectrometer with a single collector system using an isotopic dilution method and the argon-38 spike (Itaya et al., 1991). Multiple runs of a standard (JG-1 biotite, 91 Ma) indicate that the error of argon analysis is about 1% at the 2-sigma confidence level. The decay constants (Steiger and Jäger, 1977) for ^{40}K to ^{40}Ar and ^{40}Ca , and the ^{40}K content in potassium used in the age calculation are $0.581 \times 10^{-10}/\text{y}$, $4.962 \times 10^{-10}/\text{y}$, and 0.0001167, respectively.

AGE RESULTS AND DISCUSSION

Rb-Sr whole rock analytical data are given in Table 1 and their isochron diagram are shown in Figure 3. K-Ar biotite age data analyzed at VSEGEI and RINS are presented in Tables 2 and 3, respectively. Compiled age data for the igneous rocks are shown in Table 4. The Rb-Sr whole rock isochron ages give 222 Ma for the NCMUM, 213 Ma for the SMG, 203 Ma for the PBG, 138 Ma for the BMSVG, 27 Ma for the BCG, 218 Ma for the DFV, 186 Ma for the MFV and 5.8 Ma for the CBR. The K-Ar biotite ages obtained in RINS give 252 Ma for the SMG, 237 Ma for the PBG, and 24 Ma for the BCG. The ground-mass fraction of the CBR yields an age of 1.9 Ma. The age data show that the Rb-Sr whole rock isochron ages are relatively younger than the K-Ar biotite ages (RINS) for the same rock type, except for the Rb-Sr whole rock isochron ages of the BCG and CBR, which are older than the corresponding K-Ar ages. DFV is interbedded with DTF, which contains Anisian mollusks (Bach et al., 1996), indicating that the sediments were 240-233 Ma old according to the geological time scale by Odin (1994). The geochronological comparison suggests that the Rb-Sr whole rock isochron ages of Mesozoic igneous rocks provide apparently younger ages. The BMSVG, in particular, gives a pseudo isochron age (138 Ma) because its K-Ar biotite ages by VSEGE are 168-173 Ma. Thus, the major igneous activity of the SNDZ took place during Late Permian-Triassic time to form granitic and felsic volcanic rocks.

Trung et al. (2006) found relict chromian spinel having $\text{Cr}/(\text{Cr} + \text{Al})$ atomic ratio = 0.43-0.44 and olivine inclusions in the Honvang serpentinite body of NCMUM and defined the composition characteristics of the primary minerals in the ultramafic rocks. The inferred original peridotite was lherzolite harzburgite of the type that forms in an environment with a low degree of melt depletion in slow-spreading ocean floor or rift. The gabbro associated with the Honvang serpentinite body has MORB-like geochemical features, suggesting that the Honvang serpentinite body and associated gabbro represent a remnant of

paleo-oceanic lithosphere between the Indochina and South China blocks. This means that the NCMUM was formed when the paleo-oceanic lithosphere accreted into the northern edge of the Indochina block. The Late Permian-Triassic granitic and felsic volcanic rocks seem to have formed at a typical continental volcanic arc setting, based on the petrographical analyses mentioned above. It follows that the active subduction of the oceanic lithosphere occurred under the northern edge of the Indochina block during the Late Permian-Triassic time. BCG is similar to the rocks derived from a high-potassic magma in northwestern Yunnan and northern Vietnam (Chung et al., 1997; Lan et al., 2000) and is considered to belong to igneous activity within the plate. The typical intraplate alkaline basalts including CBR in the SNDZ erupted in the Pliocene (Hoang, 1996). This suggests that the paleo-ocean between the Indochina and South China blocks had already closed before the 24 Ma old BCG magmatism and that the tectonic environment of the SNDZ changed from a convergent plate margin to a matured continental margin in the time span between the Triassic and Neogene.

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