VNU Journal of Science, Earth Sciences 23 (2007) 69-75

Late Eocene metamorphism and ductile deformation age of Con Voi range, the Red River shear zone: evidence from the garnet Sm/Nd dating

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Received 26 January 2007

Abstract. Con Voi range in Vietnam was a southeastward continuity of the Red River Ailaoshan tertiary shear zone, a boundary between Indochina and south China blocks during the southeastward extrusion of Indochina block. It composed of high grade metamorphic and strongly deformed rocks with various protoliths. The foliation and schistosity folded to produce a large antiform structure during the late phase of ductile deformation and exhumation. Together with the Ailaoshan, Diancangshan, Con Voi range suffered from an intensively sheared and metamorphosed during the collision of Indian with Eurasian plates. The published radiochronological data indicated that the cooling age took place from 28 to 17 m.y. (millions years). Those data did not reflect the timing of peak metamorphic event and associated ductile deformation. New Sm/Nd isochron age on single garnet extracted from biotite-garnet-silimanite bearing gneiss rock within Con Voi range evidenced that the timing of metamorphic culmination and ductile deformation occurred as early as c.a 36 m.y. ago. This implied that the earliest stage of deformation along the Red River-Ailaoshan shear zone could be at least absorbed partially by the opening of Bac Bo basin.

Keywords: Red River shear; Sm/Nd age; Late Eocene; Metamorphism; Deformation.

1. Introduction

Con Voi range, bounded northeastward by Song Chay fault and southwestward by Song Hong fault, was a continuity of the Ailao Shan Red River shear zone which extended approximately 1000km from syntaxis to the Eastern Sea of Vietnam . This shear zone was considered as a boundary between the Indochina block and south China one in Tertiary. It was a narrow zone of amphibolitic-facies gneiss and mylonite which accommodated the left lateral ductile deformation and southeastward extrusion of the Indochina block during the India-Eurasia collision [1, 2]. At present day, the Ailao Shan-Red River shear zone is accommodating the southeastward motion of the South China block. The onset of the shift from the left to the right sense of motion along the present shear zone was constrained at Pliocene [2, 3]. Along and within the shear zone, magmatism associated with the high-grade metamorphism and ductile deformation [2, 4-9]. Partial melts in the Red River shear zone coeval with ductile deformation yielded an age

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varying from 27 to 22 millions years (m.y.) [5]. Pressure-temperature studies show that left lateral shear occurred under the amphibolitic facies conditions which corresponded to the temperature and pressure varying from 550°C to 780°C and from 3kbar to 7kbar respectively [2]. Systematically radiochronological studies of the deformed and high metamorphic rocks inside the shear zone shown that the cooling age after climax of metamorphism yielded an age of 28 to 17 m.y. [7, 10-12]. However, zircons U/Pb dating for leucogranite provided only the age of melting event associated with high grade metamorphism, hence the minimum age of metamorphism, while Ar/Ar data of micas or amphiboles reflected only cooling ages of the metamorphism. The technique Th/Pb ion microprobe dating of monazite inclusions in garnets by Gilley [13] showed that the timing of amphibolitic-grade metamorphism and synchronous left-lateral shearing for the northern segments of the Ailao Shan Red River in Yunnan, China occurred between 34 and 21 m.y. Thus ages of metamorphism along the whole shear zone were dated on the basics of minerals that had a closure temperature lower than peak metamorphic temperature and/or not growth up during the metamorphic event.

The gneissic rocks that exposed along the Con Voi range contained of frequently reddish to pink garnets. These minerals were grown up during the metamorphism and left lateral strain. This mineral was not only useful for charactering the metamorphic conditions along the whole shear zone but also very suitable for constraining the time of metamorphism. In order to determine the age of Con Voi range metamorphic peak and deformed rocks, a single garnet was selected for Sm/Nd isotope analysis.

2. Tectonic setting and structural characteristics

Con Voi range was the southernmost segment of the Ailao Shan-Red River shear zone, an important plate boundary in Cenozoic in Southeast Asia. In North of Vietnam, it extended for over 200km from Lao Cai to Viet Tri in NW-SE direction while its width varied only from 10 to 20km. Actually, this range is bounded in the north by the Song Chay fault, in the south by the Song Hong fault. Along the Song Hong fault, small sedimentary basins have been formed during Late Miocene to Quaternary.

Con Voi range composed of predominantly paragneissic, partly mylonitic and migmatitic rocks. Inside the range intercalated several of mafic and ultramafic bodies or boudinages which were crystallized and emplaced at 490 m.y. ago [14]. Synkinematic partial melting produced small leucogranite bodies which were dated as old as 30-20 m.y. [4, 5]. The peak metamorphism occurred under the almandine-amphibolitic facies [2, 10] and probably granulite facies [15]. The range was affected by a strained schistosity and foliation delineated by alternation of rich felsic and dark minerals layers. Structural observations realized through the whole range along different cross sections indicated that the foliation was folded to create an antiformal structure. The stretching lineations were marked by the oriented minerals such as silimanites or elongated feldspars, quartz or twisted phylosilicates. Despite of the variation of foliation dip angle, the lineation was constantly orientated in NW-SE direction with the plunge varied from 0 to 20°. All kinematic indicators indicated predominantly sinistral shear sense at various scale from regional to thin section one.

3. Petrological features of gneiss and kinematics of ductile deformation

Analysis of thin section of gneiss samples taken from the Con Voi range evidenced the existence of two parageneses which developed during the deformation and metamorphism.

The first paragenesis, which was typical for main rocks, was characterized by biotite + garnet + silimanite + quartz + feldspar that corresponded to the amphibolitic facies (Fig. 1). The second one developed mostly within the pressure shadow of porphyroblast of the first paragenesis. In some other cases, it was crystallized within fractures. This paragenesis was characterized by minerals: muscovite + biotite + chlorite, a typical assemblage for green schist facies.

The stretching lineation defined by silimanite and porphyroclast of feldspars or deformed quartz of the first paragenesis oriented in the same direction of extensional fractures in which the minerals of second paragenesis grown up. In many cases, silimanites and garnets suffered from a brittle deformation to produce boudinage structure. The space between boudinages was also filled up by the muscovite, biotite and chlorite of the second assemblage of minerals.

Stretching lineation defined by minerals of two parageneses had the same direction. The different criteria of shears recorded by the minerals of the first paragenesis indicated a left lateral motion. The secondary minerals crystallized within the pressure shadow of the main minerals of the first paragenesis also indicated a sinistral shears. The rotation of garnet in some cases was also compatible with the left lateral shear. Consequently, the similarity of the shear sense recorded by two parageneses, observed at different scales from thin section to outcrops implied a retrograde evolution of metamorphism and ductile deformation.

4. Samples description

To constrain the age of highly ductile deformation and metamorphism of the gneissic rocks along the Con Voi range, sample VNSH14-2 was selected for garnet Sm/Nd dating. It was taken at a quarry located about 30 km on the right side of the road N70 from Yen Bai to Lao Cai. The coordinates of the sample were 21° 47′ 54.3″ and 104° 54′ 45.1″ in WGS-84 coordinate system (see Fig. 2 for sample location). Two kinds of rocks were

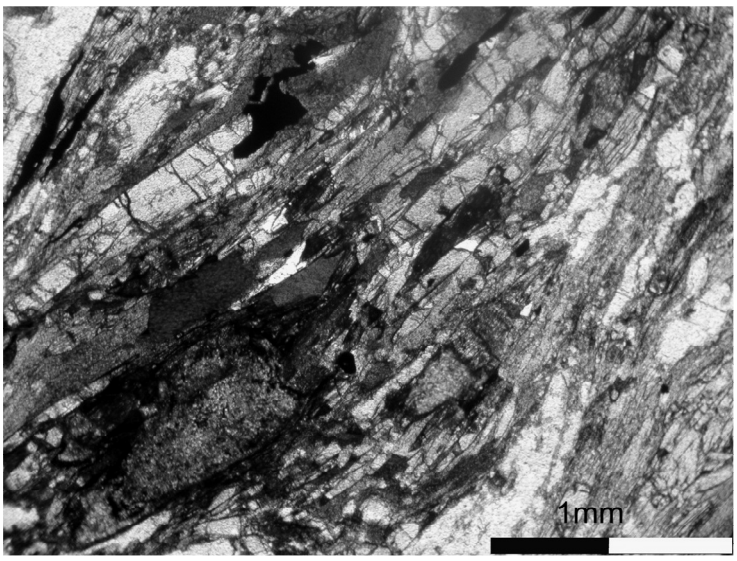

Fig. 1. Thin section photograph illustrated parageneses of paragneissic rocks from Con Voi range.

observed in this outcrop. A folded ultramafic body with the axial plan was parallel to the foliation of the gneiss country rocks. The sample VNSH14-2 was characterized by a mineral assemblage composing of biotite, garnet (almandine), silimanite, quartz, feldspar while apatite and zircon dominated in accessory minerals and by a schistosity coupled with lineation fabric.

5. Analytical method

5.1. Single mineral separation

A fresh hand sample of about 1.5 kg was cleaned, crushed and pulverized to 250 micrometer. Light minerals such quartz, feldspars, biotite were separated from heavy one like garnet, silimanite by Whilfley vibrate table. The heavy minerals then were put into Franz dynamic magnetic separator for selection garnets. Single mineral of garnets then was carefully observed and picked under binocular. Only very high transparency free inclusion as well as cracks and euhedral garnets were selected to digest with chemical agents. Feldspars fragments were also selected to analyze. Whole rock powder was obtained by crushing in ball grinder. The elimination of dusts, carbonate and sulfur film were made with HCl and HNO_3 and ultrasonic tank within one hour.

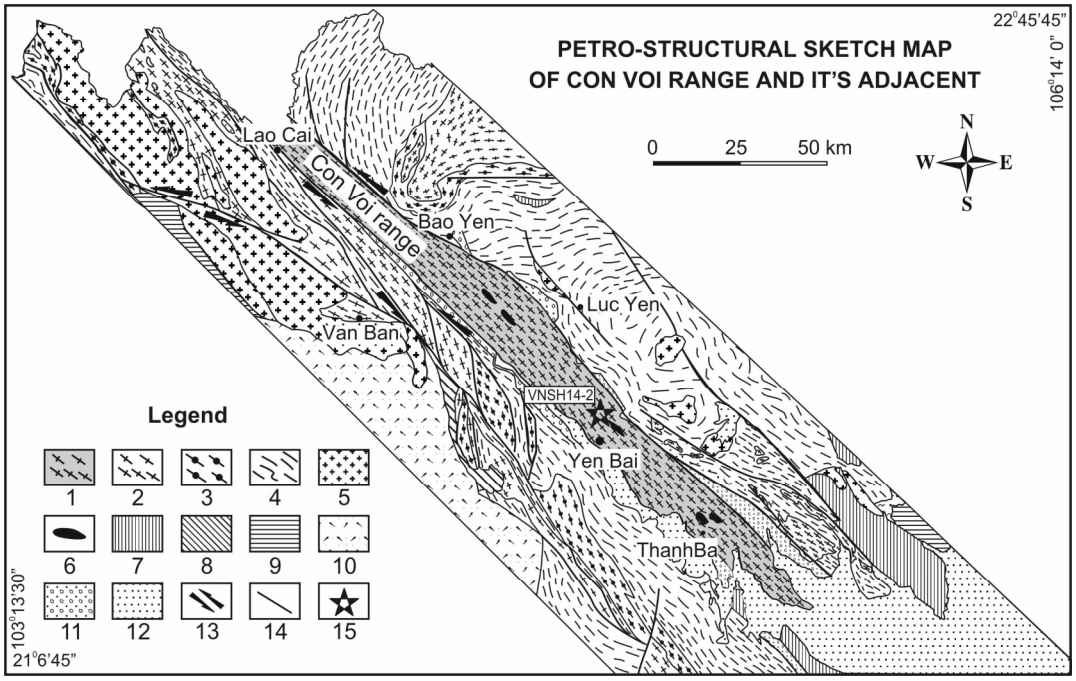

Fig. 2. Petro-structural sketch map of Con Voi range and sample location.

1- Late Eocene-Miocene metamorphic rocks of Con Voi range; 2- Triassic to Miocene metamorphic rocks; 3- Unknown age metamorphic rocks; 4- PZ weak metamorphic rocks; 5- Granites; 6- Ultramafic and mafic rocks; 7- Early-Middle Triassic terrigenous clastic and carbonate rocks; 8- Late Triassic coal bearing sedimentary rocks; 9- Jurassic-Cretaceous detrial sedimentary rocks; 10- Jurassic-Cretaceous volcanic rocks; 11- Neogene coarse grained size sediments; 12- Quaternary sediments; 13- Oligocene-Miocene sinistral shear zone; 14- Faults; 15- Sample location.

5.2. Sm and Nd separation

Garnet, whole-rock (WR) powders, feldspars were spiked with mixed ^{149}Sm-^{150}Nd tracer and dissolved in Teflon vial using an HF-HNO_3-$HCLO_4$ mixture and 6N HCl until complete material dissolution. Column procedures used cationic AG-50W-X8 (200-400 mesh) resin in order to separate rare earth elements (REE), followed by Sm and Nd separation using anionic polyteflon HDEHP LN-B50-A (100-200μm) resin. Nd and Sm were separated from the solution by 0.18 and 0.5N HCl respectively.

5.3. Isotopic ratio measurement

$^{143}Nd/^{144}Nd$ and $^{147}Sm/^{144}Nd$ ratios were measured on Finigan 262 thermal ionization multi collectors mass spectrometer under standard operation at Goettingen University. Sm and Nd were loaded as phosphate on pre-conditioned Re filaments and measurements were performed in a Re double filament configuration. La Jolla standard was performed during the course of measurement. The error of standard was not in excess of 0.003% and 0.05% for $^{143}Nd/^{144}Nd$ and $^{147}Sm/^{144}Nd$ respectively. All measured rations were normalized to $^{146}Nd/^{144}Nd$ =0.7219. Correction for blank was insignificant for Nd isotopic compositions and generally insignificant for Sm/Nd ratios. Neodymium model ages (T_{DM}) were calculated following the depleted mantle model of De Paolo [16].

The analytical results were reduced and treated by using Ludwig's program ISOPLOT 2.49.

6. Analytical results

The isotopic ratio and concentration of Sm and Nd are given in Table 1. The isochon age of garnet and whole rock was calculated and displayed in Fig. 3. In this diagram, the isotopic ratio of plagioclase was kicked out due to the very low concentration of Sm.

7. Discussion and conclusion

The peak metamorphism of the Con Voi range occurred at around 690°C and 0.65GPa [10] of amphibolitic facies. This P-T calculation was performed on the minerals corresponding to the first paragenesis observed in this study. In fact, no minerals, except for the zircon, had the closure temperature higher than the temperature at which the metamorphism of Con Voi range culminated. Although the zircon had very high closure temperature but the direct link to the metamorphism and ductile deformation lacked. Therefore, the interpretation of the zircon age for metamorphism and interfoliation leucogranite strongly depended on the structural relation of the samples and country rocks and also on the thermal history in which the rock itself experienced. All other radioactive dating methods applied for any mineral extracted from the first paragenesis indicated only the cooling age after culmination of the metamorphism and associated ductile deformation. Hence, timing of peak metamorphism hardly deduced.

Together with biotite, garnet was always used to calculate the P-T condition of metamorphism and ductile deformation. Therefore such result often reflected its culmination. However, due to the low closure temperature of biotite in comparison with garnet and metamorphic peak temperature, the age obtained on biotite was effectively younger than the real age of metamorphism. Consequently the timing of thermotectonic event could not be determined on biotite or other micas except mineral having the closure temperature as high as the one at which the peak metamorphism occurred. In case of metamorphic and sheared

Table 1. Isotope ratio and concentration of Nd, Sm of analyzed samples

Minerals	Sm (ppm)	Nd (ppm)	$^{147}Sm/^{144}Nd$	2SE Error (abs)	$^{143}Nd/^{144}Nd$	2SE Error (abs)
Garnet	3.247	5.540	0.354256260	0.001771281	0.511859746	0.000005288
WR	8.043	46.340	0.104908211	0.000524541	0.511801401	0.000007964
Plagioclase	0.424	2.647	0.096874579	0.000484373	0.511801152	0.000008356

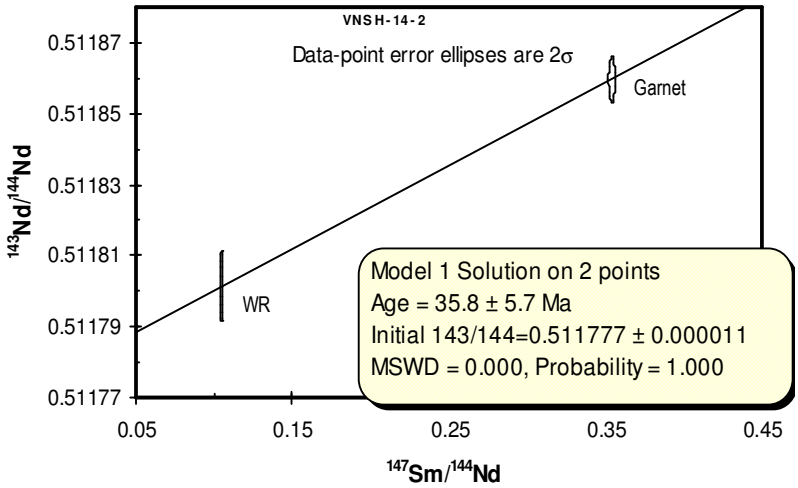

Fig. 3. Mineral isochron computed based on two point garnet and WR.

paragneissic rocks of Con Voi range, only garnet was suitable to obtain the age we expected. It was accepted that the closure temperature of garnet for Sm/Nd isotopic system was over 680°C event up to 750°C [17]. Therefore, the age of 35.6 m.y. obtained on garnet crystal in this work reflected timing of cooling down to under the garnet closure temperature for Sm/Nd isotopic system. The peak temperature of metamorphism and ductile deformation of paragneiss coincided with garnet closure temperature so that the age of 35.6 m.y. recorded timing of metamorphic culmination. This new result, together with previous data [2, 6, 7, 11-13] suggested that the metamorphism and ductile deformation of Con Voi range began as early as 36 m.y. ago. Taking in to account the late Miocene-Oligocene basal strata in the Bac Bo basin, this result also revealed the temporal and could be genetic links between the earliest stage of deformation along the Red River Ailao Shan shear zone with the opening of Bac Bo basin.

The initial ratio 143/144Nd = 0.511777 and ε_{Nd} = -15.44 suggested that the main components of those metamorphic rocks originated from the sedimentary crust with out or less contamination with the mantle materials. The model age T_{DM}=1880 m.y. calculated from the isochron suggested that the provenance of metamorphic rocks of Con Voi range might derive from the Proterozoic sedimentary rocks.

Acknowledgements

The author is indebted Prof. Bent Hansen and Dr. Klaus Wemmer who gave all favorable conditions to access the analytical facilities at GZG of Goettingen University. This work

would not be done without their valuable support.

This paper is completed with the support of the Vietnam Fundamental Research Program in Natural Sciences, the author would like to thank the Council of Natural Sciences.

References

[1] P. Tapponnier et al., The Ailao Shan/Red River metamorphic belt: Tertiary left lateral shear between Indochina and South China, *Nature* 343 (1990) 431.

[2] P.H. Leloup et al., The Ailao Shan-Red River shear zone (Yunnan China), Tertiary transform boundary of Indochina, *Tectonophysics* 251 (1995) 3.

[3] C. Rangin et al., The Red River fault system in the Tonkin Gulf, Vietnam, *Tectonohysics* 243 (1995) 209.

[4] U. Schaerer et al., Intraplate tectonics in Asia: Aprecise age for large-scale Miocene movement along the Ailao Shan-Red River shear zone, China, *Earth and Planetary Science Letters* 97 (1990) 65.

[5] U. Schaerer, L.S. Zhang, and P. Tapponnier, Duration of strike-slip movements in large shear zones: the Red River belt, China, *Earth and Planetary Science Letters*, 126 (1994) 379.

[6] T.M. Harrison et al., An Early Miocene transition in deformation regime within the Red River Fault zone, Yunnan, and its significance for Indo-Asian tectonics, *Journal of Geophysical Research* 97/B5 (1992) 7159.

[7] T.M. Harrison et al., Diachronous initiation of transtension along the Ailao Shan-Red River shear zone, Yunnan and Vietnam, in *The tectonic evolution of Asia* Ed.: A. Yin and T.M. Harrison (1996) 208.

[8] P.H. Leloup, J.R. Kienast, High temperature metamorphism in a major strike-slip shear zone: the Ailao Shan-Red River (P.R.C.), *Earth and Planetary Science Letters* 118 (1993) 213.

[9] S.L. Chung et al., Intraplate extension prior to continental extrusion along the Ailao Shan-Red River shear zone, *Geology* 4/25 (1997) 311.

[10] T.N. Nam, M. Toriumi, T. Itaya, P-T-t paths and post-metamorphic exhumation of the Day Nui Con Voi shear zone in Vietnam, *Tectonophysics* 290 (1998) 299.

[11] P.L. Wang et al., Thermochronological evidence for the movement of the Ailao Shan-Red River shear zone; a perspective from Vietnam, *Geology* 10/26 (1998) 887.

[12] P.L. Wang et al., Onset of the movement along the Ailao Shan-Red River shear zone: Constraint from $^{40}Ar/^{39}Ar$ dating results for Nam Dinh Area, northern Vietnam, *Journal of Asian Earth Sciences* 18 (2000) 85.

[13] L.D. Gilley et al., Direct dating of left-lateral deformation along the Red River shear zone, China and Vietnam, *Journal of Geophys. Res.* 108/B2 (2003) 2127.

[14] N.V. Vuong et al., Sm/Nd mineral isochron age of ultramafic rock within the tertiary Red River shear zone and its geodynamic signification, *Journal of Earth Sciences* 2/27 (2005) 97 (in Vietnamese).

[15] T.T. Thang, T.T. Anh, New mineralogical evidence of granulite facies in Red River metamorphic belt, *Journal of Earth Sciences* 4/22 (2000) 410 (in Vietnamese).

[16] D.J. De Paolo, Neodymium isotopes in the Colorado Front Range and implications for crust formation and mantle evolution in the Proterozoic, *Nature* 291 (1981) 193.

[17] K. Mezger, E.J. Essene, A.N. Halliday, Closure temperature of the Sm-Nd system in metamorphic garnets, *Earth and Planetary Science Letters* 113 (1992) 397.