Understanding Mesozoic accretion in Southeast Asia: Significance of Triassic thermotectonism (Indosinian orogeny) in Vietnam

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ABSTRACT

Results from a zircon U-Pb study of the metamorphic basement of Vietnam reveal that a large part of the continental crust was affected by a short-lived episode of ductile deformation and high-temperature metamorphism between 258 ± 6 Ma and 243 ± 5 Ma. Although coincident with final stages of North-South China collision (Qinling orogenesis), the thermotectonism in Vietnam was caused by accretion of Sibumasu to Indochina–South China. This accretion event (Indosinian orogeny) has regional significance because it contributed to the final stages of North-South China collision, an aspect not explicitly recognized in Qinling orogenic models.

Keywords: Vietnam, Qinling orogenic belt, Indosinian, U-Pb zircon ages.

INTRODUCTION

Continental Southeast Asia comprises a number of discrete terranes that amalgamated during the Mesozoic after rifting and separation from Gondwana (Fig. 1). The most significant collision, between the Yangtze (South China) and Sino-Korean (North China) blocks, formed the 2000-km-long Qinling orogenic belt that dominates present-day central China. The sequence of terrane accretion in Southeast Asia is well defined (Metcalfe, 1999), but precise amalgamation histories (timing and nature of convergence) are less well known due to the paucity of detailed local geological information. Thus, while there is growing acceptance of a Triassic age for final stages of North-South China collision (Meng and Zhang, 1999, 2000), it is unclear what role (if any) other terrane accretionary events (Indochina, Qimdao-Simao, Sibumasu-Qiantang terranes of the Cimmerian continent) had on Qinling orogenesis. In this context we consider the origin and significance of a Triassic age, high-temperature metamorphic event in Indochina.

A Triassic event was first recognized in Vietnam, where it is referred to as the Indosinian orogeny (Deprat, 1914; Fromaget, 1932). Considered to relate to continental collision between Indochina and South China blocks, its regional significance in terms of continental convergence has been questioned. In southwestern China there is little evidence for Triassic age compressional deformation or angular unconformities (Tapponnier et al., 1990; Shärer et al., 1994; Leloup et al., 1995; Lacassin et al., 1998). Recent argon dating of metamorphic basement in Vietnam, including blocks adjacent to the Day Nui Con Voi (Maluski et al., 1999; Lan et al., 2000), Truong Son belt (Lepvrier et al., 1997), and Kontum district of central Vietnam (Lo et al., 1999), recorded Indosinian metamorphism ca. 245 Ma. This coincides with the final stage of North-South China collision and peak high-grade metamorphism in the Dabie Shan region of the Qinling belt and implies that these events are related (Hacker et al., 1998; Meng and Zhang, 2000).

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ZIRCON U-Pb DATING

To assess the extent of crustal reworking during Triassic thermotectonism, rock samples for zircon U-Pb dating were collected from metamorphic basement across Vietnam. Zircon analyses were performed on SHRIMP II at Curtin University of Technology, Perth (Kennedy and de Laeter, 1994), using cathode luminescence images of sectioned zircon to target specific sites within the crystal structure and discriminate between various growth stages and to identify inherited cores. Sample locations are shown in Figure 2, and the results are summarized in Table 1 and Figure 3.[1]

[1]GSA Data Repository item 200122, Individual sample concordia plots, is available from Documents Secretary, GSA, P.O. Box 9140, Boulder, CO 80301-9140, editing@geosociety.org, or at www.geosociety.org/pubs/ft2001.htm.

The most northern samples come from metamorphic massifs located on either side of the Tertiary Day Nui Con Voi (Fig. 2). Orthogneiss VN01 from the Song Chay dome, in which argon dating recorded Triassic cooling ages (Leloup et al., 1995; Maluski et al., 1999), yielded a U-Pb formation age of 424 ± 6 Ma. On the western edge of the Day Nui Con Voi, in the pre-Mesozoic metamorphic belt, orthogneiss VN38 gave an age of 245 ± 5 Ma, similar to K-Ar biotite ages reported by Nam et al. (1998). Zircons from this sample have simple magmatic internal structures and show no evidence for inheritance or Pb loss.

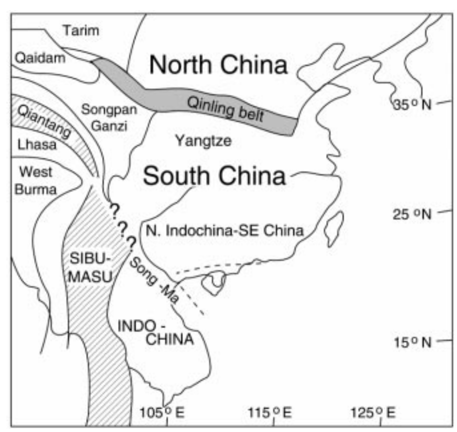

Figure 1. Principal continental terranes that form present-day Southeast Asia (after Metcalfe, 1999; Meng and Zhang, 1999). Shaded areas are Qinling orogenic belt (dark gray) and Sibumasu-Qiantang terrane (diagonal rule).

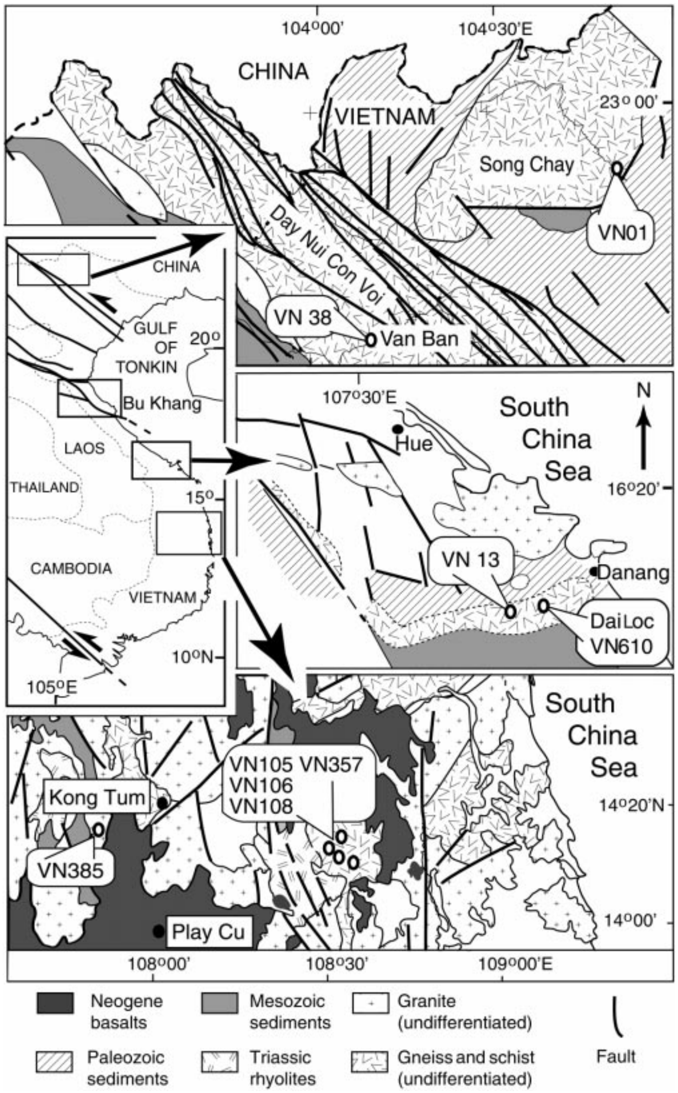

Figure 2. Location of U-Pb rock samples and their relationship to regional geology.

TABLE 1. ZIRCON U-Pb AGES

Sample Number	Protolith	Zircon U-Pb age (Ma) ±1 σ
VN 610	Gneiss	418 ± 8
VN 13	Gneiss	407 ± 11
VN 01	Gneiss	424 ± 6
VN 385	Gneiss	444 ± 17
VN 105	Gneiss	248 ± 6
VN 107	Gneiss	243 ± 5
VN 108	Migmatite	256 ± 6
VN 357	Charnockite	258 ± 6
VN 38	Orthogneiss	245 ± 5
VN 09	Gneiss	244 ± 7

Two metamorphic massifs were studied in the northern part of central Vietnam, at Bu Khang and Dai Loc. Sample VN09 from the shear zone bordering the Bu Khang dome recorded a U-Pb age of 244 ± 7 Ma. The common occurrence of inherited cores in this sample (ranging from ~600 Ma to 2541 ± 69 Ma) relates to the premetamorphic protolith. Two mylonitic orthogneiss samples were analyzed from the Dai Loc massif (Fig. 2). Zircon U-Pb gave Late Silurian ages of 407 ± 11 Ma (VN13), and 418 ± 8 Ma (VN610), in contrast to argon mica dating (Lepvrier et al., 1997), which recorded later cooling at 246 ± 1 Ma.

Samples VN385, VN357, VN105, VN107, and VN108 were collected from the Kontum massif in the Song Ba valley, north of Kannack in central Vietnam (Fig. 2). This metamorphic terrane, which comprises various granulite facies units including charnockite, has traditionally been regarded as Archean in age. The easternmost sample from this region (VN385) records a significantly younger age, 444 ± 17 Ma, similar to the results from Song Chay and Dai Loc.

The other samples from the Kontum district all record Triassic formation ages. Zircon cathodoluminscence shows simple oscillatory magmatic growth structures with no evidence for systematic inheritance or age variation. Sample VN357 showed some evidence for resorption but no age difference was observed between low-uranium (<100 ppm) rims and inner uranium rich (500–2500 ppm) cores. Th/U ratios (0.23–0.68) were also unaffected. Thus, resorption is considered a late-stage process in the formation of this sample, recorded at 258 ± 6 Ma.

INTERPRETATION

Late Ordovician–Silurian ages are characteristic of the Caledonian or Guangxi event recognized across Indochina, south China, and the Kitakami microplate of northeast Japan (Ehiro and Kanisawa, 1999; Wu, 1999). Although the precise origin of this regional event is still unclear, it most probably relates to an early extension event prior to Gondwana breakup.

Identification of Triassic formation ages in most of the studied metamorphic rocks testifies to the regional significance of this high-temperature event in Vietnam. In the Bu Khang massif, a previous study linked the pressure-temperature history to mid-Tertiary

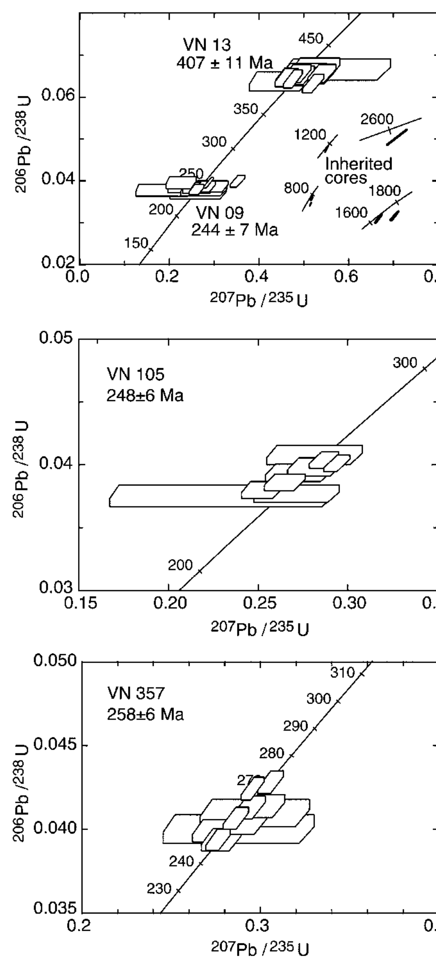

Figure 3. Representative U-Pb concordia diagrams.

exhumation (Jolivet et al., 1999), but it was unclear if primary metamorphism occurred at this time or much earlier. The zircon U-Pb results from this study show, unequivocally, that the high-pressure (11–12 kbar) stage is Triassic in age, and that it ended at 244 ± 7 Ma.

The Triassic U-Pb ages from the Kontum district are highly significant because they come from a region of Vietnam previously considered to represent Archean basement, primarily because of the high-temperature granulite facies and the common occurrence of charnockitic rocks (geothermobarometry suggests temperatures around 800 °C and pressures of 8 kbar). Hutchison (1989) referred to unpublished K-Ar ages of 1650–1800 Ma for the Kannack complex and 2300 Ma for the nearby Ngoc Linh complex. Phan (1991) reported a range of Archean to Proterozoic ages on the basis of K-Ar and U-Pb dating of the Kontum region, but no technical details were given on the dating methods used. These new results show that our understanding of the temporal framework of the Kontum block requires substantial revision.

Triassic K-Ar cooling ages (241 ± 5 Ma to 255 ± 5 Ma) obtained by Nam et al. (1998) on gneiss from the Kannak complex were interpreted as a metamorphic overprint. Similar ages were also reported in the $^{40}Ar/^{39}Ar$ study of Lo et al. (1999). The zircon U-Pb results obtained in this study are from the same locations, but their precise significance is unclear because their magmatic crystal growth can be explained in two different ways that impact their geological significance. If zircon crystallized from partial melt during an anatectic retrograde phase of granulite evolution, the ages will not record peak metamorphic *P-T* conditions. But, if the zircon crystallized under higher pressures at the time of rapid exhumation, the ages will be closer to the time of peak *P-T* conditions. Although current mineral paragenesis data are inconclusive for either scenario, the concordant U-Pb and published argon data clearly attest to rapid exhumation at or close to 243 ± 5 Ma.

SIGNIFICANCE OF TRIASSIC THERMOTECTONISM IN VIETNAM

Results from this study have confirmed that a large part of the continental crust of Vietnam was affected by an intense high-temperature event in Middle Triassic time. The studied samples came from basement terranes with broadly similar paragenesis that had undergone ductile deformation often in association with dextral shear zones (e.g., Jolivet et al., 1999; Lepvrier et al., 1997; Nam et al., 1998). These new U-Pb data, together with published argon results, show peak metamorphism and exhumation to upper (brittle) crustal levels occurred within a restricted time interval between 258 ± 6 Ma and 243 ± 5 Ma. This is broadly coincident with North China–South China and Sibumasu-Indochina collision and implies both events are related.

Discovery that the Truong Son ductile strike-slip zone was a Triassic structure led Lepvrier et al. (1997) to speculate on its cause and regional significance. It was considered that deformation could have been linked to Qinling-Dabie orogenesis, an oblique convergence between the Indosinian and South China plates, or a reactivation event following suturing of the Sibumasu terrain with the Indochina block. Deformation caused by collision between Indochina and South China could not have occurred in the Triassic because lithological, paleobiogeographic, and tectonic data show that these terranes were already in contact by middle Carboniferous time (Metcalfe, 1999). A relationship with accretion of South China–South Qinling to North China is temporally possible, given the multistage model recently proposed by Meng and Zhang (1999). However, during the early stages of this collision, Indochina was situated on the southern margin of the South China block, farthest away from the collision front (Fig. 4). Consequently, the only remaining event that could affect Indochina on the scale that we now observe is the accretion of Qiantang-Sibumasu to Indochina–South China.

The temporal history of the Qiantang-Sibumasu terrane is reasonably well documented (Metcalfe, 1999). Biogeographic affinities of floras and faunas show that Sibumasu remained attached to Gondwana until the Early Permian after which rifting and separation occurred (Metcalfe, 1996, 2000). Drift history was short-lived as the terrane passed from southern to northern paleolatitudes before docking with Indochina–South China during Late Permian–Early Triassic time (Fig. 4). Current models for Sibumasu-Indochina convergence appear contradictory. Evidence from the Bentong-Raub suture zone in Malaysia suggests paleo-Tethys was subducted beneath Indochina with collision in the Late Permian to Early Triassic (Metcalfe, 2000). In northern Thailand, evidence from the Nan Uttaradit suture and Sukhothai fold belt suggests that paleo-Tethys was subducted under eastern Sibumasu with Indochina forming a passive margin (Singharajwarapan and Berry, 2000). Timing of collision in this model is poorly defined, but within the Triassic. Late syn- to postkinematic granites provide an upper age limit of 200 Ma. U-Pb results from this study place a narrower time constraint on the main phase of collision, between 258 ± 6 Ma and 245 ± 3 Ma.

The apparently contradictory accretion models for Sibumasu-Indochina convergence are based on evidence from opposite ends of the suture zone. If both are correct they can only be reconciled if convergence between Sibumasu and Indochina was oblique. This makes sense when the configuration of the whole Cimmerian terrane is considered. Initial contact with Indochina–South China involved only the Sibumasu section of the Cimmerian continental strip. The western end (Qiantang terrane), which faced paleo-Tethys, was unconfined and continued to drift northward outpacing Sibumasu, which remained tied to Indochina–South China (Fig. 4). Such an arrangement would favor an oblique convergence, as advocated by Lepvrier et al. (1997)

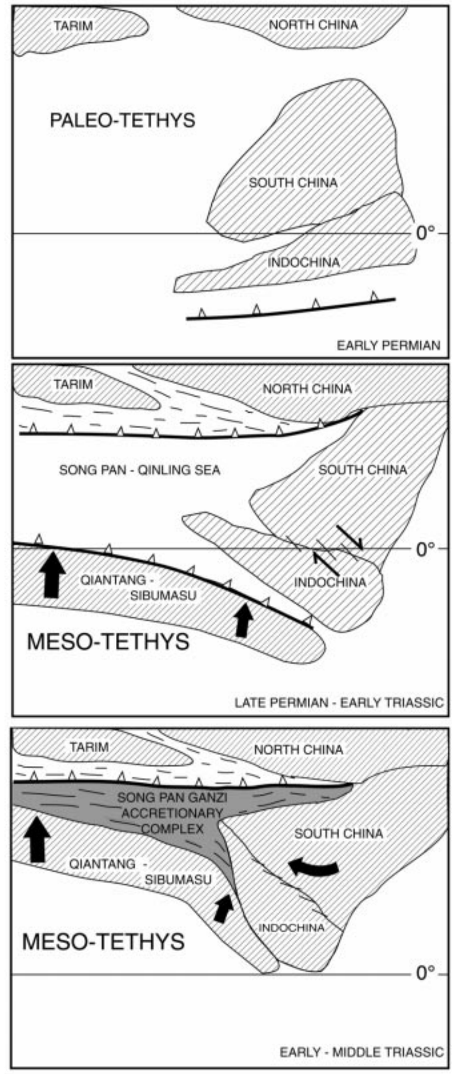

Figure 4. Paleogeographic model for Late Permian to Middle Triassic (adapted from Bruguier et al., 1997; Metcalfe, 1999, 2000). Collision between Qiantang-Sibumasu and Indochina–South China caused (or accelerated) rotation of South China–Indochina leading to closure of Song Pan Sea (paleo-Tethys) and final accretion between North and South China.

on the basis of ductile deformation in the Truong Son belt.

An oblique convergence helps to explain why there is little evidence for regional-scale Triassic age compressional deformation, although this could also be due to the paucity of structural data (the bulk of structural evidence from Vietnam relates to Tertiary tectonics). Few pre-Tertiary structures in Vietnam are well dated, although often a pervasive northwest-southeast trend can be linked to the Mesozoic. In the central region Rangin et al. (1995) identified northwest-southeast oriented pre-Tertiary faults that parallel the regional schistosity and pre-date late Mesozoic sediments. A similar structural orientation is evident in northern Vietnam (Lacassin et al., 1998). Argon and U-Pb dating (this study) in the Truong Son belt and Bu Khang massif provide the only direct evidence that links northwest–southeast trending structures to the Triassic.

At the time of the Sibumasu collision North and South China began to converge. Final amalgamation and Qinling orogenesis occurred in the Late Triassic through subduction and closure of the Song Pan Sea (eastern paleo-Tethys), as the Indochina–South China block rotated clockwise (Fig. 4). It is probable that rotation was either started or accelerated by convergence of Sibumasu. Initial docking led to Indochina becoming sandwiched between South China, causing a large part of the continental crust in Vietnam to undergo high-temperature metamorphism. This terminated at 243 $\pm$ 5 Ma with a regional rapid exhumation. Cause of the rapid exhumation is unclear but may be linked to changes in the regional stress field between initial stages of oblique convergence (transpression?) and rotation of the fully accreted Sibumasu-Indochina–South China terranes (transtension?). A robust model that fully explains Triassic thermotectonism in Vietnam requires further detailed kinematic and geochronological research. Nevertheless, this study has shown that the Indosinian event in Vietnam has regional importance because it constitutes an integral part of North-South China convergence history, which, so far, accretionary models have not explicitly recognized.

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