First evidence for Archean continental crust in northern Vietnam and its implications for crustal and tectonic evolution in Southeast Asia

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ABSTRACT

Southeast Asia, or, in a more strict sense, the Indochinese continent, was previously considered to be composed entirely of Proterozoic to Phanerozoic rocks, and reliable evidence for Archean crust was lacking. Gneisses from the Cavinh Complex, south of the Red River shear zone, northern Vietnam, however, show Archean Nd model ages of 3.4–3.1 Ga. Zircon separates from the rocks yielded U-Pb dates of 2.8–2.5 Ga, the first convincing evidence for the presence of a Late Archean complex in Southeast Asia. Given that the Red River shear zone was propagating in the South China block with a left-lateral offset of ~600 km, the Cavinh Complex can be correlated with the Late Archean Kangding Complex in the western margin of the Yangtze craton, southwestern China. The Cavinh Complex therefore represents one of the oldest crustal nuclei of the South China block.

Keywords: Southeast Asia, Vietnam, Sm-Nd, U-Pb, Yangtze craton, Archean crust.

INTRODUCTION

Southeast Asia is a tectonic collage of Precambrian microcontinents. Although the possiblity of Archean-age rocks has been raised occasionally, reliable radiometric dating data led to a general consensus that the region mainly consists of blocks of Proterozoic to Phanerozoic age (e.g., Liew and McCulloch, 1985; Cobbing et al., 1992; Zou et al., 1997; Nam et al., 2001). Although Archean rocks are reported to crop out in western and northern parts of the South China block (Bai et al., 1993; Qiu et al., 2000), a compilation of isotopic data shows that the most important period of crustal formation in South China was the Proterozoic (Chen and Jahn, 1998). This has been confirmed by Bodet and Schärer (2000), who reported ages younger than 2.5 Ga for 235 zircon and baddeleyite grains separated from sediments from four major rivers in the Indochinese continent; these findings argue for the absence of Archean crust in the area drained by these rivers.

Here we present Sm-Nd isotopic and U-Pb zircon dating data of gneisses from northern Vietnam, which crop out within the Red River shear zone (the Song Hong Complex) and south of it (Cavinh Complex) (Fig. 1B). Both complexes have been traditionally regarded as early Proterozoic in Vietnamese literature (Bao et al., 1994). However, we indicate that the Cavinh Complex is actually a Late Archean complex derived from crust older than 3.1 Ga in Southeast Asia. These data offer key constraints on both the crustal and tectonic evolution of the South China block.

GEOLOGIC BACKGROUND

Southeast Asia consists of allochthonous continental blocks from Gondwanaland. These include the South China, Indochina, Sibumasu, and West Burma blocks, which amalgamated to form the Southeast Asian continent during Paleozoic and Mesozoic time (Metcalfe, 1996). The South China block consists of the Yangtze craton in the northwest and the Cathaysian fold belt in the southeast (Fig. 1C), in which the most important period of crustal formation occurred in Proterozoic time (Chen and Jahn, 1998). However, on the basis of U-Pb zircon and Sm-Nd isotopic data (older than 3.2 Ga), remnants of Archean crust are reported in the Kongling area in the northern margin of the Yangtze craton (Qiu et al., 2000) (Fig. 1C). On the basis of conventional U-Pb zircon dates of ca. 3.0 Ga, Bai et al. (1993) documented the existence of Archean crust in the Kangding Complex from the western margin of the Yangtze craton (Fig. 1C). Good correlation of Nd isotopic data between South Korea and China led Lan et al. (1995) to propose that there may be some unexposed Archean rocks in the South China block.

The age of the Indochina block is uncertain. Nam et al. (2001)

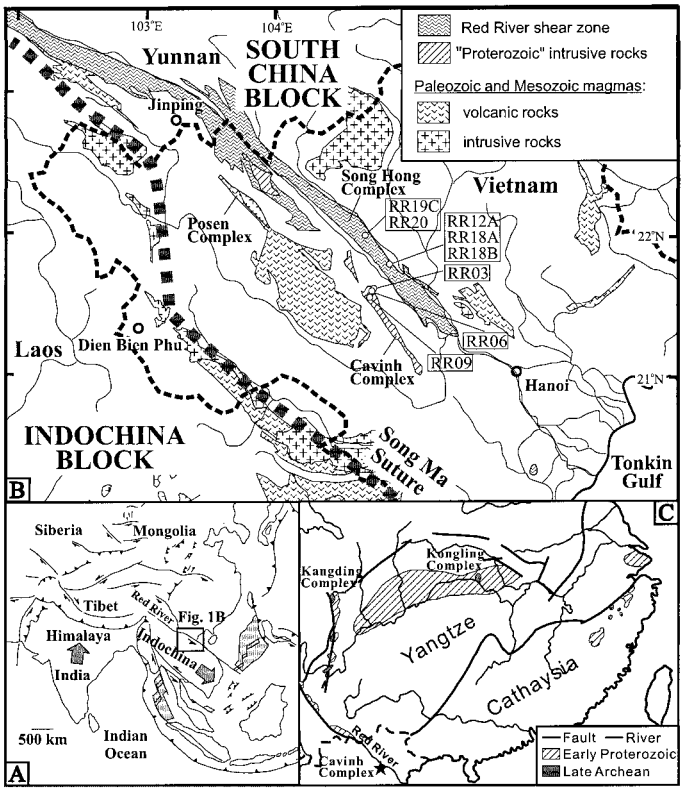

Figure 1. A: Tectonic framework and major Cenozoic faults in Asia (Tapponnier et al., 1990). B: Simplified geologic map of northern Vietnam showing basement rocks and sample localities of this study. C: Distribution of Archean and Proterozoic basement rock in South China. Star marks location of Cavinh Complex.

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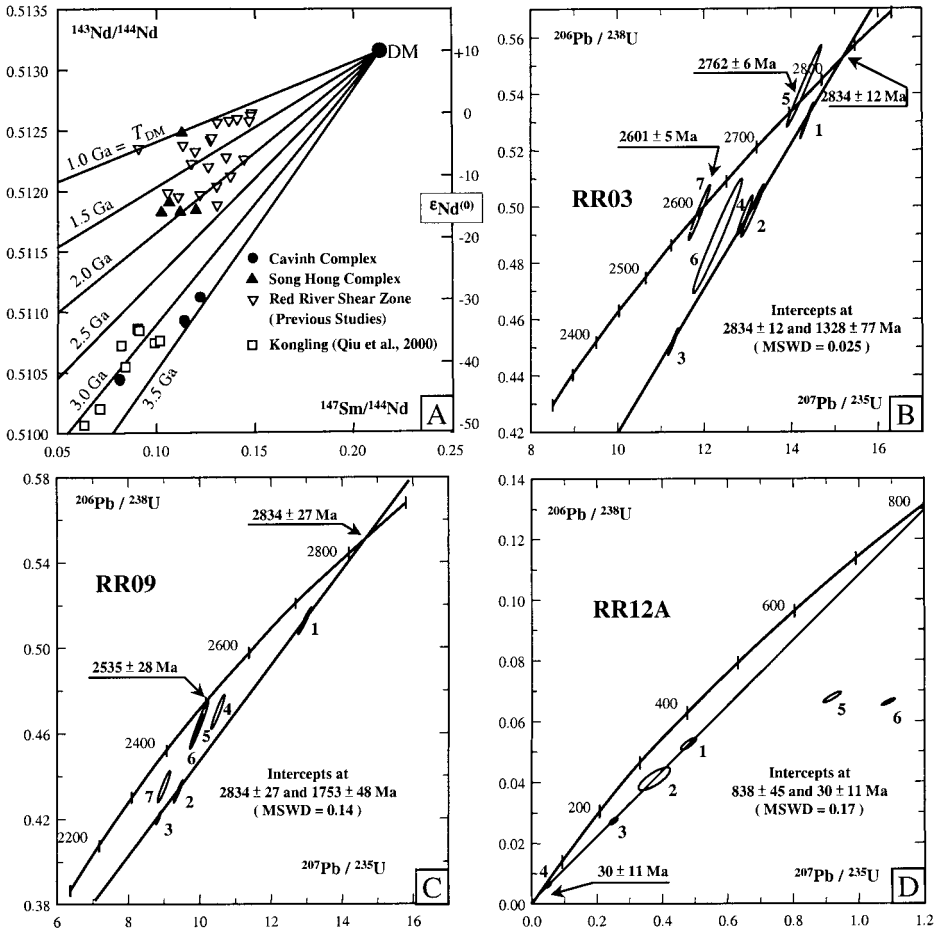

Figure 2. A: Present-day Sm-Nd isotopic data from basement rocks from northern Vietnam. Isotopic data of gneisses from Chinese Ailao Shan segment of Red River shear zone (Zhai et al., 1990; Zou et al., 1997; Zhang and Schärer, 1999) and Kongling Complex (Qiu et al., 2000) are shown for comparison. B–D: Concordia diagrams for U-Pb age data of zircon separates from Cavinh Complex (B) RR03 and (C) RR09 and from Song Hong Complex (D) RR12A.

reported a U-Pb zircon age for the Kontum massif in central Vietnam; these data suggest that the core of the Indochina block was formed sometime before ca. 1.4 Ga, consistent with the earlier inferences of Liew and McCulloch (1985). The suture between the Indochina and South China blocks is located along the Song Ma ophiolite belt (Fig. 1B). Although the fossil fish record favors a close association of the two blocks during Devonian time (Thanh et al., 1996), $^{40}Ar/^{39}Ar$ geochronologic and Nd isotopic data from the Song Ma belt imply that their final amalgamation took place along the Song Ma suture in the Early Triassic (ca. 250 Ma) (Lepvrier et al., 1997; Chung et al., 1999).

After the amalgamation, the Indochina block extruded southeastward along the Ailao Shan–Red River shear zone during the early Tertiary (Tapponnier et al., 1982). The good correlation of Mesozoic and early Tertiary magmatic suites across the shear zone indicates that the left-lateral offset along the shear zone has resulted in displacement of ~600 km (Chung et al., 1997; Wang et al., 1998). The shear zone extends for over 1000 km from Yunnan, southwestern China, to northern Vietnam (Fig. 1A) and represents one of the major geologic discontinuities in Southeast Asia. Sm-Nd isotopic data (Zhai et al., 1990; Zou et al., 1997; Zhang and Schärer, 1999) for the gneisses from the Ailao Shan segment of the shear zone in Yunnan, China, reveal Proterozoic Nd model ages of 2.3–1.0 Ga. The rocks in the Vietnamese segment, named the Song Hong Complex, consist mainly of biotite-sillimanite-garnet gneisses intercalated by lenses of amphibolites, marbles and leucogranites. To the south is the Cavinh Complex, an elongated gneissic body (Fig. 1B) that has long been regarded as Proterozoic, despite the lack of good-quality age constraints. This complex is less deformed and shows a heterogeneous composition, from quartz diorite to tonalite and granite (Bao et al., 1994).

Sm-Nd DATA AND U-Pb ZIRCON CHRONOLOGY

Sm-Nd isotopic analysis was undertaken on five gneisses collected from the Song Hong Complex and three from the Cavinh Complex (Fig. 1B) using a MAT 262 mass spectrometer at the Academia Sinica (Fig. 2A; Appendix 1[1]). All samples have "crustal" $^{147}Sm/^{144}Nd$ ratios varying from 0.1024 to 0.1222, except RR09. Samples from the Song Hong Complex, except RR19C, exhibit uniform $\epsilon_{Nd}(0)$ values of about −15. They yield depleted-mantle model ages (T_{DM}) of 2.1–1.0 Ga, whereas three samples from the Cavinh Complex show significantly lower $\epsilon_{Nd}(0)$ values (−29.6 to −43.1) and yield Archean T_{DM} ages of 3.1–3.4 Ga.

Two samples from the Cavinh Complex and one from the Song Hong Complex were subjected to single-zircon U-Pb dating using a VG354 thermal ion mass spectrometer at the Tianjin Institute of Geology and Mineral Resources. Age uncertainties are given at the 95% (2 σ) confidence level (Appendix 2; see footnote 1).

In U-Pb concordia diagrams, zircon grains from both samples from the Cavinh Complex plot on or close to the concordia curve with Archean ages. Zircons from sample RR03 define three main age groups (Fig. 2B): (1) an upper-intercept age of 2834 ± 12 Ma and a lower-intercept age of 1328 ± 77 Ma defined by four grains, (2) a concordant age of 2762 ± 6 Ma, and (3) a concordant age of 2601 ± 5 Ma. Zircons from sample RR09 define two main age groups (Fig. 2C): (1) an upper-intercept age of 2834 ± 27 Ma and a lower-intercept age of

[1]GSA Data Repository item 200123, Appendix 1 (Nd-Sm results) and Appendix 2 (U-Pb results), is available on request from Documents Secretary, GSA, P.O. Box 9140, Boulder, CO 80301-9140, editing@geosociety.org, or at www.geosociety.org/pubs/ft2001.htm.

1753 ± 48 Ma defined by three grains, and (2) a concordant age of 2535 ± 28 Ma.

By contrast, zircons from sample RR12A from the Song Hong Complex yield significantly younger ages (Fig. 2D)—an upper-intercept age of 838 ± 45 Ma and a lower-intercept age of 30 ± 11 Ma, defined by four zircon grains that all plot near the lower intercept. Zircon grains 5 and 6 fall far away from the concordia curve, owing to their much older $^{207}Pb/^{206}Pb$ ages of 1554 ± 20 and 1918 ± 10 Ma, respectively, implying a detrital origin.

DISCUSSION AND CONCLUSIONS

Age of the Cavinh Complex and Archean Rocks in Southeast Asia

Remarkably, the two samples from the Cavinh Complex exhibit an identical U-Pb zircon upper-intercept age of ca. 2.83 Ga and similar concordant ages of 2.5–2.7 Ga, which indicate that the emplacement of the magmatic protoliths of the Cavinh Complex occurred in the Archean. The younger lower-intercept dates (1.3 and 1.7 Ga) are most likely due to subsequent metamorphic overgrowth and/or Pb loss of the zircon grains. The large errors of lower-intercept ages are likely caused by the distribution of data points near the upper intercept. This interpretation is consistent with a recent ion-microprobe U-Pb zircon study of the Cavinh Complex (Tran Ngoc Nam, 2000, personal commun.), which obtained concordant ages as old as 2.94 Ga in the cores of some zircons and younger ages in multiple overgrowth rims. Because of the limited available age data, it is unclear whether the magmatism in the Cavinh Complex continued from 2.94 to 2.83 Ga or was in two or even more episodes. Nevertheless, these age data are undoubtedly the first convincing evidence for the existence of a Late Archean complex in northern Vietnam, and they are also the oldest age ever reported for the rocks in the Indochinese region. This new finding, reinforced by the Nd T_{DM} age data (3.1 to 3.4 Ga), indicates that Archean basement does exist in the western Yangtze craton, contrary to previous views. Furthermore, the emplacement age and Sm-Nd isotopic data of the Cavinh Complex is virtually identical or very close to that of the trondhjemitic magmatism (2.95–2.90 Ga) in the Kongling area (Qiu et al., 2000), located along the northern margin of the Yangtze craton (Figs. 1C and 2A).

Given the fact that the Ailao Shan–Red River shear zone was propagating along the southwestern margin of the South China block, the Late Archean Cavinh Complex would be located close to the Kangdian Oldland in southwestern China. Chemically and petrologically, this complex can be correlated with the trondhjemitic-tonalitic-granodioritic and gray gneisses in the so-called Kangdian Oldland (Zhai and Yang, 1986; Wu, 1990), which crops out in the western margin of the Yangtze craton; the Kangding Complex is the major component in the northern end (Fig. 1C). Conventional U-Pb zircon ages of ca. 3.0 Ga and Rb-Sr ages of ca. 2.5 Ga have been reported for rocks from the Kangding Complex (Bai et al., 1993). These isotopic ages agree with those of the Late Archean Cavinh Complex discussed here. Thus, the Cavinh Complex represents a possible extenuation of Archean basement in the southwestern part of the Yangtze craton. It is interesting to note that in the South China block, the Archean rocks so far identified are all exposed around the periphery of the Yangtze craton (Fig. 1C). This finding also lends support to the suggestion by Lan et al. (1995) of the possible existence of unrecognized Archean fragments in the South China block that may crop out in restricted areas and that are therefore not sampled by the major Indochinese rivers (Bodet and Schärer, 2000).

Age of the Song Hong Complex and Gneisses in the Red River Shear Zone

The U-Pb zircon upper-intercept age for the rock (RR12A) from the Song Hong Complex (838 ± 45 Ma) is broadly synchronous to that (760 ± 25 Ma) reported for the Posen Complex (Wang et al., 1999), which is exposed to the south of the Red River shear zone (Fig. 1B). This upper-intercept age is interpreted as the emplacement age of the Song Hong Complex. The lower-intercept age (30 ± 11 Ma) observed in the Song Hong Complex is coeval with Ar-Ar thermochronologic results (27.4–23.8 Ma, for various minerals) obtained for the same rock sample (Wang et al., 1998). These Tertiary ages have been interpreted to be the metamorphic and cooling ages related to the left-lateral movement of the Red River shear zone (Leloup et al., 1995; Wang et al., 1998, 2000). The metamorphic event with temperature and pressure conditions of 690 ± 30 °C and 0.65 ± 0.15 GPa, respectively, reported in the Vietnamese segment of the shear zone (Nam et al., 1998), could have resulted in resetting of the K-Ar and partial resetting of the U-Pb zircon isotopic systems in gneisses from the Song Hong Complex.

The Sm-Nd isotopic data and T_{DM} ages of the Song Hong Complex (Fig. 2A) are comparable to those of the mylonitic gneisses from the Ailao Shan segment of the Red River shear zone in Yunnan, China (Zhai et al., 1990; Zou et al., 1997; Zhang and Schärer, 1999). All basement rocks exposed in the 1000-km-long Red River shear zone show Early to Middle Proterozoic T_{DM} ages (2.3 to 1.0 Ga). This result is consistent with the notion that in the South China block, crustal formation was most active during this time period (Chen and Jahn, 1998). However, the presence of rocks (e.g., RR19C) with an apparently younger T_{DM} age (1.0 Ga) and higher $\epsilon_{Nd}(0)$ value (–3.1) may also imply that a significant mantle input occurred in the Neoproterozoic or more recently in this part of the South China block.

Crustal and Tectonic Evolution in Southeast Asia

This study provides a new constraint for the Precambrian crustal record of northern Vietnam. Figure 3 summarizes the crustal history of the Indochina region beginning in Archean time. Nd model ages suggest that a continental crust as old as 3.4–3.1 Ga may have been separated from a depleted mantle source. Synchronous Late Archean magmatism (2.9–2.8 Ga) and the trondhjemite-tonalite-granodiorite–like geochemical features observed in the Cavinh Complex and its Chinese counterparts (Kongling Complex and Kanding Complex) implied that the magmatism was probably related to slab melting in subduction-zone environments (Martin, 1999). A Middle Proterozoic (1.8–1.3 Ga) event, registered by the U-Pb zircon lower-intercept ages of the Cavinh Complex, the prominent T_{DM} ages of rocks in the Red River shear zone, the $^{207}Pb/^{206}Pb$ dates of detrital zircons from the Song Hong sample RR12A, and a Sm-Nd whole-rock isochron age (1367 ± 46 Ma) of six amphibolite enclaves in the gneisses from the Ailao Shan segment of the shear zone (Zhai et al., 1990), corresponds to the major episode of crustal formation in the South China block.

A Neoproterozoic age (850–740 Ma), obtained from the U-Pb zircon upper intercept ages of the Song Hong and Posen Complexes, is interpreted to indicate Chenjiang ''orogeny'' in the South China block where mafic to ultramafic dikes and sills, accompanied by granitic intrusions with a lateral extent of ~1000 km, have been dated as ca. 830–810 Ma. Their generation is ascribed to the early effects of the mantle plume that initiated the breakup of Rodinia (Li et al., 1999). The arrival of the mantle plume could have provided fresh mantle input and the heat required to produce magmatism. The result was a series of collision and extrusion events. The recognition of a ca. 280–240 Ma magmatic arc along the northern margin of the Indochina block and a ca. 240 Ma metamorphic belt in the Song Ma area, northern Vietnam, suggests that the collision of Indochina with South China occurred in the Early Triassic (Lepvrier et al., 1997; Chung et al., 1999; Lan et al., 2000). After suturing, widespread intraplate magmatism affected Vietnam, during Late Jurassic to Cretaceous (145–75 Ma) time (Lan et al., 2000), which most likely corresponds to the Yanshanian

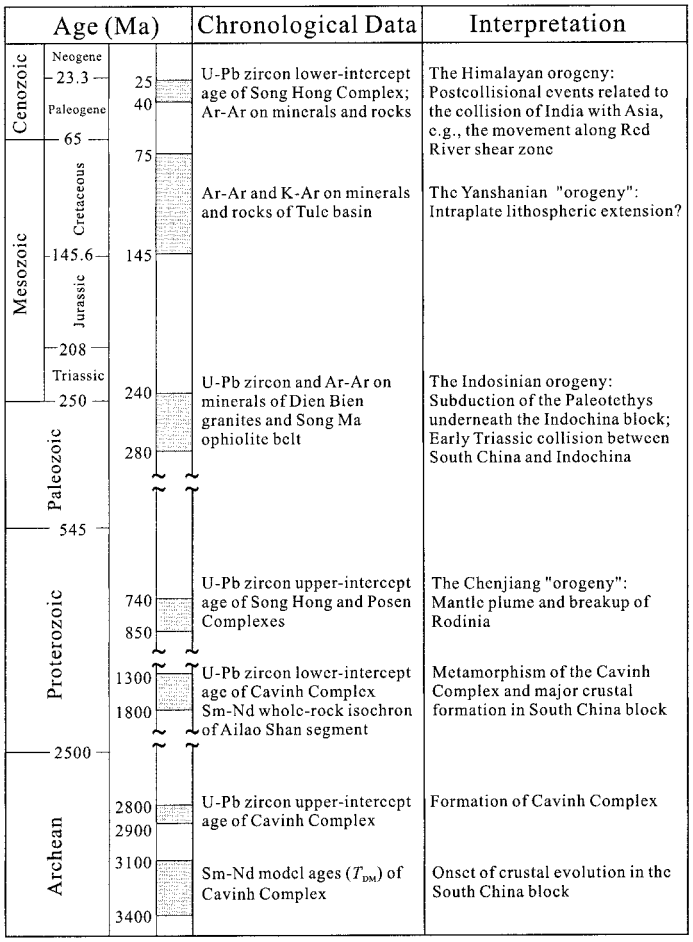

Figure 3. Summary of major tectono-thermal events in Indochina region.

''orogeny'' in South China related to lithospheric relaxation and extension. Finally, a mid-Tertiary (ca. 40–25 Ma) event is recorded by gneisses exposed within the Red River shear zone that formed because of continental extrusion resulting from the India-Asia collision.

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