行政院國家科學委員會專題研究計畫成果報告

東南亞地區新生代碰撞－脫逸地體構造演化－(總計畫及子計畫三)：紅河-哀牢山斷裂帶附近新生代熱事件及地塊運動研究（一）

Comprehensive Research on East Asia Tectonics (CREATE I): Cenozoic Thermal Events and Block Movements along Ailao Shan – Red River Shear Zone (I)

計畫編號：NSC 87-2116-M-002-020-Y
執行期限：86 年 8 月 1 日至 87 年 10 月 31 日
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摘要

出露於越南北部的達紐康渥 (Day Nui Con Voi) 變質岩體，記錄哀牢山－紅河斷裂帶左移的活動歷史，表現出從 27 Ma 至 21 Ma 左右，由東南向西北方向逐一快速冷卻剝蝕的過程，綜合此一斷裂帶活動可得的岩體冷卻與剝蝕記錄，並配合附近區域的已有地質資料可知，哀牢山－紅河斷裂帶的活動稍晚於青藏高原東部發生層脫作用 (約 40-30 Ma) 和南海海盆開始發育的時間 (約為 30 Ma)，隱示哀牢山－紅河斷裂帶的活動是發生在兩個已經存在的岩石圈薄弱處之間。

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Abstract

In order to explore the timing of strike-slip movement along the ccshear zone, an $^{40}Ar/^{39}Ar$ thermochronological study of the Day Nui Con Voi metamorphic massif in northern Vietnam was undertaken. The massif, exposed in the southeastern segment of the Ailao Shan-Red River shear zone, reveals a rapid cooling in the early Miocene (25-21 Ma) after a very slow cooling ca. 34-25 Ma. The slow cooling period most likely resulted from a geothermal perturbation in the lithosphere owing to the late Paleogene (40-30 Ma) extension in eastern Tibet and western Yunnan, China. The rapid cooling, consistent with evidence of a wider rapid cooling span from 27 to 17 Ma compiled from the entire Ailao Shan-Red River shear zone, constrains the duration of left-lateral shearing, which eventually offset Indochina from South China by about 600 km. The time constraints we have established reinforce the argument that the onset of the Ailao Shan-Red River shear zone postdates the opening of the South China Sea that began ca. 30 Ma. This result highlights the necessity for reevaluating the Cenozoic tectonic models of Southeast Asia.

Keywords: Ailao Shan – Red River Shear Zone, Isotope Thermochronology, Vietnam

Introduction

The Ailao Shan-Red River shear zone is the most significant geologic discontinuity in Southeast Asia and has been repeatedly advocated as an important boundary accommodating the convergence of India and Asia since the early Cenozoic (e.g., Tapponnier et al., 1982, 1986, 1990). On the basis of stratigraphic and structural correlations, the left-lateral movement along the Ailao Shan-Red River shear zone is occurred from 35 to 17 Ma, resultant in an offset of 700 ± 200 km (for review, see Leloup et al., 1995). The resultant southeastward displacement of Indochina relative to South China, termed continental

extrusion (Tapponnier et al., 1982), has been widely considered to be responsible for the opening of the South China Sea (e.g., Tapponnier et al., 1986, 1990; Peltzer and Tapponnier, 1988; Briais et al., 1993). Previous thermochronological studies suggested that the sinistral transtension might have propagated southeastward at a rate of ~4.5 cm/yr (Schärer et al., 1990, 1994; Leloup et al., 1993; Harrison et al., 1992, 1996). However, this conclusion was drawn mainly on the basis of data collected from the metamorphic massifs in southwestern Yunnan, China (e.g., the Diancang Shan and the Ailao Shan). Only a few studies (Leloup et al., 1995; Harrison et al., 1996) have partially investigated the Day Nui Con Voi metamorphic massif in northern Vietnam.

On the basis of correlations with different magmatic rock suites, Chung et al. (1997) argued that the sinistral displacement along the Ailao Shan-Red River shear zone approximated 600 km. One piece of magmatic evidence, the late Paleogene (40-30 Ma) potassic rocks in western Yunnan and eastern Tibet, led them to suggest that the shearing was active only after ca. 30 Ma and was preceded by an intraplate extension. The extension, along with sea-floor spreading in the South China Sea that commenced ca. 30 Ma, served as two endpoints for the initiation of the Ailao Shan-Red River shear zone (Chung et al., 1997). This view is different from the previously proposed continental extrusion model of Tapponnier et al. (1982, 1986). In this paper, a thermochronological study of metamorphic rocks from the Day Nui Con Voi massif, northern Vietnam, is presented. The results here show that motion along the Ailao Shan-Red River shear zone occurred mainly from 25 to 21 Ma. This, in turn, supports the argument by Chung et al. (1997), and provides valuable insight to the geologic evolution of Southeast Asia after the India-Asia collision.

Methods

The Day Nui Con Voi metamorphic massif is located in the southeastern part of the Ailao Shan-Red River shear zone and is bounded by the Song Hong fault in the south and the Song Chay fault in the north (General Geological Department, 1973). Both faults appear as high-angle, right-lateral slip faults having normal components on the margin of the metamorphic massif. Several Tertiary extensional basins, surrounded by Paleozoic and Mesozoic sequences, developed along the margin of the shear zone. Toward the southeast the shear zone is gradually submerged and then covered by thick Quaternary sediments that compose the Red River delta. The entire fault system is generally believed to have resulted from large-scale, left-lateral movement during mid-Tertiary time as a response to the India-Asia collision. A recent reactivation has sheared right-laterally since the early Pliocene (Allen et al., 1984; Leloup et al., 1995). Similar to its counterparts in Yunnan, southwestern China (i.e., Xuelong Shan, Diancang Shan, and Ailao Shan, the Day Nui Con Voi massif consists mainly of high-grade metamorphic rocks (mylonitic Middle Proterozoic gneisses and amphibolites) which extend about 300 km in length and have a width of 10-15 km along the Red River. Most gneisses and amphibolites show a well-defined foliation, striking subparallel to the shear zone. Mainly on the basis of petrological data from the Ailao Shan region, the peak metamorphic conditions in the Ailao Shan-Red River shear zone have been estimated to be as high as 710 ± 70 ^{o}C and ~7kbar (Leloup and Kienast, 1993). The metamorphic grade is somewhat lower in the Diancang Shan section (Leloup et al., 1993).

Gneiss, amphibolite, pegmatite, and leucogranite samples were collected from five localities in the Day Nui Con Voi metamorphic massif, northern Vietnam. The latter two rock types occur as dikes that crosscut or develop along the foliation of the gneisses and hence are regarded as products of the mid-Tertiary shear movement (Tapponnier et al., 1990). Hand-picked mineral separates of amphibole, muscovite, biotite, and K-feldspar from various rocks

were analyzed using the $^{40}Ar/^{39}Ar$ step-heating technique at National Taiwan University. Ages were calculated relative to LP-6 biotite (127.7 ± 1.4 Ma) (Odin et al., 1982). Results of $^{40}Ar/^{39}Ar$ analyses are plotted in age spectrum diagrams. Furthermore, the $^{36}Ar/^{40}Ar$ vs. $^{39}Ar/^{40}Ar$ isotope correlation diagrams were also plotted to examine the possible disturbances of argon isotopic systems. Detailed analytical data are available on request to the corresponding author. All $^{40}Ar/^{39}Ar$ dates in the discussion are plateau dates, that were calculated from the sum total gas from those steps with the ages of which fall within 2 σ of each other, except that for RR13A K-feldspar, the intercept date of which is adopted because of the presence of excess argon.

Results and Discussions

Almost all the age spectra display a fairly flat profile in shape except RR13A K-feldspar. Although several K-feldspars and amphiboles show anomalous dates at low- and/or high-temperature steps, perhaps due to the outgassing of impurities, these samples still yield acceptable plateau dates having ^{39}Ar gas proportions greater than 48%. Their plateau dates agree well with intercept dates in the isotope correlation diagrams. Their $^{40}Ar/^{36}Ar$ intercept values obtained from regressions are not significantly different from the atmospheric composition ($^{40}Ar/^{36}Ar$ = 295.5). K-feldspar from RR13A displays a complex-shaped age spectrum characterized by abnormally old ages at low-temperature steps, a hump-shaped rise over the mid-temperature steps at 40% of the total ^{39}Ar gas released, and a drop in age during the last 60% ^{39}Ar gas released. The shape of this spectrum is similar to that described by Foster et al. (1990), in which excess argon exists in large domains. In the isotope correlation diagram, all the data points scatter near the $^{39}Ar/^{40}Ar$ axis and a possible meaningful intercept date of 19.6 ± 1.8 Ma (MSWD = 1.4) is obtained with an extremely high initial $^{40}Ar/^{36}Ar$ value (730 ± 46). In this case, the intercept date is considered to be the best estimate for RR13A K-feldspar.

The plateau dates of amphiboles vary range from 23.7 to 33.8 Ma. Even for those from the same outcrop, there is a significant difference in amphibole dates from gneiss and associated amphibolite samples. This may result from different argon closure temperatures owing to different chemical compositions between amphiboles in various rock types (Onstott and Peacock, 1987). In contrast, all micas yield uniform plateau dates; the range is 21.2 to 24.8 Ma. K-feldspars yield a range of 18.4-24.3 Ma that is slightly younger than micas and amphiboles. We note here that overall mineral ages from pegmatites and leucogranites are consistent with, or younger than, the fast cooling age span, estimated from the coexisting metamorphic rocks. Strongly deformed leucogranites generally have mineral ages that are similar to their host rocks. For example, muscovite and K-feldspar ages (23.8 ± 0.2 Ma and 23.1 ± 0.1 Ma, respectively) from RR16C leucogranite agree well with those of biotite and K-feldspar (22.7 ± 0.2 Ma and 24. ± 0.1 Ma) in the host gneiss (RR16A). However, RR13C, an undeformed pegmatite vein, contains K-feldspar that yields a much younger intercept age (16.6 ± 1.4 Ma) than that for RR13A biotite and K-feldspar in the host gneiss (22.8 ± 0.1 and 19.6 ± 1.8 Ma, respectively).

The metamorphic massifs in the Ailao Shan-Red River shear zone were exhumed as a consequence of the left-lateral shearing movement (Tapponnier et al., 1990; Harrison et al., 1992, 1996; Leloup et al., 1993, 1995). Along with the radiometric dating on pegmatitic and leucogranitic veins (Schärer et al., 1990, 1994), thermochronological studies on the metamorphic rocks have provided important time constraints regarding the metamorphic exhumation and the sinistral displacement (e.g., Harrison et al., 1992, 1996; Leloup et al., 1993). In general, the Ar

closure temperatures for all minerals analyzed in this study are lower than 550 ^{o}C, significantly lower than the peak metamorphic temperatures of the Ailao Shan-Red River shear zone (Leloup and Kienast, 1993; Leloup et al., 1993). This leads us to interpret the $^{40}Ar/^{39}Ar$ dates we obtained as recording the time for these rocks to cool through their closure temperatures during exhumation. Therefore, with suitable diffusion parameters, the closure temperatures for amphiboles and micas are calculated according to Dodson's closure temperature scheme (Dodson, 1973) and then used to construct cooling paths. Following the multidomain diffusion model (Lovera et al., 1991), the cooling, and hence exhumation, history of the metamorphic massif can be further constrained.

The results show that the Day Nui Con Voi metamorphic massif underwent a high-temperature stage around 500 ^{o}C from 34 to 25 Ma, and then cooled rapidly ca. 25 to 21 Ma. In addition, the sample from the southeastern part cooled and was exhumed earlier than those in the northwestern part, demonstrating a north-westward-younging trend for the fast cooling stage. Assuming that cooling rate changes are due to the onset of shearing, the north-westward propagation rate of the exhumation front passing through the 400 ^{o}C isotherm, caused by the southeastward shearing movement, is estimated to be around 5 cm/yr. It is consistent with that estimated by Harrison et al. (1996) (~4.5 cm/yr) on the basis of results from the Ailao Shan massif. Comparing thermochronological data available from the entire Ailao Shan-Red River shear zone, we can further infer that there was no significant exhumation event recorded prior to 27 Ma in the metamorphic massifs. After ca. 27 Ma, however, a pronounced rapid cooling took place from the Day Nui Con Voi through Ailao Shan to the Diancang Shan regions.

A careful examination of the cooling paths indicates that each segment in the Ailao Shan-Red River shear zone exhibits somewhat different temperature ranges, exhumation durations, and cooling rates. Both the Day Nui Con Voi and Ailao Shan massifs display northwestward propagation of the exhumation front at similar rates, but such a variation is unclear in the Diancang Shan massif. This feature has been explained as a result of diachronous initiation of transtension along the shear zone (Harrison et al., 1996). We suggest that each massif has had its own response to the left-lateral shearing movement. Both the Ailao Shan and Day Nui Con Voi massifs had been exhumed from depths corresponding to about 700 and 500 ^{o}C, respectively, to near-surface levels prior to 17 Ma, as inferred from the K-feldspar ages. However, the Diancang Shan had not exhumed to the surface until ca. 5 Ma. After a tectonically quiescent period between ca. 17 and 5 Ma within the entire shear zone, the Diancang Shan massif underwent a rapid cooling due to active normal faulting with a right-lateral component (Leloup et al., 1993). Overall, owing to the left-lateral shearing, the metamorphic massifs in the Ailao Shan-Red River shear zone were exhumed rapidly to various levels from ca. 27 to 17 Ma. The rapid cooling, likewise, began slightly earlier in the southeastern part of each metamorphic massif and propagated gradually northwestward through time.

Our $^{40}Ar/^{39}Ar$ thermochronological results demonstrate that the Day Nui Con Voi metamorphic massif underwent two stages of thermal evolution, i.e., a very slow cooling around ~500 ^{o}C from ca. 34 to 25 Ma and subsequent rapid cooling from ca. 25 to 21 Ma. The latter, together with a wider rapid cooling age range, about 27 to 17 Ma, recorded in the entire Ailao Shan-Red River shear zone, provides a straightforward time constraint on the left-lateral displacement of the shear zone. Furthermore, no significant thermal events older than ca. 27 Ma have been observed in the metamorphic massifs. These high-grade metamorphic rocks were still residing in lower crustal levels (down to

~7kbar; Leloup and Kienast, 1993) at relatively high temperatures (710 ± 70 ºC). We interpret such a high geothermal structure as a consequence of an intraplate extension that took place from 40 to 30 Ma from eastern Tibet to western Yunnan and resulted in widespread potassic magmatism (Chung et al., 1997). The extension, probably caused by removal of the thickened lithosphere around the eastern Tibetan plateau, might be associated with a significant perturbation of the geothermal structure of the lithosphere owing to replacement of the lithospheric mantle by a hotter and lighter asthenosphere (Platt and England, 1993). This study confirms the notion of Chung et al. (1997) that continental extrusion along the Ailao Shan-Red River shear zone was preceded by an intraplate extension in eastern Tibet and western Yunnan.

The collision of India with Asia since early Cenozoic time has been generally accepted as one of the most important processes in the Cenozoic tectonic evolution of East Asia. The resultant strike-slip movement along the Ailao Shan-Red River shear zone, for example, has been widely regarded as the key process responsible for opening the South China Sea (cf. Leloup et al., 1995) and for shaping Southeast Asia (e.g., Lee and Lawver, 1995). Pioneered by Tapponnier et al. (1982), there have been many investigations of this shear zone and, as summarized by Leloup et al. (1995), a general consensus has been that the shearing was active between 35 and 17 Ma. This time span is nearly identical with that of the sea-floor spreading of the South China Sea (ca. 30-16 Ma; Taylor and Hayes, 1983; Briais et al., 1993; Cande and Kent, 1995), and is thus consistent with the continental extrusion model, which advocates a displacement of Indochina relative to South China to initiate the opening of the South China Sea (cf. Tapponnier et al., 1986). Chung et al. (1997), however, argued against this scenario, and proposed that the shearing could have begun only after ca. 30 Ma, because the high-K volcanic rocks would imply a rift setting in this area in the late Paleogene time. The time constraints for the movement of the Ailao Shan-Red River shear zone provided by this study (27-17 Ma) reinforce the suggestion of Chung et al. (1997), and confirm that the Ailao Shan-Red River shear zone was actually initiated later than the onset of the opening the South China Sea. Furthermore, these findings also raise questions concerning the recognition of the Cenozoic tectonic evolution in Southeast Asia. The collision-extrusion model and the interactions among all relevant plates in this region need further examination and reevaluation.

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