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Discussion

# Reply to comment on "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" by Wang et al., 2000. Journal of Asian Earth Sciences 18, 281–292

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We welcome the comment from Leloup et al. because it is certainly necessary to clarify why in the Ailao Shan-Red River (ASRR) shear zone discrepant kinematic models could be derived from the same thermo chronological data pool. We would like to take this opportunity to show how different geological hypotheses were adapted, eventually leading to different interpretations or, in some cases, over-interpretations. In the comment, Leloup et al. raised four arguments about our data interpretation and two opinions about kinematics of the ASRR shear zone that can be summarized as two important questions: (1) Does the correlation between cooling age and location, i.e. 'diachronism', along the strike of the Day Nui Con Voi (DNCV) massif really exist? (2) What kind of age data may be used to constrain the timing of left-lateral motion along the ASRR shear zone? The former might simply be caused by misunderstanding of our data presentation. The latter is a real dispute on data interpretation. We encourage readers to go through the original papers for a careful and, hopefully, more objective examination.

## 1. The cooling history of the DNCV massif

The data plotted in Fig. 8 of Wang et al. (2000) are not the low-temperature (LT) K-feldspar plateau ages; these are ages recorded by the metamorphic rocks in the Day Nui Con Voi (DNCV) massif when they were cooled though 350°C during their cooling paths (Wang et al., 1998, 2000). For a given sample, its cooling path represents a combination of overall thermo chronological data and is basically dominated by that derived from the multi-domain diffusion (MDD) modeling of K-feldspar. In this sense, the cooling ages at 350°C and LT K-feldspar plateau ages are similar, but they are not identical and thus may imply different geological meanings. For example, the sample (RR58) from the Nam Dinh area has a rapid cooling age of ~27 Ma (Fig. 8 of Wang et al., 2000), in contrast to the LT K-feldspar age of ~25 Ma (Table 1 of Wang et al., 2000 and Fig. 2 of the comment). We did not correlate the cooling histories with sample locations by using the LT K-feldspar plateau ages as stated by Leloup et al. These ages cannot reveal any specific temperatures of the massif during cooling. They may only roughly reflect a fast cooling stage in a relatively lower temperature range. In Fig. 2 of the comment, Leloup et al. plotted some of our LT K-feldspar plateau age data (i.e. those in open squares) to 'dismiss' the cooling age versus distance correlation proposed for the DNCV massif by Wang et al. (2000). They, however, might not have gone through the discussion carefully by Wang et al. (1998, 2000) about why these age data were excluded in establishing the cooling history of the massif. The $^{40}Ar/^{39}Ar$ dates of pegmatite and leucogranite veins (RR13C, RR12D, RR16C of Wang et al., 1998 and RR58A of Wang et al., 2000) should not be used because of the uncertainties such as when and how these igneous intrusions were generated and incorporated into the massif. Two K-feldspar dates of the gneissic rocks (RR12B and RR58C) were also excluded owing to apparent inconsistency between their cooling histories and the dates of coexisting micas (see, for RR58C, Fig. 6 of

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Wang et al., 2000). With the above consideration, Wang et al. (2000) suggested that there is a good correlation between the cooling paths and locations along the DNCV massif (for RR15A, RR15B, RR12A, RR16A and RR58D). This, in turn, enabled us to draw to the conclusion that in this part of the Ailao Shan-Red River (ASRR) shear zone the left-lateral movement may have occurred at ~27.5 Ma with a northwestward propagation rate of ~6 cm $\text{yr}^{-1}$. We noticed that in a recent paper Leloup et al. (2001) reported a new $^{40}$Ar/$^{39}$Ar date (V126, 27.5 ± 0.6 Ma) of biotite separated from a mylonitic mica schist sample also from the Nam Dinh area, and this is virtually consistent with the result of Wang et al. (2000).

Wang et al. (2000) have neither argued for the same cooling history shared by the DNCV and Ailao Shan massifs, nor suggested that "the DNCV pursues the trend evidenced in the Ailao Shan". Instead, in Wang et al. (1998) we addressed the difference between the cooling paths revealed by these two segments in the ASRR shear zone. The Ailao Shan massif was cooled rapidly from the temperature of peak metamorphism, while the DNCV massif showed a slow cooling stage around 500° C after its peak metamorphism. What we envisioned is that in both massifs there exists a similar cooling diachronism, i.e. northwestward propagation of the fast cooling stage of the mylonitic massifs. Thus, the 'zipper tectonics' model proposed for the Ailao Shan massif (Harrison et al., 1996) may be applied to the DNCV massif as well. Consequently, the fast cooling of the massif could have started as early as ~27.5 Ma in the southeastern end (i.e. around the Nam Dinh area) of the ASRR shear zone.

## 2. The timing of the ASRR shearing

Theoretically speaking, in order to study the onset of shear zones it is crucial to date the oldest growth of syn-deformational minerals (cf. Resor et al., 1996). We agree that the $^{40}$Ar/$^{39}$Ar dates of the metamorphic rocks from the shear zone, with the highest Ar closure temperatures of ~500°C (amphibole), should not be used directly to imply the onset of motion along the ASRR shear zone. However, cooling paths of these rocks provide straightforward time constraints on the shearing activity and thus the fast cooling record is generally accepted to be an appropriate indicator of tectonothermal events. This logical argument has been accepted by numbers of workers, including Leloup et al. (1993), Leloup et al. (1995), Harrison et al. (1996), Leloup et al. (2001). Up to now, no reliable age data obtained from highly deformed metamorphic rocks in the ASRR shear zone could be ascribed to indicate that left-lateral shearing actually took place prior to 28 Ma (Wang et al., 1998; Leloup et al., 2001).

In addition to the metamorphic rocks, dates of deformed and undeformed igneous intrusions in and near the ASRR shear zone have been used to explore the timing of the shearing (Schärer et al., 1990, 1994; Zhang and Schärer, 1999). All such intrusions, mostly of leucogranitic composition, yielded U–Pb dates of 27–22 Ma ($n = 14$) with only two exceptions: YS26 (33.1 ± 0.2 Ma) from the Xuelong Shan massif and YS13 (31.9 ± 0.3 Ma) from the Ailao Shan massif (Zhang and Schärer, 1999). There are several reasons to query whether these dates should be used as time constraints for shearing. First of all, Leloup et al. (2001) reported new geochronological, structural and petrologic data that show a complex evolution history of the Xuelong Shan massif from Triassic to Miocene time. The left-lateral deformation temperature was only slightly above 300°C on the basis of micro structural observations. The peak temperature during shearing probably did not exceed the closure temperatures of U–Pb and Rb–Sr systems, so that Triassic and early Tertiary dates were recorded for host orthogneiss (YS25) by these two methods (Leloup et al., 2001; Zhang and Schärer, 1999). Thus, even the U–Pb age of the Ti–U-rich oxides (YS26) could be interpreted as the crystallization time of the leucogranitic layer; no strong evidence indicates it could have been generated by partial melting during the left-lateral shearing. Second, the two samples (YS25, YS26) were collected in the river that crosses the massif, not from outcrops (Zhang and Schärer, 1999). One should be cautious in interpreting these dates. And finally, the U–Pb date of monazite from the layered granite (YS13) is too old to be consistent with other U–Pb data (<27 Ma, $n = 12$) from the rest of the Ailao Shan massif. Deformed intrusions are generally older than coexisting leucocratic layers in the ASRR shear zone, but the maximum difference is commonly less than 4 Ma (Schärer et al., 1990, 1994; Zhang and Schärer, 1999). This layered granite is less deformed (60% of the minerals preserve their igneous character) (Zhang and Schärer, 1999) and the U–Pb date of the monazite is significant older (~9 Ma) than monazite from a leucocratic vein in the nearest location (YS11: 22.7 ± 0.3 Ma, 10 km separation) (Schärer et al., 1990; Leloup et al., 2001). If both of them were generated by the heat of shearing and were incorporated into the metamorphic massif at different times, this age difference would infer a very slow cooling stage at that period. This interpretation is totally different from the general observation in the Ailao Shan massif, which was cooled in a fairly rapid fashion from the temperature of peak metamorphism. Consequently, these two U–Pb dates should be carefully examined, especially for their genetic link with the shearing along the ASRR shear zone.

We agree that it is unwarranted to discuss in any details the petrogenesis of the Paleogene K-rich rocks in eastern Tibet, Yunnan and NW Vietnam, but do not agree with the statement by Leloup et al. that the "potassic magmatism and (the ASRR) left-lateral shear were coeval". According to Fig. 9a of Leloup et al. (2001), the outcrop of the Fan Si Pan (FSP) granite, the largest potassic magma body, is located ~20 km south of the shear zone. We do not see any structural relationships that can be explained as 'syntectonic' and thus 'coeval' to the shearing along the ASRR shear zone. The U–Pb date of the FSP granite (YS50 titanite: 35.2 ± 0.4 Ma) is significantly older than the dominant episode of the leucogranitic activity (27–22 Ma) in the shear zone or even the oldest, uncertain U–Pb date (YS-26: 33.1 ± 0.2 Ma) from the Xuelong Shan massif. In our view, there is no convincing evidence to argue for a genetic link between the FSP granite and the ASRR shear zone. It is hence inappropriate to use the former as the time constraint for the latter. Instead, the FSP granite is broadly synchronous and compositionally comparable to the felsic component of the Pu Sam Cap alkaline complex (~37–29 Ma, Chung et al., 1997 and unpubl. data) from the nearby region. They both, moreover, can be correlated to contemporaneous potassic rocks emplaced in eastern Tibet, Yunnan, and NW Vietnam (Chung et al., 1997, 1998; Lan et al., 2000).

## 3. Summary

We hope that this reply can be of help in clarifying some fundamental aspects about the interpretation of thermo chronological data from the ASRR shear zone. As widely granted, in such a tectonically complex region these data must be considered with great caution particularly when one wants to explore the geodynamic implications. For the absence of direct methods, dating of various metamorphic mineral phases in highly deformed rocks from the shear zone by the $^{40}Ar/^{39}Ar$ methodology is probably the best way to study the cooling history of the metamorphic massifs and the timing of the strike-slip movement along the shear zone. Dating of leucogranitic intrusions within the shear zone may provide supplemental, though even more indirect, age constraints. Other igneous bodies that crop out away from the shear zone but have been claimed to have genetic links with the shearing movement should be carefully examined in the light of diverse magma throughout the region.

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