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Discussion

Comment on "Onset timing of left-lateral movement along the Ailao Shan-Red river shear zone: $^{40}Ar/^{39}Ar$ dating constraint from the Nam Dinh area, northeastern Vietnam" by Wang et al., 2000. Journal of Asian Earth Sciences 18, 281–292

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Wang et al. claim to have dated the onset of left-lateral shear along the Ailao Shan-Red River shear zone (ASRR) (Leloup et al., 1995; Tapponnier et al., 1990) at ≈ 27 Ma ago, thus 3 Ma after the initiation of seafloor spreading in the South China Sea (Wang et al., 2000). We show below that their argument is fundamentally flawed and that motion along the ASRR started at least a few Myr earlier than seafloor spreading.

Wang et al. (2000) present biotite, muscovite and K-feldspar $^{40}Ar/^{39}Ar$ data from the southernmost exposure of the ASRR near Nam Dinh (site 23 on Fig. 1; Harrison et al., 1996; Leloup et al., 1996). From these data, they propose that rapid cooling from ≈ 400 to ≈ 150°C occurred in this part of the shear zone, between ≈ 27 and 25 Ma (Fig. 6 of Wang et al., 2000). Then they suggest: (1) that there is a correlation between rapid cooling ages, mainly constrained by K-feldspar data, and distance along strike in the Nam Dinh and Day Nui Con Voi (DNCV) range (Fig. 8 of Wang et al., 1998; Wang et al., 2000); (2) that this correlation reflects a cooling diachronism comparable to that described elsewhere along the Ailao Shan by Harrison et al. (1994; 1996) and Leloup et al. (1994); (3) that the extrapolation of this correlation to a postulated Southeast termination of the ASRR, which is located 50 km away from Nam Dinh, dates the onset of left-lateral shear along the ASRR at 27.5 Ma; and (4) that this onset age is younger than the oldest magnetic anomaly in the South China Sea, implying that seafloor spreading was not caused by left-lateral shear along the ASRR as suggested by Briais et al. (1993), Tapponnier et al. (1986) and Leloup et al. (1995). We do not dispute the data presented by Wang et al. (2000) and their interpretation of rapid cooling at Nam Dinh around 27 Ma. However, we show that their interpretation of this data is wrong, which invalidates all their final conclusions. We write this comment to warn readers of their erroneous reasoning and conclusions concerning the time of motion and cooling history of the ASRR.

1. There is no clear correlation between cooling ages and distance along strike in the DNCV

Fig. 8 of Wang et al. (2000) aims to show a correlation between the ages of rapid cooling and the distance along strike, from which a regression line is drawn with a 6.25 cm/yr slope (Fig. 2a). To build this relationship, Wang et al. (2000) use only part of their data (Wang et al., 1998; 2000) without discussing why certain data points (open square on Fig. 2a) should be dismissed. A plot incorporating all available low-temperature (LT) K-feldspar plateau ages yields a different picture (Fig. 2a). Leloup et al. (2001) review all available $^{40}Ar/^{39}Ar$ data for the DNCV. After thorough discussion of uncertainties and measurement quality, they retain only the best of the LT K-feldspar plateau ages (black diamonds and squares on Fig. 2b). These data do not show a simple correlation between age and distance in the DNCV and rather suggest that cooling was almost synchronous along strike (Fig. 2b). At the most, cooling probably occurred 2 My earlier near Nam Dinh (site 23) than in much of the rest of the DNCV.

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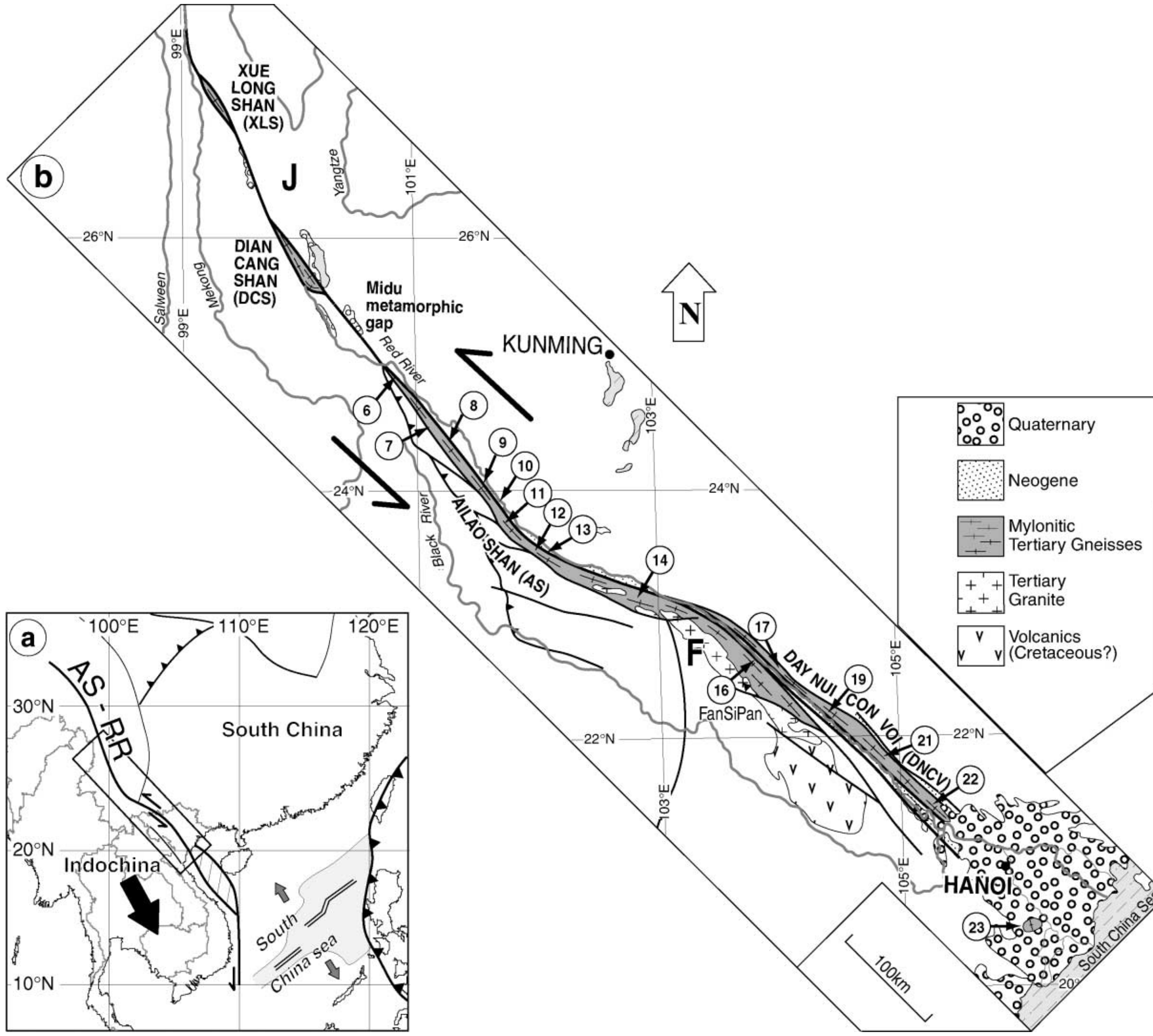

Fig. 1. Schematic map of ASRR shear zone. Modified from Harrison et al. (1996) and Leloup et al. (1996)). Numbers refer to sampling sites visible on Fig. 2. High alkali magmatic rocks: J. JianChuan and F. FanSiPan.

2. The cooling histories of the DNCV and the Ailao Shan are different

Wang et al. (2000) suggest that the cooling diachronism they propose for the DNCV pursue the trend evidenced in the Ailao Shan by Harrison et al. (1994, 1996) and Leloup et al. (1994). Inspection of the data on a larger scale shows, beyond doubt, that there is no single allegedly continuous cooling trend but two distinct ones (Fig. 2b). Low temperature cooling is diachronous along the strike of Ailao Shan and nearly synchronous in the DNCV.

3. The oldest cooling age (Nam Dinh) does not date the onset of left-lateral shear along the ASRR

Left-lateral deformation occurred at temperatures above 600°C (Leloup et al., 1993; 1995; 2001; Leloup and Kienast; Nam, 1998), above the highest argon closure temperatures (amphiboles, ≈ 500°C). Thus, the oldest rapid cooling age (≈ 27 Ma) documented by $^{39}Ar/^{40}Ar$ data, cannot be interpreted as the time of onset of left-lateral shear. Such shear started before and continued during the cooling and denudation of the shear zone (Leloup and Kienast, 1993; Leloup et al., 1995, 2001).

In the Ailao Shan, the correlation between LT K-feldspar rapid cooling ages and distance along strike (Fig. 2b) was interpreted by Leloup et al. (1994) and Harrison et al. (1996) as reflecting a shift to transtension along the SE part of the ASRR shear zone, for which the term ‘zipper tectonics’ was coined. In keeping with this interpretation, samples recording the age of onset of zipper tectonics must indeed lie towards the SE. Three important points, however, have to be taken into consideration: (a) as stated above, cooling diachronism is not evident in the DNCV; thus the cooling

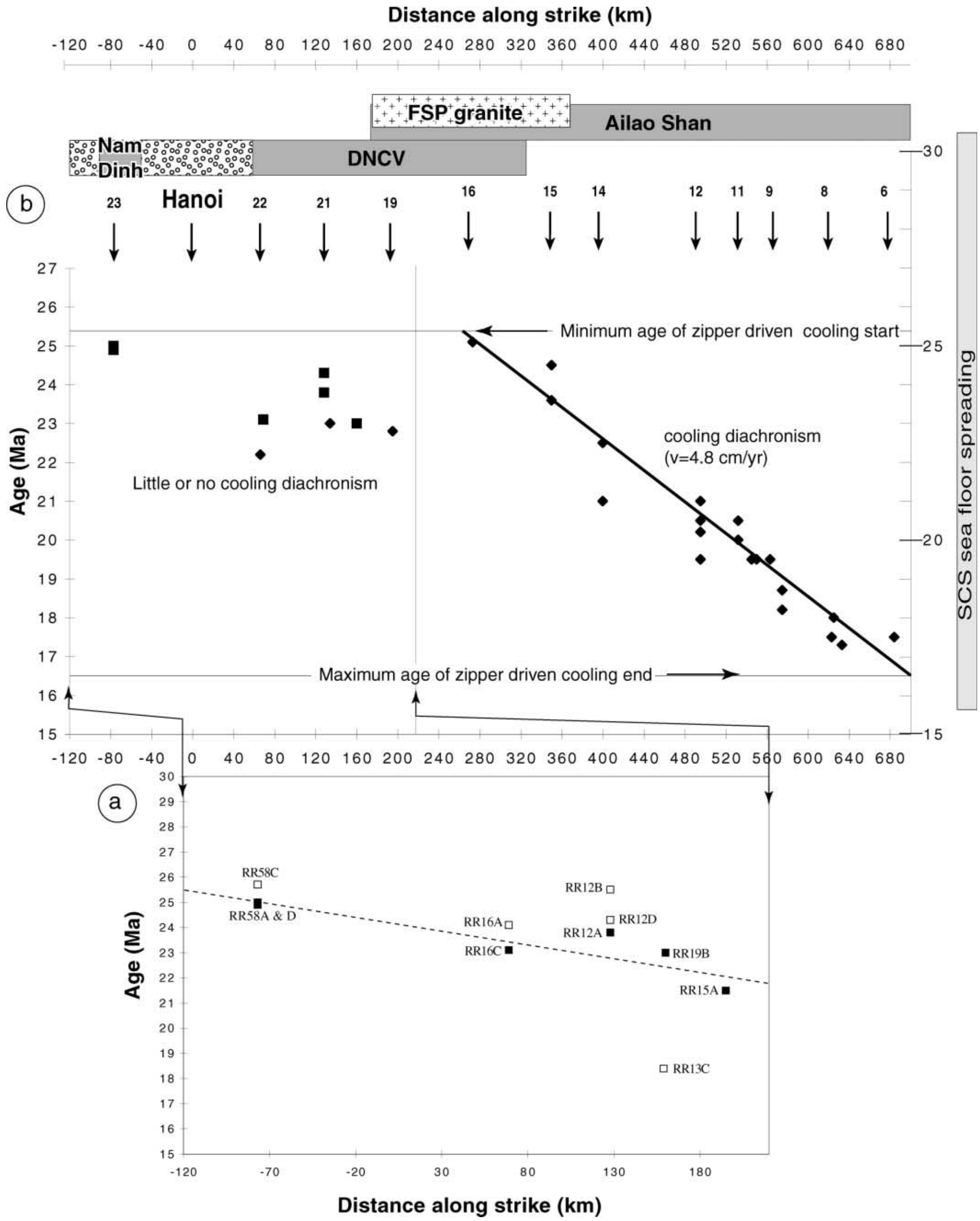

Fig. 2. Plot of ASRR $^{39}Ar/^{40}Ar$ K-feldspar low temperature plateau ages as a function of distance along strike. Hanoï is chosen as the origin. Numbers from 6 to 23 refer to sampling sites located on Fig. 1. (a) Data of Wang et al. (1998; 2000) for DNCV range. Black symbols represent samples used in Fig. 8 of Wang et al. (2000). Dotted line is best-fit line calculated using only these samples. Open symbols correspond to data not used by Wang et al. (2000) for calculation of the regression line. Note that Wang et al. (2000) plot ages of rapid cooling. These ages are thus slightly older than K-feldspar low temperature plateau ages we plotted here. (b) Data from DNCV and Ailao Shan ranges (Harrison et al., 1996; Leloup et al., 2001; Wang et al., 1998; 2000). See Leloup et al. (2001) for discussion of criteria used for data selection.

mechanism in the Ailao Shan cannot be the same as in the DNCV; (b) cooling due to zipper tectonics starts at higher temperatures than the LT K-feldspar closure temperature (≤300°C); (c) strike-slip deformation started before the uplift and cooling due to zipper tectonics. From the Ailao Shan LT K-feldspar data, a minimum age of ≈ 25 Ma can be proposed for the recording of cooling by zipper tectonics (Fig. 2b).

4. Left-lateral shear along the ASRR preceded sea-floor spreading in the South China Sea

4.1. High temperature left-lateral shear timing

Twenty five Ma being the minimum age of recorded zipper driven cooling, when did left-lateral shear begin along the ASRR? Most geochronometers were reset

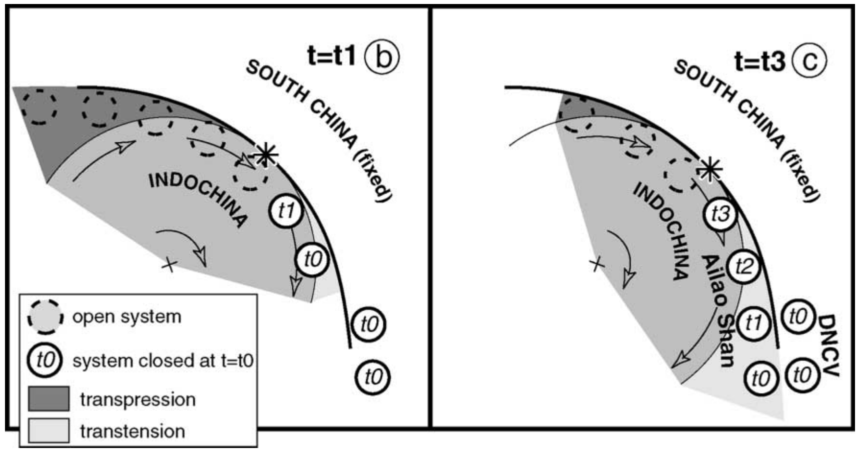

Fig. 3. Cartoon showing different time evolution of Ailao Shan and DNCV samples within the framework of the zipper tectonic model. t0, t1, t2 and t3 refer to progressively younger closure ages. For $^{39}Ar/^{40}Ar$, low temperature K-feldspar plateau ages t0 is ≈ 25 Ma and t3 ≈ 17 Ma. Modified from Leloup et al. (2001). The neutral point (star) is the locus of transition from transpression to transtension that was located in the Midu metamorphic gap (Fig. 1).

during high temperature metamorphism (>600°C) contemporaneous with left-lateral shear (Leloup and Kienast, 1993; Leloup et al., 1995; 2001). The oldest U/Pb ages of granitoids emplaced and deformed within the shear zone are 31.9 ± 0.3 and 33.1 ± 0.2 Ma, as constrained by concordant ages derived from monazites from an orthogneiss in central AilaoShan and Ti–U oxides from a leucocratic layer of XueLong Shan (Zhang and Schärer, 1999). These ages are only minimum ages that post-date both initial shearing, and prograde metamorphism along the ASRR (Leloup et al., 2001).

The oldest magnetic anomalies on both sides of the South China Sea northern ridge are anomalies 10r according to Briais et al. (1993), which corresponds to an absolute age of 28.7–29.4 Ma (Cande and Kent, 1995). Anomaly 11r was possibly identified on the northern flank of the ridge (Briais et al., 1993) suggesting that spreading initiated at 30.1–30.5 Ma (Cande and Kent, 1995). These ages are clearly younger than the onset of left-lateral shear along the ASRR, and are fully compatible with linking the opening of the South China Sea to left-lateral shear along the ASRR (e.g. Briais et al., 1993; Harrison et al., 1996; Leloup et al., 1995; 2001; Tapponnier et al., 1986; 1990).

4.2. High-alkali magmatism and left-lateral shear

Following Chung et al (1997; 1998; submitted), Wang et al. (2000) claim that movement along the ASRR cannot have started before ≈ 30Ma. In their view, Paleogene (29–40 Ma) high alkali magmatic rocks found in eastern Tibet, Yunnan and Vietnam result from partial melting due to delamination of a thickened lithosphere. Matching such rocks from the JianChuan and FanSiPan areas on both side of the ASRR (J and F on Fig. 1), they conclude that a total left-lateral offset of ≈ 600 km accrued after 29 Ma. It is beyond the scope of this comment to discuss if the high-alkali magmatic rocks effectively result from delamination (Chung et al., 1998), hot spot activity (Zhang and Schärer, 1999), shear heating within the shear zone (Leloup et al., 1999), continental lithosphere subduction (Roger, 2001), or another cause. In any case, none of these interpretations discard the possibility that left-lateral deformation started before, and continued during, the magmatic episode. The fact that potassic magmatism and left-lateral shear were coeval is confirmed by structural relationships showing that the largest alkaline body located adjacent to the ASRR (FSP granite in Vietnam, sample V40, 35.2 ± 0.4 Ma, Zhang and Schärer, 1999) was syntectonic (Leloup et al., 2001). This confirms that shearing was active at least as early as 35 Ma and that the ≈ 600 km offset between the JianChuan and FanSiPan alkaline bodies does not correspond to the total offset.

4.3. Tertiary kinematics of the ASRR

Using the $^{39}Ar/^{40}Ar$ data to constrain the timing of shearing is difficult because these data do not directly document the timing of strike-slip motion, but rather the final cooling history and denudation of the shear zone. Thermochronology data from the entire length of the ASRR have to be taken into account to constrain the timing of shear. An exhaustive study of the problem (Leloup et al., 2001) reveals that each metamorphic range of the ASRR experienced its own cooling history. Such histories however, can be incorporated in a unique, self consistent, kinematic model (Fig. 3). This model, first suggested by Briais et al. (1993) and Harrison et al. (1996), is based on the fact that the ASRR does not follow a small circle of the pole of rotation between the Indochina and the South China blocks. This induces continuous transtension in the southeast part of the ASRR, south of the neutral point, with denudation exhuming metamorphic rocks along the shear zone (Fig. 3). Since the DNCV rocks belong to the South

China block, they never experienced a passage from the transpressive to the transtensive domain along the fault and thus have no reason to show cooling diachronism (Fig. 2b and 3). The AilaoShan rocks, by contrast, which are attached to the Indochina block, successively entered the transtension domain as a result of sinistral slip and were diachronously denudated (Fig. 3). These rocks thus show linear diachronous cooling with a slope (4.8 cm/yr from ≈ 25 to ≈ 17 Ma for LT K-feldspar, Fig. 2b) corresponding to their lateral rate of arrival into the transtensional domain. The initiation of denudation in the DNCV (≈ 28 Ma Leloup et al., 2001) approximately corresponds to the oldest cooling age at the SE extremity of the Ailao Shan Leloup (28.1 for biotites from BatXat section, no 16 on Fig. 2; Harrison et al. 1996). We reiterate that this age cannot be used as a proxy to date the onset of left-lateral shear which is known to have occurred earlier at higher temperatures. It only documents the oldest recorded exhumation by zipper tectonics. The coevality of the latest recorded denudation in the Ailao Shan and of the end of seafloor spreading (Fig. 2b), and the fact that the rotation pole for the South China Sea seafloor spreading describes both qualitatively and quantitatively (3–5 cm/yr) the motion observed along the ASRR (Briais et al., 1993; Harrison et al., 1996; Leloup et al., 2001), further confirm the intimate link between shear along the ASRR and the opening of that sea.

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