How the paradoxal Longmen Shan belt has been built: through new petrological structural geochronological data?

Julia de Sigoyer[1], Audrey Billerot[2], Alexandra Robert[1], Stéphanie Duchêne[3], Olivier Vanderhaeghe[2], Manuel Pubellier[1], Patrick Monié[4]

[1] ENS-CNRS UMR 8538, Paris France, sigoyer@geologie.ens.fr
[2] G2R Nancy University, France
[3] GET Toulouse University, France

The paradox of a high eastern Tibetan plateau associated with very low convergence rate (Gan et al., 2007) has led to an underestimation of the seismic hazard in the Longmen Shan area (China) prior to the May 12th 2008, Mw 7.9 earthquake. This paradox has spawned a vigorous debate regarding the relative roles of upper-crustal faulting (Hubbard et al., 2009, Arne et al., 1997) of roughly pure-shear thickening of the Tibetan crust (Robert et al., 2010a, b,) and lower-crustal flow (Royden et al., 2008, Vanderhaeghe and Teyssier 2001) in building and maintaining a high Tibetan margin. Very few data exist regarding the timing and processes of thickening of this eastern Tibetan plateau. Compounding this difficulty is the complexity of structural and petrological records in this area, due to the polycyclic events that have affected this eastern Tibetan margin. Two main events are described (1) the Late Triassic to Late Jurassic Indosinian orogeny and the (2) Cenozoic orogeny (Himalayan collision). The recent uplit history of the Longmen Shan belt has been dated at ~11 Ma (Arne et al., 1997, Godard et al., 2009), however it is not clear how it is directly related to the thickening of eastern Tibetan margin. This study addresses the problem of thickening of this area through time; the aim is to identify the contribution of each event to the present thickening.

Our seismological experiment across the belt (Robert et al. 2010a) showed a sharp vertical offset of the Moho below the Longmen Shan belt, from thick (63 km) east Tibetan crust to a near-normal (44 km) Yangtze crust below the Sichuan basin.
Part of our scientific effort has been deployed to identify the nature of the basement on each part of this Moho step. With geochemical analysis (major trace isotopic) we have first identified that the Neoproterozoic Yangtze basement extended from the Pengguan crystalline massif in the Longmen Shan to the Gezong and Gongcai slices in the Danba area (Fig. 1).
Many Mesozoic granites (Fig 1) emplaced at the end of and after the Indosinian orogeny, between 228,4±1,9 and 153±3 Ma (Zhang et al., 2007, Roger et al 2004), crop out in this eastern border of the Tibetan plateau.

We review all available data on the Songpan Ganze granitoids and studied five new granitoids (Billerot Ph-D). Many different and incoherent sources have been proposed previously for all the granites in this area (Roger et al., 2004, Yuan et al., 2010, Zhang et al., 2007). We identified three different types of granitoids : (i) alkaline granites (ii) high-K calc-alkaline granites represented by the majority of granitoids and (iii) some S-type granites. We have shown that the different types of granitoids can coexist in the same locality. Three types of sources, that underwent various degrees of mixing, have been identified by their elemental and isotopic signatures: the undepleted mantle, the basal continental crust of the Yangtze craton and the Songpan Garze sediments. Two subduction zones were active during late Triassic in this area (Fig 1) we propose a context of slab retreat of the subduction zone for the majority of high-K calc-alkaline granites. The A type granites have an undepleted mantle signature (Yuan et al., 2010), probably due to the upwelling of the asthenosphere located under the subduction slab. This observation suggests the existence of a tear fault in the subduction zone preceding a slab break-off.

Our geochemical analyses on the eastern Tibetan margin suggest then that the nature of the basement is the same on both side of the Moho step. However, the western side has recorded the Triassic orogeny and an intense episode of magmatism (probably related to the slab break off). Whereas the eastern side has not been affected. The thermal and rheological consequence of this Triassic evolution (slab break-off or delamination) has then to be considered In order to understand the the thickenning of the eastern Tibetan margin.

The thickening of the eastern Tibetan plateau is approached by a metamorphic study of the Longmen Shan (Wenchuan-Xuelongbao), Danba and Songpan Garze area. It indicates a much more important zone of high grade metamorphism compared to the previous studies of Zhou et al., 2008.
This metamorphism presents an invert gradient, identified in Danba, Xuelongbao and Wenchuan areas. Garnet, staurolite, biotite±kyanite assemblages allows the estimation of the peak conditions of this event at 580°C for 6 kbar, using several petrological tools (garnet-biotite thermometer and pseudosection using Perplex modelling). The peak of pressure is locally followed by a peak of temperature (about 700°C) at constant pressure that lead to the migmatization of metasediments in Danba. U-Pb ages (microsims) on overgrowing zircon attested a Triassic age (220 Ma) for the high grade metamorphism, as previously proposed by Huang et al.,2002 who related the high grade metamorphism to the Indosinian orogeny.
We identified a greenschist facies overprint of all the area (Songpan Garze-Danba and Longmen Shan internal zones Wenchuan-Xuelongbao zone and Pengguan massif). Analyses of the multiequilibrium between chlorite and phengite solide solution following Lanari et al (2010) method, allow the estimation of metamorphic conditions at 400°C for 5 Kbar for this last event.
U-Pb geochronological studies (Wallis et al., 2003, PhD Robert) indicate a 60-70 Ma event recorded in metamorphic monazites. We don't know whether these ages represent mixing ages or reflect a late Cretaceous reactivation of metamorphism.

While ^{39}Ar-^{40}Ar ages ranging between 75 and 27 Ma were obtained in the Danba area similar to the Itaya et al. (2009) ages. The oldest ages can be clearly interpreted as mixing ages between Indosinian (Triassic) event and Cenozoic reactivation (47-26 Ma).

According to these results a first event of crustal thickening occurred during Triassic time. This zone was probably reactivated by the end of Cretaceous when the Lhasa block was accreted to the Tibetan plateau. Then a second reactivation of deformation and metamorphism under greenschist facies conditions occurred between 47 to 27 Ma. It predates the final uplift phase of the Longmen Shan (since 11 Ma).

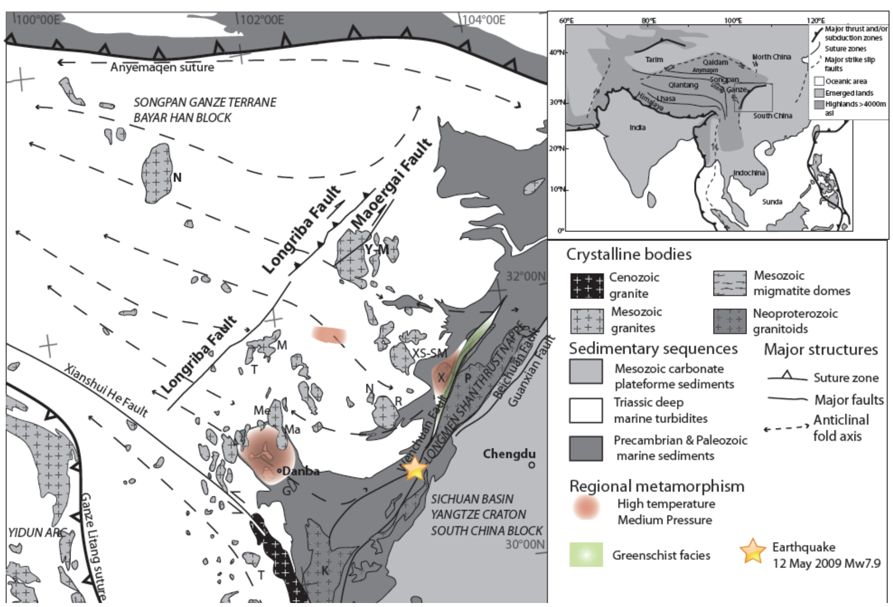

Figure 1 :Geological sketch map of the studied area. Letters represent granitic bodies : T= Tagong, Ma= Manai, M= Markam, R= Rilong, XS-SM= Xue Sheng and Sheng Meng, Y-M= Yaggon et Maoergai, N= Nyanbaoyeche**,** X= Xuelongbao, P= Pengguan, K= Kangding. Insert map represents the global context. See the two opposite suture north and south of the Songpan Garze.

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