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# Comment on « Displacement along the Karakoram fault, NW Himalaya, estimated from LA-ICP-MS U–Pb dating of offset geologic markers » published by Shifeng Wang et al. in EPSL, 2012.

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## Abstract

Field evidence for syn-deformation migmatization and crystallization along the Karakorum fault contradicts the study of Wang et al. [2012]. The ages of such magmatic rocks provide minimum ages for the onset of deformation at ~23 Ma in North Ayilari and ~19 Ma in Tangtse. The onset of deformation at 12 Ma in the Ayilari range inferred by Wang et al. [2012] from a muscovite Ar/Ar age is a cooling age, thus only a minimum age. The ~60 Ma granodiorite bodies, the

ophiolitic rocks and the south Kailash thrust that are correlated across the fault to provide a 52±2 km finite offset do not define reliable piercing points. Such observations as well as our previous work concur to show that the Karakorum fault initiated in the Oligo-Miocene, and has a long-term dextral slip-rate between 7.5 and 13 mm/yr, approximately twice that proposed by Wang et al. [2012].

## Introduction

Wang et al. [2012] published a high quality set of new U/Pb zircon ages from the Ayilari and Kunsha granites located across the Karakorum fault (KKF) in western Tibet. They confirm that both granites experienced crystallization events at ~60 and ~50 Ma, and that the North Ayilari granite (also called Zhaxigang) experienced a late crystallization event at ~20 Ma. Based on this chronological data, and on consideration of other potential offset markers, they infer a finite offset of 52±2 km on the KKF, dismissing previously proposed larger offsets. They propose that motion on the KKF initiated at ~16 Ma in its central part at Tangtse (Ladakh, India), and propagated to the southeast to reach the Gar-Namru area (Ayilari range) by ~12 Ma. They consequently calculate a slip rate of 4.5±0.1 mm/yr since 12 Ma. This is taken as evidence for Tibet deforming in distributed fashion rather than by localized strain through extrusion along major faults.

This debate on initiation age, total offset and slip rate of the KKF, which started 25 years ago, continues despite significant technical advances and much improved knowledge of this remote area [e.g., *Chevalier et al.*, 2005; *Lacassin et al.*, 2004a; *Murphy et al.*, 2000; *Peltzer and Tapponnier*, 1988; *Robinson*, 2009; *Searle*, 1996; *Searle and Phillips*, 2007; *Valli et al.*, 2008]. Wang et al. [2012] contribute to this effort by bringing new age constraints on granites located on both sides of the fault. Regrettably, they do not take into account key structural observations that must be considered in order to understand and constrain the deformation timing, offsets and displacement rates along the fault. We show below that the initiation age inferred by Wang et al. [2012] is based on an erroneous assumption, and is incompatible with older ages of demonstrably synkinematic granites. We also argue that the piercing points the authors define are far from adequate to measure the total offset on the fault.

**Timing of right-lateral deformation along the Karakorum fault.**

Ductile mylonites related to the KKF have been described at three locations: Nubra Valley, Darbuk-Tangtse-Pangong region and North Ayilari range. In Tangtse, a key outcrop shows a mylonitic granitic dyke (sample P11) concordant to the foliation whose crystallization has been dated at 15.87 ±0.08 Ma and an undeformed cross-cutting dyke (sample P8) with an age of 13.73 ±0.34 Ma [*Searle and Phillips*, 2007 and references therein] (Fig. 1a). This was interpreted as bracketing the ductile deformation that would have lasted less than 2.2 Ma [*Searle and Phillips*, 2007 and references therein]. Because comparable dykes give similar ages in the Nubra Valley, and disregarding evidence for synkinematic partial melting in the granites and migmatites, the inference that most magmatism predates fault movement was extended from a single outcrop to the entire KKF [*Searle and Phillips*, 2007 and references therein]. Following this inference, Wang et al. [2012] assume without producing new evidence, that none of the granites of the Ayilari and Tangtse ranges are synkinematic and that the KKF must be younger than 16 Ma.

However, evidence for synkinematic melting and granite migration in the Darbuk-Tangtse-Pangong and North Ayilari regions are plentiful, and some of the data provided by Searle and Phillips [2007] are inaccurate. For example, their P8 dyke, which is depicted as cross-cutting the whole KKF Tangtse mylonitic strand (Fig. 3 in [*Searle and Phillips*, 2007]), is in fact only 8 m-long and shows dextral deformation tails attesting that it is syntectonic (Fig. 1a & b). Other evidence for syntectonic magmatism are: 1) At a microscopic scale, late melt channels following two distinct orientations, are parallel to the S-C fabric resulting from right-lateral shear in the Karakorum Shear Zone (Fig. 1f), thus implying that magma migration was coeval with deformation [*Hasalova et al.*, 2011]. 2) Dykes cross-cutting foliation but which are themselves deformed (e.g. P8, Fig. 1a,b; K1C32, Fig. 1e), [*Boutonnet et al.*, 2012; *Valli et al.*, 2008]. 3) Leucosome pods affecting the foliation but overprinted by right-lateral shearing (Fig. 1c & d) [*Boutonnet et al.*, 2012]. 4) Magmas formed by local anatexis and migrating during folding into axial-planar leucosomes, sub-parallel to the mylonitic foliation, indicating that anatexis, folding and right-lateral shearing were coeval [*Weinberg et al.*, 2009 and references therein] (Fig. 1h). 5) Leucosomes filling boudin necks, indicative of *in situ* partial melting during deformation [*Mukherjee et al.*, 2012] (Fig. 1g). 6) At a macroscopic scale, the close relationship between the dyke network and the structures resulting from right-lateral shear has led Reichardt et al. [2010] to propose that magma migration was controlled by stresses related to right-lateral transpression. 7) Last but not least, the 18.5±0.2 Ma South Tangtse granite shows progressive transition from an undeformed granite in its central part, to a granite with faint magmatic foliation, and finally to a mylonitic orthogneiss along the Tangtse strand of the KKF, indicative of its syntectonic nature [*Leloup et al.*, 2011].

The ages of granitoids with robust structural evidence for syn-deformation crystallization are ~23 Ma in North Ayilari [*Valli et al.*, 2008] and span between ~19 and 14 Ma in Tangtse [*Boutonnet et al.*, 2012], implying that the KKF deformation started prior to the Lower Miocene at these locations. Note that such observations neither imply nor necessitate magma generation to be due to strike-slip deformation.

Wang et al. [2012] take the 12±1 Ma muscovite Ar/Ar age from sample A12 within the KKF shear zone in the Ayilari range as reflecting the onset of deformation at this location although there is no clear evidence for such an interpretation. Indeed, Ar/Ar ages are acquired at or below the closure temperature of a mineral and do not alone provide an age for the initiation of deformation. In the case of the Ayilari range, microstructural evidence, such as feldspar core-andmantle structures and subgrain rotation deformation regime in quartz, indicate that deformation started at temperatures above 500°C [e.g. *Valli et al.*, 2008] while the closure temperature for Ar in muscovite is ~ 425°C. Thus, sample A12 Ar/Ar age only provides a minimum age for the onset of deformation.

We therefore argue that our previous conclusions that the KKF initiated prior to 19 Ma in Tangtse, 23 Ma in North Ayilari and 13 Ma in South Ayilari are more accurate determinations than Wang et al.'s suggestion.

**Amount of offset across the Karakorum fault.**

Wang et al. [2012] link the Namru ~60 Ma granodiorite body located southwest of the KKF (sample Z03, Fig. A1) with another ~60 Ma granodiorite body located across the KKF (samples K11 and K07, Fig. A1), in order to restore a 52±2 km right-lateral offset across the fault. However, granodiorite bodies of this age relate to the most voluminous magmatic pulse in the Ladakh and Gangdese batholiths and can be found all the way to the Lhasa region more than 1000 km farther east [e.g., *Ji et al.*, 2009]. The challenge is thus to determine which ~60 Ma granodiorite body correlates with the Namru one. Matching granodiorite K13 results in a ~27 km left-lateral offset (Fig. A1) inconsistent with a right-lateral KKF. Matching any granodiorite body located north of the KKF and east of Menci yields a right-lateral offset larger than 52 km.

According to Wang et al. [2012], the proposed ~50 km offset is confirmed by a similar offset of rocks from the Yarlung-Zangbo (YZ) suture and of the Great Counter Thrust (GCT, locally called the South Kailash Thrust), two more distinctive markers. However, the trace of the KKF depicted in Wang's et al. [2012] Figure 4 is misleading: morphological and geological evidence show that the KKF bends eastwards and that its main trace lies north of the Menci basin, trending ~N120° north of the Raksas lake [Figs. 2, 8 & 12 in *Chevalier et al.*, 2012; Figs. 7b & c in *Lacassin et al.*, 2004b], and that the South Kailash thrust is a transpressive branch of the KKF itself (Fig. A1). The northernmost ultramafic rocks, including those taken by Wang et al. [2012] to define a piercing point because supposedly lying NE of the KKF, are in fact exposed in narrow slivers bounded by WNW-SSE splays of the KKF (Fig. A1). Such slivers show clear structural evidence for right-lateral shear [Figs. 7b & c in *Lacassin et al.*, 2004], and are thus best interpreted to lie within the KKF zone. The YZ piercing point thus only yields a minimum offset, with the KKF following the northern edge of the suture after having obliquely cut the batholith (Fig. A1).

Wang et al. [2012] consider the apparent offset of the GCT to constrain both the age (less than 12 Ma) and the total offset (~60 km) of the KKF. However, the EW striking GCT and the NW-SE striking right-lateral KKF are compatible with the same regional state of stress. The GCT may have formed at a time when the KFZ was already active, in which case it cannot be used to define the piercing points of a total offset. Furthermore, the Kailash thrust has been interpreted as part of a flower structure branching on the KKF [*Lacassin et al.*, 2004b] (Fig. A1).

A more detailed assessment of the most probable propagation timing and large-scale offsets of the KKF is beyond the scope of this comment. We refer to the detailed discussions in Valli et al. [2008] that favour a total offset of 200 to 240 km, with an offset of ~120 km since ~14 Ma in the central section of the KKF. These estimates are based on the large-scale bending of the YZ suture, the offsets of the Late Cretaceous Shyok and Shiquanhe sutures, and the minimum dogleg offset of the Indus river. Corresponding long-term dextral slip-rates thus range between 7.5 and 13 mm/yr, approximately twice that proposed by Wang et al. [2012], but consistent with the Late Pleistocene rates derived from the offsets of dated moraines and fluvial surfaces by Chevalier et al. [2012].

**Conclusion.**

As opposed to what is asserted by Wang et al. [2012], there is compelling evidence for synkinematic migmatites and granites within the KKF zone. These granitic melts are the rocks that provide a minimum age for dextral shear initiation: ~23 Ma in North Ayilari and ~19 Ma in Tangtse. The temperature of deformation recorded in the KKF outcrops in North Ayilari and Tangtse are higher than 450°C, implying that the Ar mica ages are cooling ages, which cannot be used to date the onset of right-lateral movement on the fault. The Lower Cenozoic granodiorite rocks found across the KKF, the YZ ophiolites and the GCT cannot be used to define accurate piercing points adequate to pin down the total offset on the KKF.

We conclude that the ~20 Ma magmatism along the KKF is synkinematic and that slip-rates, total offset and initiation age of movement on the fault are all significantly larger than those proposed by Wang et al. [2012]. More generally, this discussion illustrates the way, and the pitfalls that must be avoided, to define piercing points and date deformation on large continental strike-slip shear zones. Finally, while some distributed faulting and block rotation occurs in Tibet, there can be no doubt that the KKF is one of the main, long-lived, block-boundary faults in the India/Asia collision zone.

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**Figure 1.** Examples of published evidence for synkinematic melting along the KKF. (a) Leucocratic dyke P8 that crosscuts the right-lateral N130°-trending foliation, but exhibits two asymmetric tails indicative of NW-SE ductile right-lateral shear. The intrusive contact is underlined by red short dashes and the foliation by yellow long dashes. Oblique view from above. (b) Detail of one of the ductile tails of P8 showing cross-cutting relationship (intrusive, red short dashes) with the amphibolitic schists, and concordant contact with the marbles lying parallel to the main shearing direction. View from above, with a hammer for scale. (a) and (b) are from the Tangtse strand of the KKF [*Boutonnet et al.*, 2012]. (c) Pegmatitic dyke LA58, stretched and boudinaged parallel to the right-lateral foliation (N135°/vertical, lineation pitch of 5 SE). The black frame corresponds to Figure 1d. (d) Detail of LA58, showing the schist layers embedded in the pegmatite as well as the right-lateral deformation (red arrows). (top) Field picture

taken from above, (bottom) interpretative sketch. (c & d) are from the Muglib strand of the KKF [*Boutonnet et al.*, 2012]. (e) Cross-cutting veins in the foreground are intensely right-laterally sheared in the background. North Ayilari range [*Valli et al.*, 2008]. (f) Thin section map showing the distribution of neo-crystallized material at micro-scale (sample TNG165, Muglib strand of the KKF). The neo-crystallized material forms an interlinked extensive network broadly defining a right-lateral S-C fabric indicative of syn-magmatic shearing [*Hasalova et al.*, 2011]. (g) Accumulation of mica-rich melt in boudin necks (BN) of the deformed Ladakh granite indicating *in situ* partial melting during right-lateral deformation [*Mukherjee et al.*, 2012]. Tangtse strand of the KKF, view from above. (h) Deformed migmatites from the Tangtse gorge. View towards the NW, nearly vertical outcrop with a coin for scale. The fold axial planes are sub-parallel to the right-lateral shear of the KKF. The axial planar leucosomes, accommodating disruption and small slip of the antiform and synform, indicate syn-anatectic folding. Folds are part of dextral transpression on the KKF. The preferential preservation of antiforms and destruction of synforms is typical of deformation during partial melting.

**Figure A1. Simplified geologic map of the Karakorum fault between 79°30’E and 82°E.**

Active faults drawn from Chevalier et al. [2012] and Valli et al. [2007]. The ophiolites and ophiolitic melanges as well as the other faults are drawn from the 1/250 000 geologic maps. The KKF trace inferred by Wang et al. [2012] (green short dashes) cuts across the ophiolitic melange ignoring several fault branches. The northern boundary of the KKF zone (green long dashes) follows the northern edge of the suture zone north of Menci.

Kmz files of the active faults (ActiveFaults.kml) and the other faults (Faults.kml) are provided as supplementary material.

Figure

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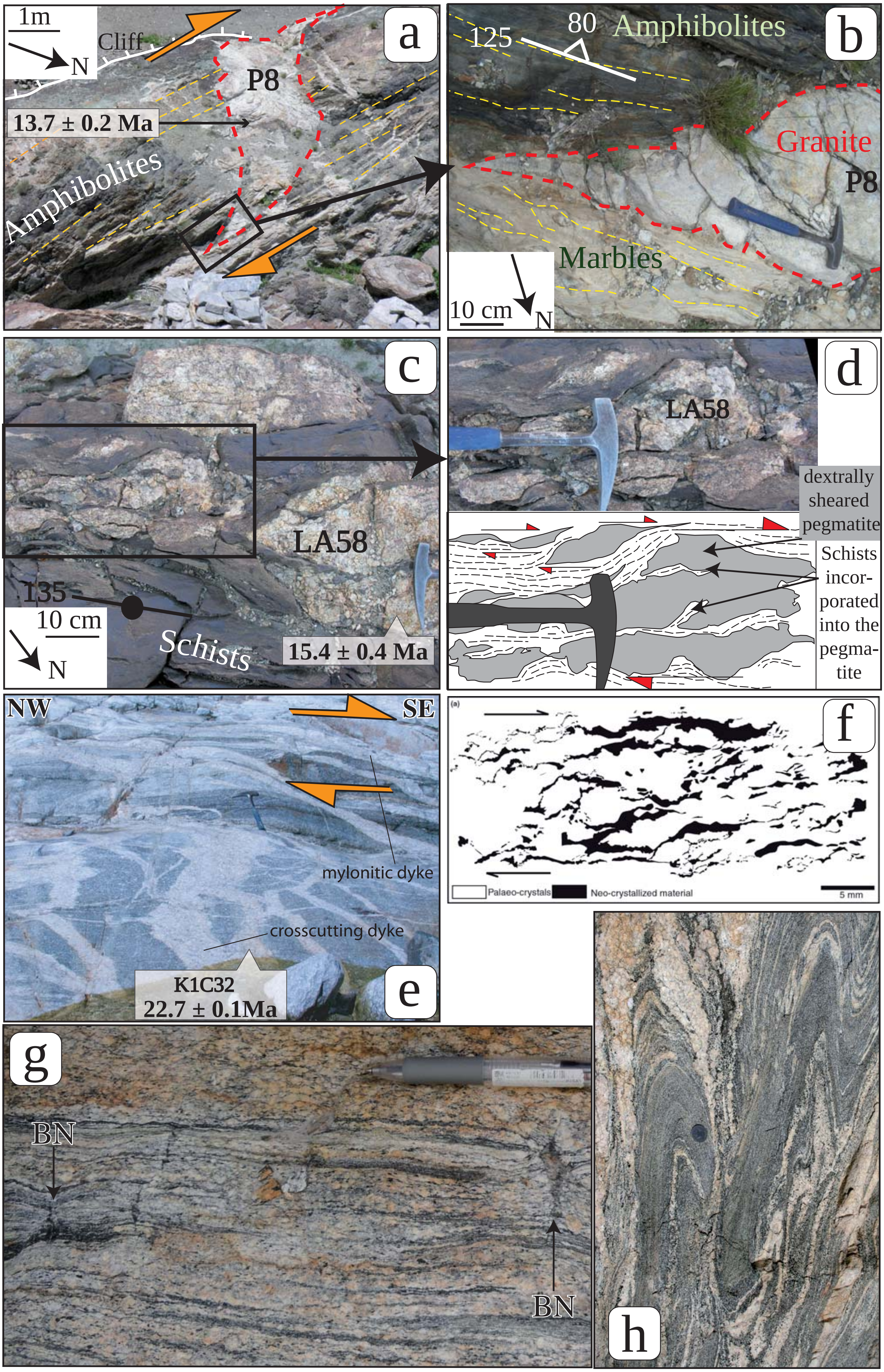

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