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ABSTRACT

The net slip on the southern portion of the Karakoram fault system in southwest Tibet is estimated by restoring a piercing line defined by two key surfaces in the South Kailas thrust system, a regional counter thrust along the Indus-Yalu suture. Assuming that the thrust system is planar across the Karakoram fault, we calculate 66 ± 5.5 km of normal right slip. Documentation of the South Kailas thrust active at 13 Ma implies that the Karakoram fault in southwest Tibet did not initiate until after the cessation of motion on the thrust. However, field investigations of the central portion of the Karakoram fault system document the fault to have been active at 17 Ma and to have accumulated a maximum of 150 km of right slip. We suggest that these along-strike variations in the magnitude of slip and timing constraints are best explained by southward propagation of the Karakoram fault system. This is inconsistent with major right-lateral slip on the fault system, which was used in support of extrusion models for Tibet.

Keywords: Himalayan orogeny, Indus-Yarlung Zangbo suture zone, Karakoram, Pamir Range, strike-slip faults.

INTRODUCTION

Two unresolved issues regarding the evolution of the Tibetan Plateau are (1) the fundamental deformation mode by which ~2500 km of convergence was accommodated since the initial collision of India and Asia ca. 50 Ma, and (2) the geodynamic significance of active regional-scale strike-slip faults bordering Tibet. The regional extent and apparent large translation of geologic features across the Karakoram fault system have suggested to many that it has participated significantly in accommodating deformation related to the Indo-Asian collision. Kinematic models for the role of this fault system include (1) a transform fault accommodating wholesale extrusion of Tibetan crust (Peltzer and Tapponnier, 1988; Tapponnier et al., 1982); (2) a strike-slip fault accommodating oroclinal bending of the Himalayan arc (Klootwijk et al., 1985); (3) a transfer fault accommodating northward indentation of the Pamirs (Strecker et al., 1995; Ratschbacher et al., 1996; Searle, 1996); and (4) a transfer fault linking extension in the Pamirs and southwest Tibet (Ratschbacher et al., 1994). These models make specific predictions about the timing and magnitude of slip on the Karakoram fault system and how it may have evolved through time, yet our current understanding of its slip history remains poor. Herein we present field observations and discuss their implications for the evolution of the Karakoram fault system in an area in southwest Tibet, where the timing and magnitude of slip can be constrained.

KARAKORAM FAULT SYSTEM

The active trace of the Karakoram fault system extends more than 1000 km from the Pamirs to Mount Kailas (Fig. 1). Slip estimates on the fault system are ~1000 km from offset of the Ladakh-Gangdese batholith (Peltzer and Tapponnier, 1988); ~200 km from offset of the Indus-Yalu suture (Ratschbacher et al., 1994); and ~150 km from offset of Baltoro-type granites, which are a part of the Karakoram batholith (Searle et al., 1998) (Fig. 1).

We established the geometry and kinematics of the Karakoram fault system by mapping portions of the fault system at a scale of 1:100 000 between Zhaxigang and Barga (Fig. 2A). The fault system shows striking similarities at each of the localities that we mapped, as outlined in the following. From east to west, traversing from Gar Valley into the Ayi Shan (Fig. 2A), an ~2-km-wide zone of subparallel vertical to northeast-dipping right-slip and normal-slip brittle faults occupies the base of the range front. Alluvial fans, glacial moraines, and colluvium are both cut by, and unconformably overlie, faults within this zone. Fault surfaces are in general poorly exposed. Consequently, shear sense was primarily determined from offset geomorphic features, such as alluvial fans or stream channels. Most of these faults show <10 m of offset and cannot be traced more than 1 km along strike.

At the range front, between Namru and Baer (Fig. 2A), right-slip faults, normal-slip faults, and normal right-slip faults dip moderately (~45°) to the east and west (Fig. 2B). Slip on these faults created flatirons along the east side of the range. The tops of the flatirons are ~500–1500 m above the valley floor. We refer to this set of through-going, range-bounding faults

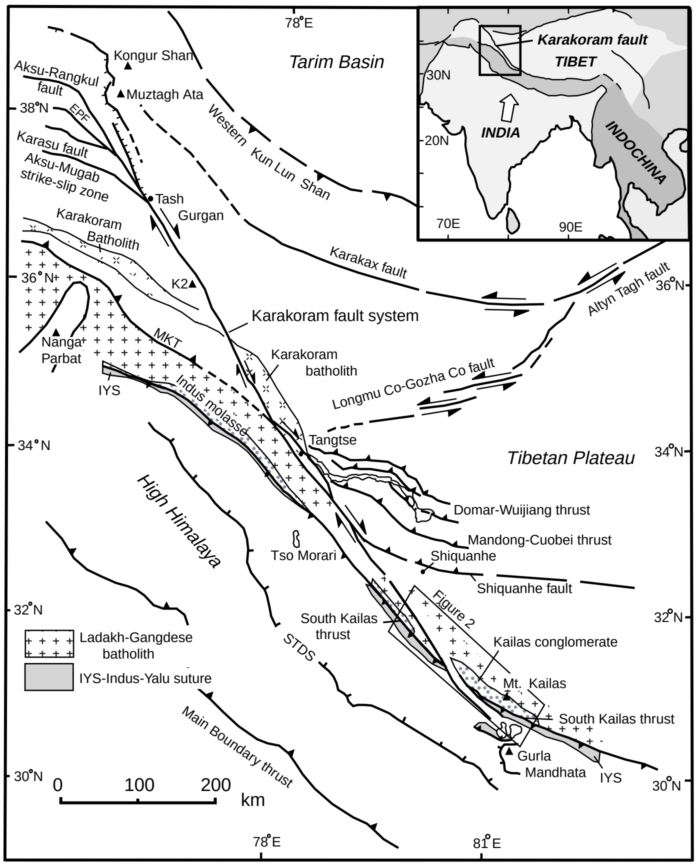

Figure 1. Geologic sketch map of Karakoram fault system, including adjacent major structures in western Himalaya and western Tibet. Abbreviations: MKT—Main Karakoram thrust, EPF—East Pamir fault, IYS—Indus-Yalu suture, and STDS—South Tibet detachment system. Modified from Searle et al. (1998).

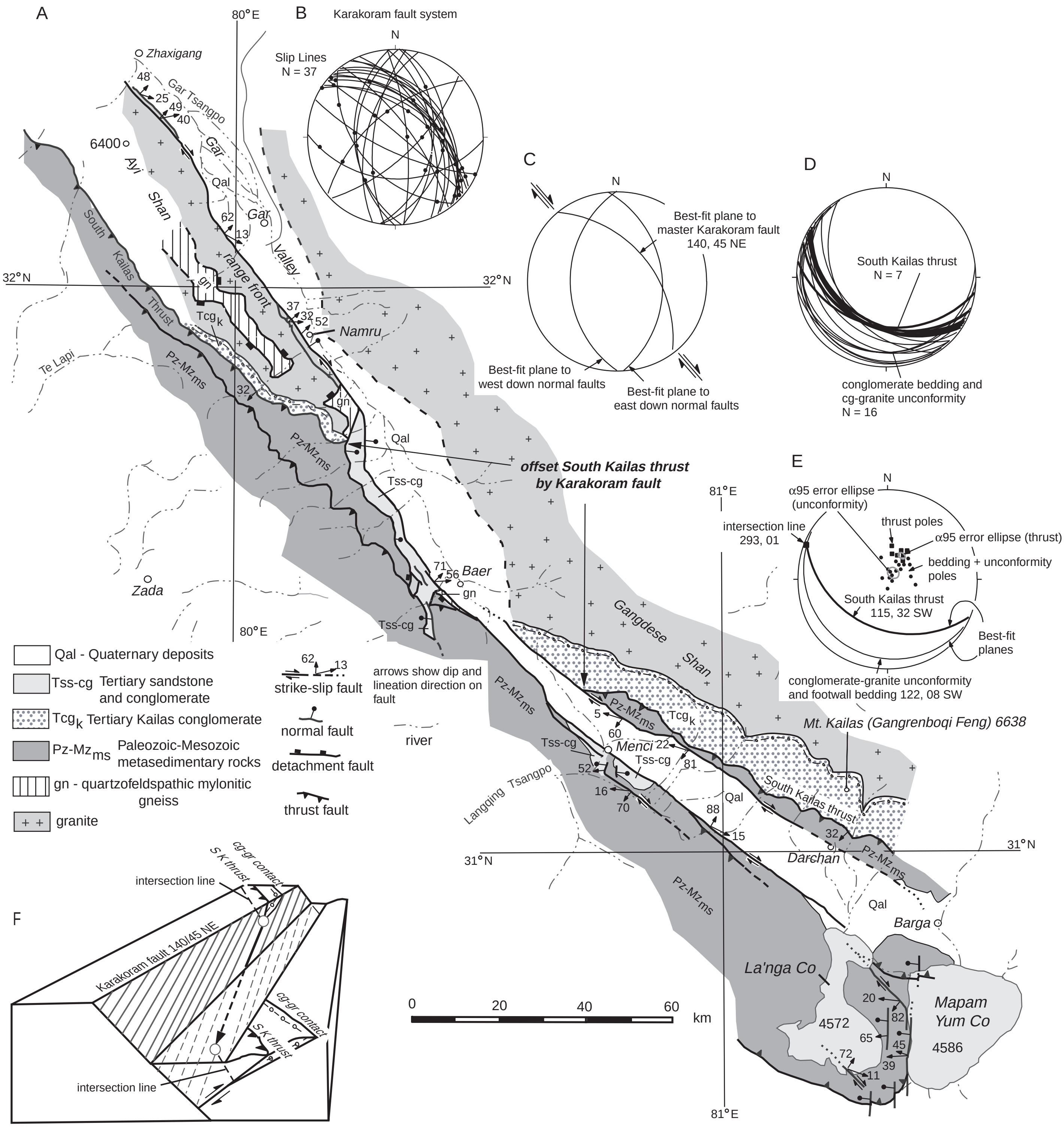

Figure 2. A: Geologic map of southwest Tibet compiled from our mapping, Chen and Xu (1987), and Tibetan Bureau of Geology and Mineral Resources (1987). Map shows main trace of Karakoram fault system and key components of South Kailas thrust discussed in text. B, C, D, E: Lower hemisphere, equal-area stereonets showing orientation data from Karakoram fault system and South Kailas thrust. F: Schematic representation of South Kailas thrust offset along geometrically simplified trace of Karakoram fault.

collectively as the master fault. It has a linear trace across the range front, and along much of its length cuts granodiorite belonging to the Gangdese batholith. Granodiorites exposed in the Namru areas can be correlated across the fault and imply ≥500 m of normal slip on the master fault. Where exposed, a thin layer (<10 cm) of foliated gravely clay gouge defines the fault surface. East of Menci (Fig. 2A), where the master fault cuts serpentinite, the gouge zone is thicker, ranging from 1 to 10 m. Shear sense on the master fault was determined primarily from tool marks and chatter marks that suggest dominantly right slip motion.

Fault-slip data were collected at each mapped area along the Karakoram fault system, and were used to characterize its regional slip direction. Measurements of the master fault strike between 133° and 152° and dip between 35°

and 60° to the northeast. Most of the kinematic data from the master fault and satellite small-scale right-slip faults plot with a rake ≤20° from the south, indicating a dominant component of right slip (Fig. 2C). Fewer kinematic data plot along two north-striking great circles dipping east and west. These measurements are from north-striking normal faults generally concentrated at places where the master fault steps to the right.

SOUTH KAILAS THRUST SYSTEM

In order to determine net slip on the Karakoram fault system, we mapped the South Kailas thrust on both sides of the Karakoram fault system (Fig. 2A). This thrust has been correlated with the Renbu-Zedong thrust in southeast Tibet, and the Main Zanskar backthrust in the Western Himalaya (Searle, 1986); collectively, they were referred to as the Great Counter thrust by Yin et al. (1999). We mapped the thrust at four areas, Namru, Baer (southwest side of Karakoram fault), Menci, and Darchan (northeast side of the Karakoram fault) (Fig. 2A). The South Kailas thrust at each of these localities shows similar stratigraphic and structural relationships. It is composed of a system of north-directed thrusts. The most foreland of these cuts upsection at a 30°–35° dip, placing Triassic-Jurassic strata and locally ultramafic bodies over Tertiary conglomerate. The conglomerate, referred to as the Kailas conglomerate by Gansser (1964), contains red and green volcanic and granitic clasts. This unit unconformably overlies a Cretaceous-Tertiary granite (Chen and Xu, 1987; Yin et al., 1999). In the Baer area, this foreland-most thrust is not exposed because it has been cut by the Karakoram fault system. Except where serpentinite abuts the fault, the thrust displays brittle fabrics. There is a <1-m-thick zone of coarse-grained foliated pebbly-sandy clay gouge. Adjacent to the fault, the footwall strata display drag folds, suggestive of thrust motion. Farther from the fault (>10 m) the footwall strata are planar. These similarities suggest that the thrust at each locality represents the same fault. Moreover, the observation that the thrust juxtaposes nearly identical units on both sides of the Karakoram fault system implies a similar magnitude of slip across the fault system.

MAGNITUDE AND TIMING OF SLIP

In order to calculate the net slip on the Karakoram fault, we define an intersection line between the conglomerate-granite unconformity and the South Kailas thrust, which is offset by the Karakoram fault system (Fig. 2A). The strike and dip of the South Kailas thrust at these three areas are similar (Fig. 2D). The best-fit plane to the South Kailas thrust is oriented 115°, 32°SW (Fig. 2E). Our measurements of the conglomerate-granite unconformity include both attitudes of the unconformity and bedding immediately above the unconformity. The best-fit plane to the unconformity and footwall bedding is oriented 122°, 08°SW (Fig. 2E). The intersection line of these two best-fit planes is oriented 293°, 01° (Fig. 2E).

We calculate the offset of this line along our estimated regional orientation of the master Karakoram fault between 32°40′ and 31°20′ (Fig. 2C), which is based on our own measurements and those presented in Liu (1993). Figure 2F shows a schematic representation of our geometric simplification and structural analysis. The geometrically simplified trace of the Karakoram fault system is chosen to daylight midway along the approximately north-striking right step in the fault system ~30 km south of Namru (Fig. 2A). The intersection line between the South Kailas thrust and the conglomerate-granite contact intersects the west side and east side of the Karakoram fault at the 5600 m and 1800 m structure contours, respectively. The calculated net slip is 66 ± 5.5 km oriented 137°, 3°. The net slip decomposes into 65 ± 5.5 km of right slip oriented 140°, 00° and 3.8 ± 0.6 km of normal slip oriented 050°, 45°. The error we associate with our slip estimate is based on the uncertainty of the orientation of the intersection line.

Because our slip calculation is based on offset of the South Kailas thrust and the conglomerate-granite unconformity, it only constrains the magnitude of slip since the thrust ceased moving. On the basis of modeled K-feldspar $^{40}Ar/^{39}Ar$ data from clasts in the footwall conglomerate of the South Kailas thrust, Yin et al. (1999) suggested that the thrust was active ca. 13 Ma. This constraint places an upper bound on the timing of slip on the Karakoram fault system of <13 Ma.

DISCUSSION

We estimate that the southern portion of the Karakoram fault system has accumulated ~66 km of dominantly right slip since after 13 Ma. On the basis of the apparent offset of the northern extent of the Ladakh-Gangdese batholith (Fig. 1) from long 78°E to 85°E across the Karakoram fault system, Peltzer and Tapponnier (1988) estimated 1000 km of right slip since about 50 Ma, which implied large-scale extrusion of Tibetan crust. Considering both these estimates requires that ~940 km of right slip on a proto-Karakoram fault occurred prior to initiation of the South Kailas thrust. However, the northern limit of the Gangdese batholith on the northeast side of the Karakoram fault must be west of long 81°E because granites representing the batholith are

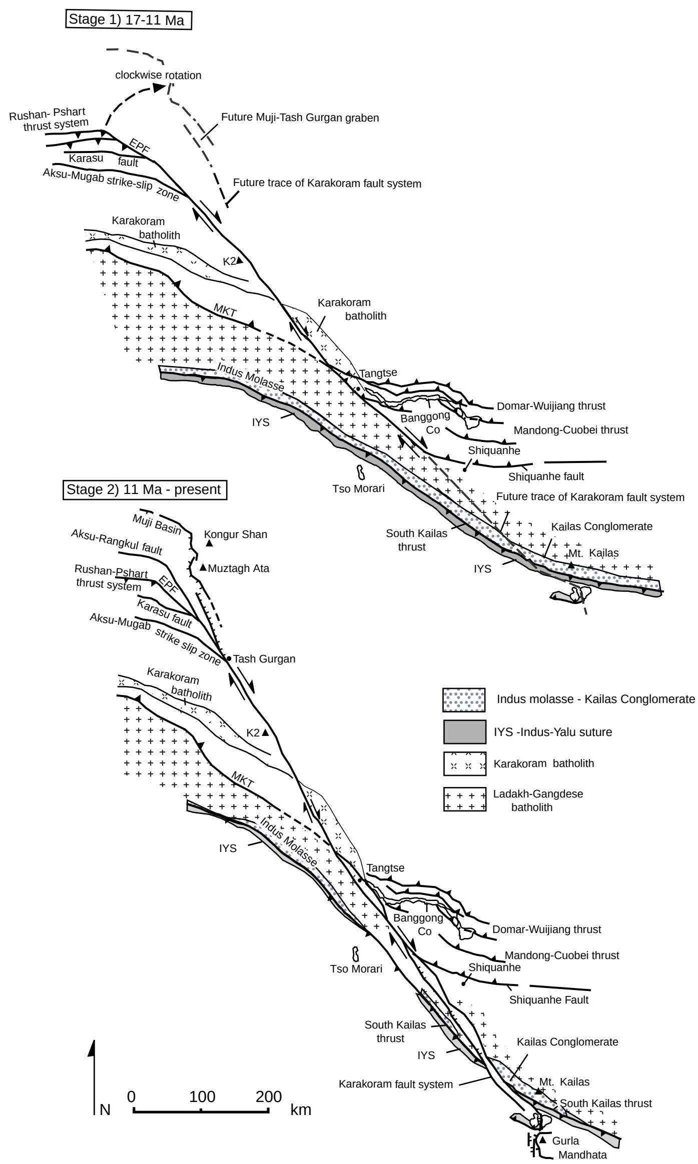

Figure 3. Proposed two-stage evolution of Karakoram fault system showing its southward propagation into southwest Tibet. Abbreviations: EPF—East Pamir fault, IYS—Indus-Yalu suture zone, MKT—Main Karakoram fault. Stage 1: Karakoram fault system transfers slip between north-directed thrusts belonging to Rushan-Pshart ophiolite zone and south-directed thrusts between Banggong Co and Shiquanhe. Stage 2: Karakoram fault system propagates southward into southwest Tibet. Refer to text for details.

present in the Mount Kailas area (Gansser, 1964; Chen and Xu, 1987; Yin et al., 1999; observations noted herein) and potentially as far west as the Gar Valley (Chen and Xu, 1987) (Fig. 2A), thus lowering this slip estimate by at least 500 km and possibly as much as 700 km. Although this feature may be a viable candidate for which Tertiary offsets along the Karakoram fault may be calculated, its position in western Tibet is not well constrained. Therefore, we emphasize the lack of evidence supporting the existence of a proto-Karakoram fault and thus large-scale eastward extrusion of Tibetan crust.

Alternatively, our results along the southern portion of the Karakoram fault system combined with those from the central Karakoram fault system (Searle et al., 1998; Dunlap et al., 1998) suggest that it has lengthened through time. Two complementary studies along the central Karakoram fault (37°N–33°N) by Searle et al. (1998) and Dunlap et al. (1998) documented two periods of rapid cooling of fault-zone rocks resulting in exhumation of 21–17 Ma leucogranites along the central Karakoram fault in Ladakh during a transpressional phase from 17 to 11 Ma, and a later dominantly strike-slip phase from 11 to 0 Ma. Searle et al. (1998) estimated a maximum of 150 km of accumulated slip on the Karakoram fault system since 17 Ma (Fig. 1). The timing and style of faulting in southwest Tibet is only consistent with the second (strike slip) phase. An explanation for the lack of 17–11 Ma transpressional deformation along the Karakoram fault in southwest Tibet is that slip may have been transferred to one of several Cenozoic thrusts in the Banggong Co and Shiquanhe areas (Fig. 1). Geologic maps by De Terra (1932), Chen and Xu (1987), Matte et al. (1996), and Kapp et al. (1999) show several south to south-southeast–directed thrust faults extending eastward from the Karakoram fault system. On the basis of the timing and slip constraints we propose the following kinematic model for the evolution of the Karakoram fault system (Fig. 3). During stage 1, 17–11 Ma, the Karakoram fault system acts as a transfer fault linking thrust systems now exposed in the central Pamirs along the Rushan-Pshart zone (Burtman and Molnar, 1993; Strecker et al., 1995; L. Ratschbacher, 1999, personal commun.) and west Tibet (De Terra, 1932; Chen and Xu, 1987; Matte et al., 1996; Kapp et al., 1999). It is attractive to link the Karakoram fault system to thrusts in west Tibet during the middle Miocene because it explains the lack of strike-slip faulting in southwest Tibet at that time, during which the South Kailas thrust is interpreted to have been moving (Yin et al., 1999). It has been suggested (Burtman and Molnar, 1993; Searle, 1996) that indentation of the Pamirs during the middle Miocene was accompanied by clockwise rotation of the western Tibet. During stage 2, from 11 Ma to present, the Karakoram fault system evolves or reactivates as a transtensional fault system and lengthens southward into southwest Tibet. Assuming that the Karakoram fault system evolved in this manner, the slip estimate and timing constraint of Searle et al. (1998) implies that the Karakoram fault system accumulated ~84 km of slip between 17 and 11 Ma, yielding an average slip rate of 14 mm/yr. The average slip rate on the southern segment of the Karakoram fault system since ca. 11 Ma has been 6 mm/yr.

CONCLUSIONS

A regional backthrust system, locally referred to as the South Kailas thrust, is offset by the Karakoram fault system in southwest Tibet. By assuming that the thrust system is planar across the Karakoram fault system, we calculate 66 ± 5.5 km of normal right slip. Documentation of the South Kailas thrust being active ca. 13 Ma by Yin et al. (1999) implies that the Karakoram fault in southwest Tibet did not initiate until after the cessation of motion on the thrust. However, field investigations of the central portion of the Karakoram fault system (Banggong Co area) document that the fault was active at 17 Ma and has accumulated a maximum of 150 km of right slip. We suggest that these along-strike variations in the magnitude of slip and timing constraints reflect southward propagation of the Karakoram fault system.

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