Tectonophysics 530–531 (2012) 152–179

Contents lists available at SciVerse ScienceDirect

Tectonophysics

journal homepage: www.elsevier.com/locate/tecto

Spatially constant slip rate along the southern segment of the Karakorum fault since 200 ka

Marie-Luce Chevalier [a,b,*], Paul Tapponnier [c], Jérôme Van der Woerd [d], Frederick J. Ryerson [e], Robert C. Finkel [f], Haibing Li [a]

[a] State Key Laboratory for Continental Tectonics and Dynamics, Institute of Geology, CAGS, 26 Baiwanzhuang St, Beijing 100037, China
[b] Laboratoire de Tectonique et Mécanique de la lithosphère, Institut de Physique du Globe de Paris, 4, Place Jussieu, 75252 Paris cedex 05, France
[c] Earth Observatory of Singapore, 50 Nanyang Ave, N2-01a-09, Singapore 639798, Singapore
[d] Institut de Physique du Globe de Strasbourg, UMR 7516 CNRS/Université de Strasbourg, 5 rue Descartes, 67084 Strasbourg, France
[e] L-231, Atmospheric, Earth and Energy Division, Physical and Life Sciences Directorate, Lawrence Livermore National Laboratory, Livermore, CA 94550, USA
[f] Earth and Planetary Science Department, University of California, Berkeley, 371 McCone Hall, Berkeley, CA 94720, USA

ARTICLE INFO

Article history:
Received 24 June 2011
Received in revised form 6 December 2011
Accepted 9 December 2011
Available online 23 December 2011

Keywords:
Active tectonics
Tectonic-geomorphology
Slip-rate
Karakorum fault
Tibet
Cosmogenic dating

ABSTRACT

Determining the slip-rate history along the right-lateral Karakorum fault (KF) is fundamental to understanding its present-day kinematic role in the deformation of Tibet. Geodetic and geologic studies suggest slip-rates of 0–11 mm/yr along this structure. Whether slip-rate variability exists along strike and/or time, or simply results from different measuring techniques/timescales, remains unknown. In order to constrain slip-rates within a timescale of 200 ka, we studied fluvial and glacial geomorphic features that are right-laterally or vertically offset by the fault by varying amounts from 7 ± 1 m to 430 ± 30 m and up to 53 ± 5 m, respectively. We constrained their ages using ^{10}Be surface exposure dating on 141 quartz-rich samples collected on 4 lateral moraines and at 3 alluvial sites along the southernmost segment of the KF (Menshi–Kailas basin) and along the Gurla Mandhata detachment fault in the Pulan graben. From the 30° fault bend at Baer (80.5°E) to Mount Kailas area, the slip-rate along the KF is $>7.1^{+3.2}/_{-1.7}$ mm/yr at Menshi and $>7.9^{+3.2}/_{-2.5}$ mm/yr at Kailas (slip on two parallel fault strands). In the Pulan graben, the normal fault slip-rate is $>1.6^{+0.4}/_{-0.3}$ mm/yr. Our data suggest that the Quaternary slip-rate along the southern KF does not decrease eastward but is constant along strike for at least 200 km, from >5–11 mm/yr in the Gar basin further north to >7–8 mm/yr in the Menshi–Kailas basin. Because no expected along-strike slip-rate gradient is observed, it implies that the KF does not end at the Kailas but must extend where the slip rate decreases, i.e. eastward along the Yarlung Zangbo suture and southward along the Gurla Mandhata–Humla fault system.

1. Introduction

Slip-rates on the major strike-slip faults of the Tibetan Plateau (inset, Fig. 1) have been the target of detailed studies in the past decade. Using ^{14}C or cosmogenic nuclides (^{10}Be, ^{26}Al) dating techniques, an increasing number of late Pleistocene/Holocene geological slip-rates have been determined from offset geomorphic features, such as glacial moraines (e.g. Brown et al., 2002; Chevalier et al., 2005a; Harkins et al., 2010; Lasserre et al., 2002; Meriaux et al., 2004), fluvial fans (e.g. Brown et al., 2002; Gold et al., 2011; Meriaux et al., 2005; Van der Woerd et al., 1998, 2000, 2002) and terraces (e.g. Chevalier et al., 2011b; Cowgill et al., 2009; Gold et al., 2009, 2011; Harkins and Kirby, 2008; Harkins et al., 2010; Kirby et al., 2007; Lasserre et al., 1999; Li et al., 2005; Meriaux et al., 2004, 2005; Van der Woerd et al., 1998, 2000, 2002). Geodetic techniques, such as GPS and InSAR (e.g. Bendick et al., 2000; Chen et al., 2000, 2004; Jolivet et al., 2008; Wallace et al., 2004; Wang et al., 2001; Wright et al., 2004; Zhang et al., 2004) yield short timescale slip-rates (10–20 yrs). On certain faults (e.g. Altyn Tagh), the discrepancy between geodetic and geologic slip-rates is a subject of debate (e.g. Cowgill, 2007; Cowgill et al., 2009; Hanks and Thatcher, 2006; Ryerson et al., 2006; Thatcher, 2007).

The slip-rate on the >1000 km-long right-lateral Karakorum fault (Fig. 1), north of the western Himalayan and Karakorum Ranges, is also debated. At the decadal timescale, InSAR observations suggest a rate of 1 ± 3 mm/yr (Wright et al., 2004), while GPS data yield estimates of ~3–4 mm/yr (Chen et al., 2004; Jade et al., 2004, 2010) to 11 ± 4 mm/yr (Banerjee and Burgmann, 2002). At the late Pleistocene timescale, Liu (1993) inferred a geologic slip-rate of ~30 mm/yr, by correlating the emplacement of offset moraines or alluvial fans mapped from 10 m-resolution SPOT satellite images with cold or warm climatic epochs, respectively. On one branch of the fault

---

* Corresponding author at: State Key Laboratory for Continental Tectonics and Dynamics, Institute of Geology, CAGS, 26 Baiwanzhuang St, Beijing 100037, China. Tel.: +86 13466654223.

E-mail addresses: mlchevalier@hotmail.com (M.-L. Chevalier), tappon@ntu.edu.sg (P. Tapponnier), jeromev@unistra.fr (J. Van der Woerd), ryerson1@llnl.gov (F.J. Ryerson), rfinkel@berkeley.edu (R.C. Finkel), lihaibing06@yahoo.com.cn (H. Li).

0040-1951/$ – see front matter © 2011 Elsevier B.V. All rights reserved.
doi:10.1016/j.tecto.2011.12.014

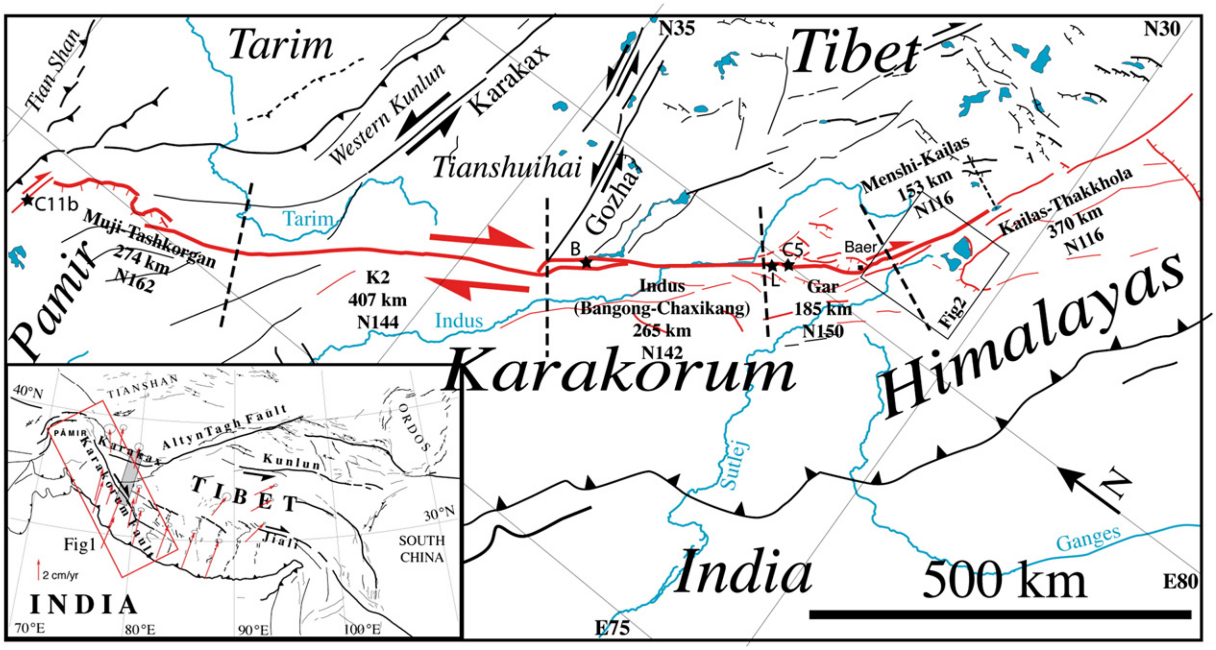

Fig. 1. Large-scale segmentation of the Karakorum fault (KF). First-order geometrical segmentation based on sharp bends and fault junctions divide the KF into six segments with lengths ranging from 150 to 407 km. The Menshi–Kailas segment presented in this paper strikes N116°E and is linked to the average N145°E striking central segments of the KF through a sharp 30° bend at Baer within the Gar segment. Black stars show location of other studies: B = Brown et al. (2002), L = Lacassin et al. (2004), C5 = Chevalier et al. (2005a, 2005b), C11b = Chevalier et al. (2011b). Inset map shows location of the KF within the Tibetan Plateau and Asia. Red arrows show a subset of representative GPS velocities relative to Siberia (Wang et al., 2001; Zhang et al., 2004). The shaded rectangle shows the position of the InSAR swath used by Wright et al. (2004).

north of Bangong Lake in India, Brown et al. (2002) obtained a Holocene slip-rate of 4 ± 1 mm/yr from ^{10}Be cosmic-ray surface exposure dating of a debris flow. Using the same technique on large, well-defined moraines on another single branch of the fault on the west side of the Gar pull-apart basin, Chevalier et al. (2005a, 2005b) determined a late Pleistocene slip-rate of $>5.5 \pm 0.5$ to $>10.7 \pm 0.7$ mm/yr. At the northernmost tip of the KF, along the Muji–Tashkorgan segment, Chevalier et al. (2011b) recently determined, based on offset terraces, a minimum Holocene slip-rate of 4.5 mm/yr along one single branch of the fault (the Muji fault), or >9 mm/yr across the KF system. From joint inversions of geologic and geodetic observations, Loveless and Meade (2011) recently suggested, making the assumption that time variation in fault slip-rates from decadal to Quaternary scales is negligible (using a microplate rotation model), that the segment south of Bangong Lake was moving at a rate of 3.0 ± 0.1 to 5.4 ± 0.3 mm/yr. They note however that if the model assumes larger blocks in central Tibet, this rate could be up to ~8 mm/yr.

Like the Altyn Tagh fault (e.g. Meriaux et al., 2004, 2005; Peltzer et al., 1989), the Karakorum "fault" is a rather complex fault system that splays and joins at places, with several adjacent active or recent faults onto which slip is transferred. For example the KF meets with the Altyn Tagh–Karakax fault south of the Paghman basin, with the Gozha fault north of Bangong Lake, and with one branch of the Karakorum–Jiali fault zone near Chaxikang (Fig. 1 and inset). This contrasts with the Kunlun fault, another major Asian fault with a relatively simple geometry and constant slip-rate along strike (e.g. Harkins and Kirby, 2008; Harkins et al., 2010; Van der Woerd et al., 1998, 2000, 2002). This study aims at better understanding if the KF slip-rate behaves like that of the Altyn Tagh fault (not constant along strike, decreasing away from the central segment, e.g. Meriaux et al., 2005; Meyer et al., 1996; Zhang et al., 2007) or like that of the Kunlun fault.

In this paper, we add quantitative geomorphologic and chronologic data along the southernmost, Menshi–Kailas segment of the Karakorum fault (Figs. 1 and 2). By measuring geomorphic offsets across two branches of the Karakorum fault (Kailas Range Front and Darchen faults) and constraining the offset ages with ^{10}Be cosmic-ray surface exposure dating of fluvial and glacial surfaces, we determine the slip-rate across the two main active branches of the Karakorum fault (KF) system at longitude ~81°E.

This new evidence improves our understanding of the macro-tectonics of Central Asia because slow rates have been argued to favor continuous deformation models (e.g. Bendick et al., 2000; England and Molnar, 1997, 2005) while fast rates argue in favor of block models (e.g. Armijo et al., 1989; Avouac and Tapponnier, 1993; Peltzer and Tapponnier, 1988; Tapponnier et al., 2001). As discussed in recent papers (e.g. Flesch and Bendick, 2007; Loveless and Meade, 2011; Meade, 2007a,b; Thatcher, 2007, 2009), existing velocity fields and geologic rates on active faults in Asia are still too sparse and poorly constrained, both spatially and temporally, to discriminate between a wide range of mechanical conditions. Thus, new slip-rate data at different timescales and locations are warranted to determine whether the discrepancy between geodetic and geologic rates is real, as well as to better understand deformation in this region.

2. Regional active tectonics

The Menshi–Kailas segment, ~160 km-long, is the southernmost segment of the KF system, and borders the southern Kailas Range (Figs. 1 and 2). It strikes on average N116°E, north/south of a ~30° bend in the N150°E striking Gar segment near the village of Baer at the western terminus of the Ayilari Range (~80.5°E, Fig. 1). The Menshi basin marks the drainage divide between the Indus-Gar and Sutlej catchments (Fig. 1).

In Fig. 2, we present detailed mapping of fault strands that offset Quaternary moraines, alluvial fans and terraces. The geometry of the KF south of the Kailas Range is particularly complex, characterized by splaying into multiple branches (Armijo et al., 1989; Lacassin et al., 2004; Murphy and Burgess, 2006; Murphy and Copeland, 2005; Valli et al., 2007). In general, faulting is characterized by strike-slip and thrust faulting that is partitioned along different fault branches. Strike-slip faulting mostly characterizes the right-stepping fault segments across the middle of the basin, separated by pull-aparts or normal faults.