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Slip-rates along the Chaman fault: Implication for transient strain accumulation and strain partitioning along the western Indian plate margin

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ABSTRACT

The Chaman fault in Western Pakistan marks the western collision boundary between the Indian and Eurasian plates and connects the Makran subduction zone to the Himalayan convergence zone. Geomorphic-scale slip-rates along an active strand of the Chaman fault are added to the sporadic data set of this poorly investigated transform system. Field investigations coupled with high-resolution GeoEye-1 satellite data of an alluvial fan surface (Bostankaul alluvial fan) show ~1150 m left-lateral offset by the fault since the formation of the alluvial fan surface. A weighted mean ^{10}Be exposure age of 34.8 ± 3 kyr for the Bostankaul alluvial surface yields a slip-rate of 33.3 ± 3.0 mm/yr. This rate agrees with the geologically defined slip-rates along the Chaman fault, but is approximately twice as large as that inferred from the decade-long global positioning system measurements of 18 ± 1 mm/yr. The contrast in geomorphic and geodetic slip-rates along the Chaman fault, like other major intra-continental strike–slip faults, has two major implications: 1) the geodetic rates might represent a period of reduced displacement as compared to the averaged Late Pleistocene rate because of transient variations in rates of elastic strain accumulation; or 2) strain partitioning within the plate boundary zone. While strain partitioning could be the reason of slip-rate variations within the western Indian plate boundary zone, transient strain accumulation could explain contrasting slip-rates along the Chaman fault at this stage in its poorly understood seismic cycle.

1. Introduction

Models of the dynamics of large-scale intracontinental deformation are influenced by two end-member views: 1) highly localized deformation in which the lithosphere is deforming as a rigid plate (Avouac and Tapponnier, 1993; Meade, 2007; Peltzer and Saucier, 1996; Peltzer and Tapponnier, 1988; Tapponnier et al., 2001; Thatcher, 2007); and 2) regionally distributed, continuous deformation within the lithosphere which deforms in a fluid-like-fashion (Bendick et al., 2000; England and Houseman, 1986; Molnar and Tapponnier, 1975; Zhang et al., 2007). The Himalayan–Tibetan orogeny provides the opportunity to test these two hypotheses with advances in both GPS/InSAR techniques and in dating techniques to date Late Quaternary landforms and sediments, including, terrestrial cosmogenic nuclides (TCN) and ^{14}C methods. The plate bounding crustal scale strike–slip faults within the orogen are central to such studies. Rigid-plate localized deformation supports high long-term (10^3–10^6 years) geomorphic slip rates (Chevalier et al., 2005; Mériaux et al., 2004, 2005; Tapponnier et al., 2001; Van der Woerd et al., 1998, 2000), while diffused deformation is supported by relatively low short-term (10^0–10^1 years) geodetic slip rates along these major strike–slip faults (Bendick et al., 2000; Chen et al., 2000; England and Molnar, 2005; Phillips et al., 2004; Shen et al., 2001).

Defining the temporal and spatial distribution of strain along plate boundaries is challenging, but is essential for developing and testing tectonic models. This is particularly true for the Himalayan–Tibetan orogen, which is one of the most logistically and politically difficult regions to study, yet ideal for examining the nature and dynamics of continent–continent collision. In brief, the Himalayan–Tibetan orogen formed from the collision of the Indian and Eurasian continental lithospheres (Yin and Harrison, 2000). Underthrusting of the Indian plate beneath the Himalaya accommodates around half (Thatcher, 2007) of its 36–45 mm/yr northward movement (Klootwijk et al., 1998; Molnar and Stock, 2009), but much of the remaining movement is adjusted within the Tibet plateau, either localized along the crustal scale strike–slip faults (Tapponnier et al., 2001) or distributed within the blocks bounded by these strike–slip faults (England and Molnar, 2005; Zubovich et al., 2010). While many studies (Bendick et al., 2000; Chevalier et al., 2005; He and Chéry, 2008; Wright et al., 2004) have focused on understanding the deformation along these mega-structures

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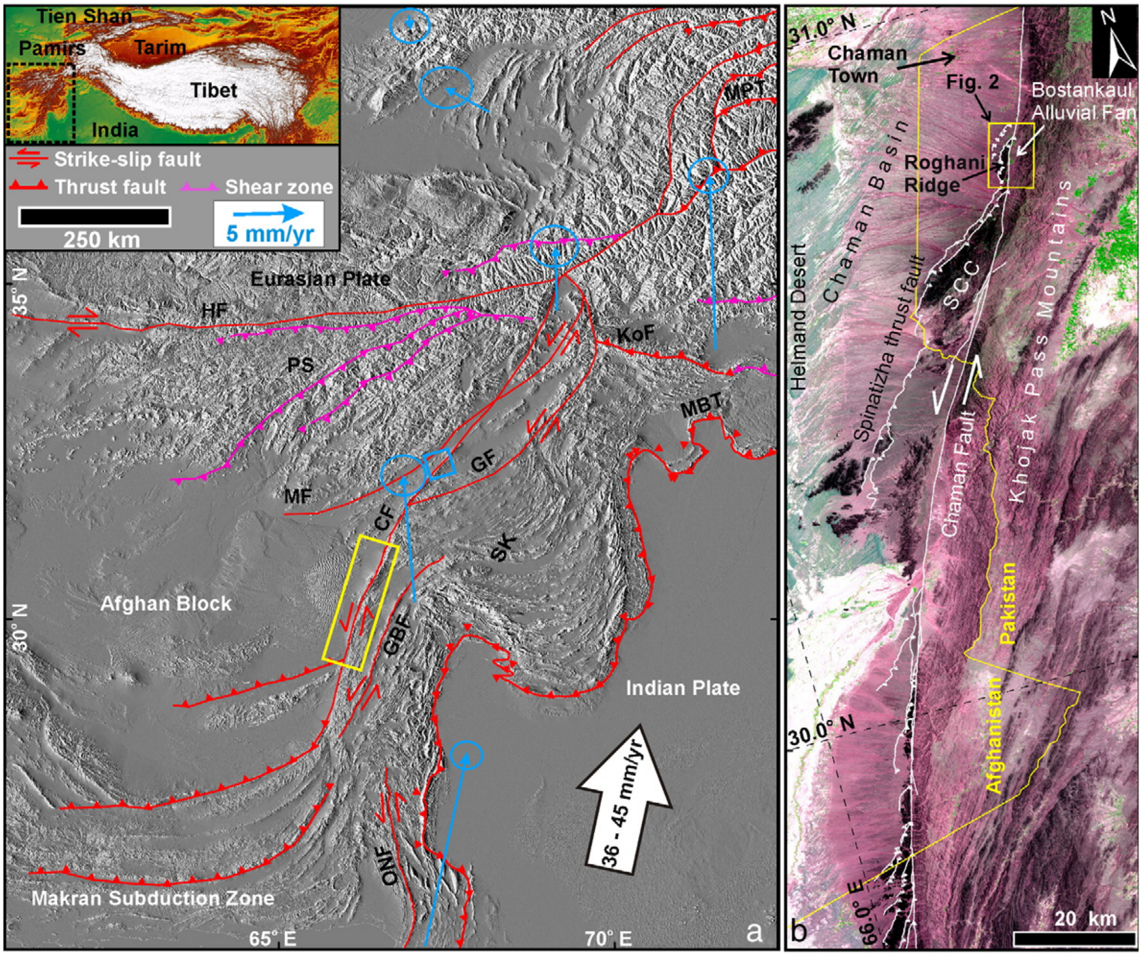

Fig. 1. (a) Tectonic framework of the northwestern Indian Plate margin and Eurasia. Major active strike–slip faults, thrusts and suture zones (modified after Mohadjer et al., 2010; Taylor and Yin, 2009) are displayed on SRTM elevation data. Blue arrows show GPS velocities with respect to fixed Eurasian plate/Afghan block (Mohadjer et al., 2010). The blue box is the position of Synthetic Aperture Radar (SAR) data used in InSAR studies (Furuya and Satyabala, 2008). Notice the azimuth of the Indian plate motion (N12°E) against the average N34°E azimuth of the strike of the CF is responsible for the strain partitioning in the Suliman–Kirthar Fold-thrust Belt (SK). The yellow rectangle shows position of part B. GF: Gardiz Fault; HF: Herat Fault; KoF: Konar Fault; MBT: Main Boundary Thrust; MF: Mokur Fault; MPT: Main Pamir Thrust; ONF: Ornach-Nal Fault; PS: Panjao shear. The inset map shows location of (a) within the Himalayan–Tibetan orogen. (b) Central section of the Chaman fault (CF) in western Pakistan shown on an Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) image (bands 1-3-2 displayed as RGB). The gentle bend in strike of the CF just north of the present study area helps create the Spinatizha thrust fault and the transpression uplifting the Spinatizha Crystalline Complex (SCC), and a part of the alluvial fan complex of the Chaman basin (Center of the map). Yellow box shows the location of the Bostankaul alluvial fan and Roghani Ridge in Fig. 2.

in the Himalaya and Tibet, little focus has been given to the western Indian plate boundary, which is largely defined by the Chaman transform fault system (Fig. 1a). It has been thought that the Chaman fault zone does not play any significant role in accommodating shortening between the Indian and Eurasian plates so it has been largely ignored, and adding to this is the civil unrest in this region, which hinders access to critical sites.

The geomorphic expression of the Chaman fault system is evident throughout its entire length of ~860 km along the border regions of Pakistan and Afghanistan. The shear zone is most apparent at the contact between the Quaternary alluvial deposits to the west and the meta-sediments of the Late Eocene to Oligocene Katawaz Basin (Carter et al., 2010) to the east of the fault (Ruleman et al., 2007; Fig. 1). The fault also brings slivers of the Late Jurassic to Cretaceous arc rocks west of the fault zone in contact with the meta-sediments in some places (Lawrence et al., 1981). The shear zone varies in width with linear zones of <1 km wide to about 20 km wide zones of multiple strands with conjugate Riedel shears and thrust fault systems (Lawrence and Yeats, 1979; Wheeler et al., 2005). The strike of the fault ranges from N10°E to N35°E (Lawrence et al., 1992) resulting in several double bends responsible for the popup zones that are present throughout its length. Several incipient transpressional structures of varying sizes have been reported throughout the length of the fault system (Ruleman et al., 2007; Ul-Hadi et al., 2012). The difference in azimuth of the Indian plate movement and strike of the Chaman fault system essentially requires some convergence (Molnar and Dayem, 2010), which is accounted for by these features, and is a phenomenon that shapes the geomorphic expression of a strike–slip fault system (Frankel and Owen, 2013).

Recent GPS and InSAR studies on the Chaman fault yield slip rates of 18 ± 1 mm/yr (Mohadjer et al., 2010) and a post-seismic slip-rate of ~8 mm/yr (Furuya and Satyabala, 2008; Fig. 1a; Table 1). Lawrence et al. (1992) obtained a larger slip-rate over a geologically longer (>10^6 years) timescale. They defined a displacement of 460 ± 10 km, which was based on: 1) the presence of a major thrust fault that is laterally displaced for ~250 km on both sides of the Chaman fault; 2) the correlation of subduction complexes present on both sides of the fault; 3) the depression of the Kharan desert south of the Ras Koh that is equivalent/correlated to that of the Ab-e-Istada depression south of the Gardez fault, and (4) the sediment of the eastern Makran Ranges