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Partitioning of India-Eurasia convergence in the Pamir-Hindu Kush from GPS measurements

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[1] Convergence of 29 ± 1 mm/yr between the NW corner of the Indian plate and Asia is accommodated by a combination of thrust and strike-slip faulting on prominent faults and apparent distributed deformation within the Hindu Kush, Pamir, South Tien Shan and Kohistan Ranges. An upper bound to the slip rate of known faults is obtained by ignoring distributed strain and rotation: convergence occurs on thrust faults north of the Peshawar Basin (13 ± 1 mm/yr) and in the Alai-South Tien Shan (12 ± 2 mm/yr), and shear on the northeast-trending northern Chaman-Gardiz-Konar system (18 ± 1mm/yr) and the Darvaz-Karakul fault zone (11 ± 2 mm/yr). Slip rates on the Herat and Talas-Ferghana faults are small (<2 mm/yr). Shortening not attributable to known active faults occurs within the Hindu Kush and central Pamir (16 ± 2 mm/yr) with concomitant east-west extension in the latter of 9 ± 2 mm/yr. This diversity of strain styles confirms the importance of mechanical heterogeneity to continental tectonics and shows that the Pamir, although less than half the size, behaves more like Tibet than like a linear belt of localized deformation. **Citation:** Mohadjer, S., et al. (2010), Partitioning of India-Eurasia convergence in the Pamir-Hindu Kush from GPS measurements, *Geophys. Res. Lett.*, *37*, L04305, doi:10.1029/2009GL041737.

1. Introduction

[2] Spatially varying deformation mechanisms in continental collision zones are significant to the general study of continental tectonics, because they help to constrain the relationship between rheology and the localization of deformation in continental lithosphere [e.g., *Bürgmann and Dresen,* 2008; *England et al.*, 1985]. Oceanic lithosphere, where plate tectonics works well, has a relatively simple vertical strength profile with little lateral variation, such that relative plate motion is entirely accommodated in narrow fault zones, and plate interiors are effectively rigid. Deformation of continental lithosphere, in contrast, seems to reflect a range of vertical strength profiles, depending on laterally varying temperature and composition. Therefore, the mechanisms by which continents respond to tectonic forces must have length-scale dependence [*England et al.*, 1985], as different mechanical properties are sampled at different scales. For example, at the length scale (normal to strike) of single continental faults (~10 km), the behavior of continental crust can be described using the accumulation and release of elastic deformation on the faults [*Okada,* 1985]. At the scale of a single mountain range (~100 km), as in Taiwan, the underthrusting of a wedge of effectively plastic material (brittle deformation obeying Coulomb friction) can account for the topography and the dynamics [e.g., *Dahlen et al.*, 1984]. At the length scale of the Tibetan Plateau (~1000 kilometers), the deformation of a thin viscous sheet can match the hypsometry and strain rate field of the whole plateau, demonstrating that the vertically averaged constitutive relation is viscous [e.g., *England and McKenzie,* 1982; *England and Houseman,* 1986]. The region of central Asia encompassing NW Pakistan, Afghanistan, Tajikistan, and Kyrgystan (Figures 1 and S1), containing an actively deforming region, the Pamir, affords an opportunity to investigate whether scale dependence including viscous dynamics is important regions of lengths less than 1000 km.[11] Geodetic observations of the region also constrain the regional kinematics, including slip rates on several very large faults.

2. Methods

[3] We installed a network of GPS sites in the area (Tables 1 and Table S1) between 30° and 44°N latitude and between 60° and 76°E longitude (Figure S1) including eastern Afghanistan, Tajikistan, northwestern Pakistan, Baluchistan, and western Kyrgyzstan. Geodetic measurements at these new sites are supplemented with observations from two IGS (International GNSS Service) sites, KIT3 in Uzbekistan and POL2 in Kyrgyzstan. All of the sites with velocities reported here (Table 1 and Figure 1) operate continuously with the exception of Kabul (KBUL),

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[11]Auxiliary material are available in the HTML. doi:10.1029/2009GL041737.

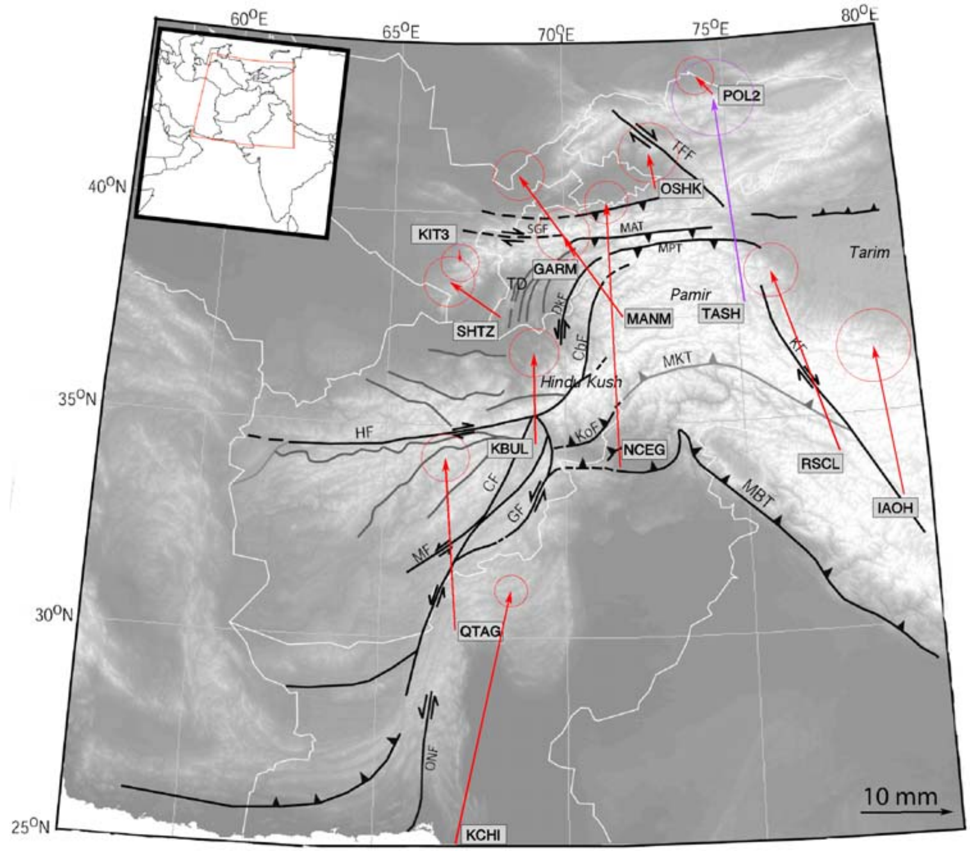

Figure 1. Locations of major active faults (heavy black lines), inactive faults (fine lines), and GPS velocity vectors with respect to Eurasia fixed reference frame from this study in red. The purple vector is transformed from [*Gan et al.* 2007]. The error ellipses represent 95% confidence. Abbreviations of fault names: TD, Tajik Depression; TFF, Talas-Ferghana Fault; SGF, South Gissar Fault; DkF, Darvaz-Karakul Fault; MPT, Main Pamir Thrust; MAT, Main Alai Thrust; CbF, Central Badakhshan Fault; HF, Herat Fault; CF, Chaman Fault; GF, Gardiz Fault; KoF, Konar Fault; ONF, Ornach-Nal Fault; MF, Mokur Fault; KF, Karakoram Fault; MBT, Main Boundary Thrust; and MKT, Main Karakoram Thrust. Other geographic names used in the text are shown in Figure S1.

which was occupied for 93 days in 2006 and 10 days in 2008 (Table S1). See auxiliary material for site details.

[4] Site position estimates were calculated for each day with the GAMIT software package [*Herring et al.*, 2006] in a loosely constrained global reference frame including 14 IGS sites aside from POL2 and KIT3. The resulting time series of site positions (Figure S3) were used to estimate site velocities in ITRF05 [*Altamimi et al.*, 2007] and Eurasia-fixed (Table 1) and India-fixed reference frames (Table S2) using GLOBK [*Herring et al.*, 2006]. More details are provided in the auxiliary material.

Table 1. Station Coordinates and Velocities[a]

Site	Longitude (deg.)	Latitude (deg.)	East (mm/yr)		North (mm/yr)	
			ITRF05	Eurasia	ITRF05	Eurasia
KBUL	69.130	34.574	28.2 ± 1.1	−0.1 ± 1.1	14.2 ± 1.1	10.0 ± 1.1
QTAG	66.991	30.166	26.8 ± 1.0	−1.4 ± 1.0	23.6 ± 1.0	18.8 ± 1.0
NCEG	71.487	34.004	27.7 ± 0.9	−0.8 ± 0.9	32.5 ± 0.9	29.0 ± 0.9
MANM	71.680	37.542	17.7 ± 1.1	−10.7 ± 1.1	19.3 ± 1.1	15.8 ± 1.1
SHTZ	68.123	37.562	−5.5 ± 1.1	22.7 ± 1.1	8.3 ± 1.1	3.9 ± 1.1
GARM	70.317	39.006	27.0 ± 1.2	−1.2 ± 1.2	6.2 ± 1.2	2.4 ± 1.2
OSHK	72.777	40.530	27.7 ± 1.3	−0.6 ± 1.3	7.2 ± 1.3	4.0 ± 1.3
KCHI	67.113	24.931	33.6 ± 0.7	5.6 ± 0.7	32.7 ± 0.7	28.0 ± 0.7
IAOH	78.973	32.779	27.0 ± 1.6	−1.7 ± 1.6	18.0 ± 1.6	16.6 ± 1.6
RSCL	77.600	34.128	22.9 ± 1.2	−5.7 ± 1.2	22.2 ± 1.2	20.3 ± 1.2
TASH[b]	75.230	37.770	N.D.[c]	−1.9 ± 1.8	N.D.	22.5 ± 1.7
KIT3	66.885	39.135	28.2 ± 0.8	0.1 ± 0.8	3.4 ± 0.8	−1.4 ± 0.8
POL2	74.694	42.680	26.4 ± 0.8	−1.8 ± 1.6	4.8 ± 0.8	2.1 ± 0.8

[a]ITRF05 – Eurasia pole is 55.873° ± 0.7°N, −95.825° ± 0.8°E, 0.258° ± 0.003 °/Ma.
[b]Data for TASH is from *Gan et al.* [2007].
[c]N.D. = no data.

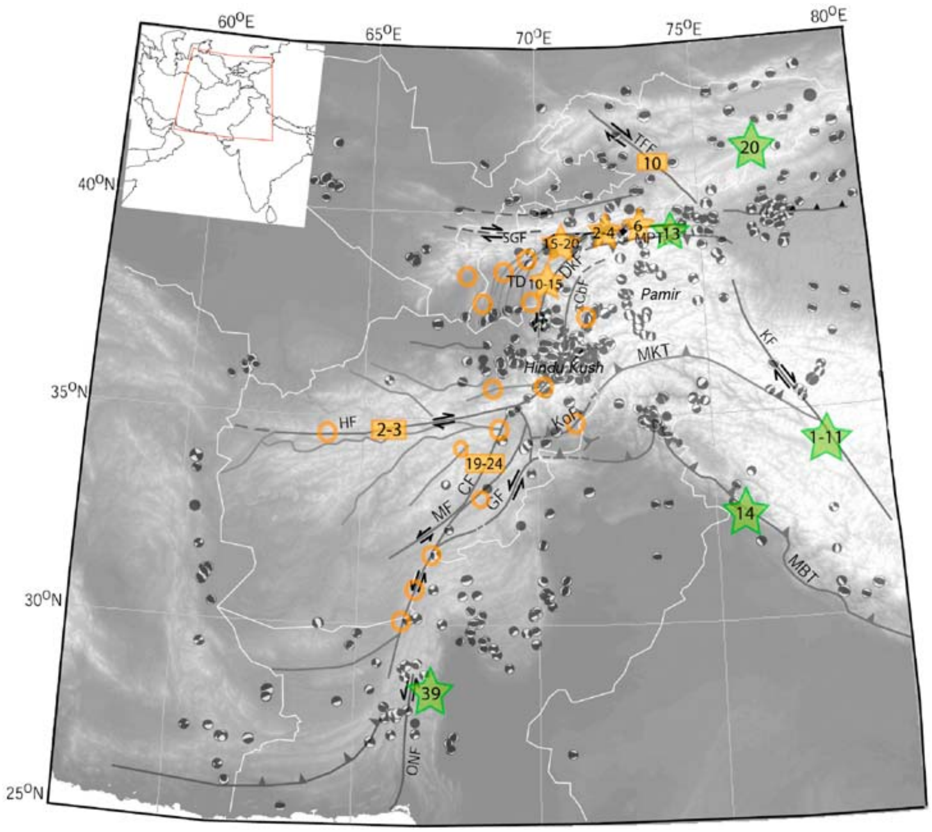

Figure 2. Map of the study area showing localities where observations of Quaternary offsets (orange open circles), geologic slip rates of known locality (orange stars), geologic slip rates of unknown locality along faults (orange rectangles), and geodetic slip rates of known locality (green stars) have been made. Data and fault locations are from [*Abdrakhmatov et al.* 1996], *Ambraseys and Bilham* [2003], *Arrowsmith and Strecker* [1999], *Banerjee and Bürgmann* [2002], *Burtman et al.* [1996], *Burtman and Molnar* [1993], *DeMets et al.* [1990], *Guseva* [1986], *Jade et al.* [2004], *Konopaltsev* [1971], *Lawrence et al.* [1992], *Legler and Przhiyalgovskaya* [1979], *Nikonov* [1970], *Nikonov et al.* [1983], *Reigber et al.* [2001], *Ruleman et al.* [2007], *Sborshchikov et al.* [1981], *Shareq and Chmyriov* [1977], *Trifonov* [1978], *Wellman* [1966], *Wolfart and Wittekindt* [1980], and [*Wright et al.* 2004].

[5] To estimate the parallel and normal components of slip rates on major faults (Table S3) and to compare them to geologic slip rates (Figure 2), we first compiled major faults from a range of relevant sources [*Ambraseys and Bilham,* 2003; *Burtman and Molnar,* 1993; *Ruleman et al.*, 2007; *Shareq and Chmyriov,* 1977; *Wolfart and Wittekindt,* 1980]. We treat the relative velocity between two bracketing geodetic sites as an upper bound on the slip rate on that fault (or parallel related faults), ignoring elastic strain. This is a better assumption for strike-slip faults than for dip-slip faults, where the elastic strain associated with the fault may extend over long distances or reflect fault geometry. We also ignore possible contributions to the velocity field from block rotations, since our sparse geodetic network cannot constrain these. Error bars on the slip rates are from the GPS velocities alone and do not represent uncertainties related to these assumptions.

[6] In locations where no major faults have been identified, specifically the Hindu Kush and central Pamir, we simply calculate velocities normal and parallel to the main, east-west topographic trend using GPS site pairs spanning the region. For the Pamir, we separately estimate a rate of east-west extension using the reported velocity at Tashkurgan (TASH) [*Gan et al.*, 2007] and that at Khorog (MANM) by calculating a local transformation (north and east adjustments) between our Eurasia-fixed frame and the Eurasia-fixed frame of *Gan et al.* [2007] using common sites POL2 and SELE.

3. Results

3.1. Chaman Fault System

[7] The northern extension of the Chaman fault splays into a suite of large strike-slip faults (Figure 2), including the Gardiz Fault and the Mokur Fault, both with evidence for left-lateral displacement of Quaternary basin deposits [*Ruleman et al.*, 2007]. The difference in velocities of GPS sites at Quetta (QTAG) and Kabul (KBUL) allows an upper bound of 5.4 ± 2 mm/yr of sinistral shear across the combined Gardiz and Mokur faults. The difference between the Kabul (KBUL) and Peshawar (NCEG) velocities allows as much as 18.1 ± 1 mm/yr of total sinistral shear accommodated by the Gardiz-Mokur-Konar system, therefore a bound on the total left-lateral rate along the northern end of the Chaman fault system. The locus of Himalayan convergence lies to the north of the Peshawar basin with less than 3 mm/yr of convergence between Karachi (KCHI) and Peshawar (NCEG).

3.2. Hindu Kush-Pamir

[8] Quaternary faults mapped in this region include north- to northwest-trending strike-slip faults that cut across older north- to northeast-trending thrust faults [*Ruleman et al.*, 2007] and active east-west striking thrust faults in the region between the Peshawar Basin and the Panj Valley. No single large fault appears in structural, morphological, or seismic data. We therefore assume that GPS sites spanning and within the Pamir region are not recording elastic deformation about dislocations. The relative velocity between Peshawar (NCEG) and Khorog (MANM) places an upper bound of north-south shortening at a rate of 13.2 ± 1 mm/yr with 9.9 ± 1 mm/yr of sinistral shear on the total surface deformation (either the sum of slip on many faults or the integral of a continuous strain field) south of Khorog.

[9] The relative velocity between the western Tarim margin (TASH) [*Gan et al.*, 2007] and the site at Khorog (MANM) indicates 8.8 ± 2 mm/yr of east-west extension across the central Pamir. Combined with a paucity of mapped active faults within the Pamir [*Strecker et al.*, 1995] and the topography of the region, such internal extension normal to the principal shortening direction suggests dynamic similarities between the Pamir and the Tibetan Plateau. We cannot isolate shortening within the Pamir from that on its margins with our current array; ignoring elastic strain the total shortening between Peshawar (NCEG) and Garm (GARM) is 31.8 ± 1.5 mm/yr, but much of this may be accommodated on structures south of the main Pamir or on its edges. Shortening of the central and northern Pamir between Khorog (MANM) and Garm (GARM) occurs at 16.2 ± 1.6 mm/yr; some of this might occur by slip on the Darvaz-Karakul Fault.

3.3. Darvaz-Karakul Fault

[10] Offsets of Holocene and late Pleistocene landforms, especially early Holocene terraces and alluvial fans, give slip rates of 10–15 mm/yr on the Darvaz-Karakul Fault [*Kuchai and Trifonov,* 1977; *Trifonov,* 1978]. The component of velocity between Khorog (MANM) and Shaartuz (SHTZ) parallel to the mean strike of the Darvaz-Karakul Fault (in this region) of N5°E limits total sinistral shear on the fault to 11.4 ± 2 mm/yr, consistent with the geologic rates. This rate, however is a maximum, because there is reported evidence of late Quaternary strike-slip displacement along some faults in the Tajik Depression [*Trifonov,* 1978; *Nikonov,* 1970; *Legler and Przhiyalgovskaya,* 1979] (Figure 2).

3.4. Tajik Depression

[11] The topography of the Tajik Depression is characterized by regularly spaced, arcuate ranges, averaging ~1 km in maximum elevation, and with ~ 400–500 m of relief. Range spacing along with the regional stratigraphy suggest shortening of the top 10 km of sedimentary rock detached from the underlying basement [*Bekker et al.*, 1983; *Bernard et al.*, 2000; *Burtman and Molnar,* 1993]. Relative velocities between Khorog (MANM) and Shaartuz (SHTZ) confirm shortening of 6.2 ± 1 mm/yr across most of the depression; additional shortening is indicated by the presence of low ranges extending into Uzbekistan to the west and a shortening rate of 6.1 ± 1 mm/yr between Shaartuz (SHTZ) and Kitab (KIT3), including the southwest Gissar Range.

3.5. Main Alai Thrust

[12] *Reigber et al.* [2001] report a geodetically estimated rate of 13 ± 4 mm/yr of shortening across the eastern end of the Alai Valley between Kara Kul and the Ferghana Valley. This rate is significantly higher than the geologically estimated lower bound on the rate of 6 mm/yr [*Arrowsmith and Strecker,* 1999] along the 50-km-long east-west striking central Main Pamir thrust. GPS sites in Khorog (MANM) and Osh (OSHK) provide an upper bound on total shortening in the combined Central Alai and northernmost Pamir of 11.8 ± 2 mm/yr.

3.6. Herat Fault

[13] Limited field studies suggest that at least the eastern part of the Herat Fault has not been active since Miocene time [*Tapponnier et al.*, 1981] (Figure 2). We confirm a lack of present-day active slip by observing a sinistral shear rate of 6.4 ± 2 mm/yr between Kabul (KBUL) and Shaartuz (SHTZ), opposite in sense to geologic interpretations that show dextral slip on the Herat Fault. Shortening between these stations occurs at 5.1 ± 2 mm/yr, consistent with small mapped thrust faults and topographic relief in northernmost Afghanistan west of the Hindu Kush, and similar to that between Khorog (MANM) and Shaartuz (SHTZ).

3.7. Talas-Ferghana Fault

[14] The M~7.6 Chatkal earthquake of 1946 has been attributed to the Talas-Ferghana Fault. Dextral slip parallel to the main trace of the Talas-Ferghana Fault between Osh (OSHK) and Bishkek (POL2) occurs at 0.4 ± 2 mm/yr, significantly slower than the Holocene rate of 10 ± 2 mm/yr inferred by *Burtman et al.* [1996]. Rotation of the Ferghana Valley with respect to Eurasia is better constrained by *Reigber et al.* [2001] than by our observations.

4. Discussion

[15] Slip rate bounds within the Hindu Kush-Pamir-Kohistan region (summarized in Table S3) show that measurable strain accumulates not just where a major fault passes between the sites. Geodetic sites with relative velocities also bracket regions without obvious major active faults, specifically the Hindu Kush, Pamir, and Tajik Depression. Within the study area, we therefore observe four different kinematic conditions: high relative rates (>10 mm/yr) between sites on opposite sides of major faults (e.g., Chaman system); high rates where major faults are absent (e.g., central Pamir); low rates (<5 mm/yr) between sites spanning some major faults (e.g., Talas-Ferghana and Herat faults); and low rates in deforming regions where major faults are absent or unknown (e.g., Tajik Depression). This variation of strain localization is also apparent in the regional velocity field of *Reigber et al.* [2001].

[16] The Pamir-Hindu Kush system shares these four styles of strain accumulation with the Himalayan-Tibetan region. They also share structural and morphological similarities: major faults surround regions of high elevation and subdued relief in both cases; within the high plateaux, faults are shorter and seem to slip at lower rates. In Tibet, many short normal and strike-slip faults have total offsets on the order of 10 km. The distribution of such features in the high Pamir is not yet determined, but fault plane solutions of earthquakes with small to at most moderate seismic moments

show normal and strike-slip faulting under both the High Pamir [*Burtman and Molnar,* 1993; *Strecker et al.*, 1995] and Central Tibet [e.g., *Molnar and Lyon-Caen,* 1989].

[17] The sum of slip rates on known individual large faults in either the Pamir-Hindu Kush or Tibet does not account for the total India-Eurasia convergence across the entire deforming zone. In Tibet, ~30–50% of India's total convergence with Eurasia is absorbed by distributed deformation (hence presumably by low slip rates on large numbers of minor faults) [e.g., *Chen et al.*, 2004; *Zhang et al.*, 2004]. Slip rates that are < ~10 mm/yr on region-bounding faults in both systems also appear to preclude rapid lateral translation of the interior as a rigid or deforming unit ("escape" or "extrusion") at least at the present time [*Zhang et al.*, 2007; *Kirby et al.*, 2007]. Therefore, the Pamir-Hindu Kush region, like neighboring Tibet, accommodates relative motion between India and Eurasia both by slip on large coherent faults and by distributed strain within a region of high topography. Taken together, these two examples suggest that multiple deformation mechanisms are a fundamental feature of continental tectonics. A scale-dependent approximation of continental rheology including viscous mechanics is appropriate even at the smaller length scale of the Pamir.

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References

Abdrakhmatov, K., et al. (1996), Relatively recent construction of the Tien Shan inferred from GPS, *Nature*, *384*, 450–453, doi:10.1038/384450a0.

Altamimi, Z., X. Collilieux, J. Legrand, B. Garayt, and C. Boucher (2007), ITRF05: A new release of the International Terrestrial Reference Frame based on time series of station positions and Earth orientation parameters, *J. Geophys. Res.*, *112*, B09401, doi:10.1029/2007JB004949.

Ambraseys, N., and R. Bilham (2003), Earthquakes in Afghanistan, *Seismol. Res. Lett.*, *74*, 107–123.

Arrowsmith, J. R., and M. Strecker (1999), Seismotectonic range-front segmentation and mountain-belt growth in the Pamir-Alai region, Kyrgyzstan (India-Eurasia collision zone), *Geol. Soc. Am. Bull.*, *111*, 1665–1683, doi:10.1130/0016-7606(1999)111<1665:SRFSAM>2.3.CO;2.

Banerjee, P., and R. Bürgmann (2002), Convergence across the northwest Himalaya from GPS measurements, *Geophys. Res. Lett.*, *29*(13), 1652, doi:10.1029/2002GL015184.

Bekker, Y., Y. Konovalov, G. Koshlakov, and D. Muchaidze (1983), New data about the structure of the Earth's crust of Tadjikistan (in Russian), in *Tectonics of the Tien Shan and Pamir*, edited by I. Y. Gubin and S. A. Zakharov, pp. 118–123, Nauka, Moscow.

Bernard, M., B. Shen-Tu, W. Holt, and D. Davis (2000), Kinematics of active deformation in the Sulaiman Lobe and Range, Pakistan, *J. Geophys. Res.*, *105*, 13,253–13,279, doi:10.1029/1999JB900405.

Bürgmann, R., and G. Dresen (2008), Rheology of the lower crust and upper mantle: Evidence from rock mechanics, geodesy, and field observations, *Annu. Rev. Earth Planet. Sci.*, *36*, 531–567, doi:10.1146/annurev.earth.36.031207.124326.

Burtman, V., and P. Molnar (1993), Geological and geophysical evidence for deep subduction of continental crust beneath the Pamir, *Spec. Pap. Geol. Soc. Am.*, 281.

Burtman, V., S. Skobelev, and P. Molnar (1996), Late Cenozoic slip on the Talas-Ferghana Fault, the Tien Shan, central Asia, *Geol. Soc. Am. Bull.*, *108*, 1004–1021, doi:10.1130/0016-7606(1996)108<1004:LCSOTT>2.3.CO;2.

Chen, Q., J. Freymueller, Q. Wang, C. Yang, C. Xu, and J. Liu (2004), A deforming block model for the present-day tectonics of Tibet, *J. Geophys. Res.*, *109*, B01403, doi:10.1029/2002JB002151.

Dahlen, F., J. Suppe, and D. Davis (1984), Mechanics of fold-and-thrust belts and accretionary wedges, *J. Geophys. Res.*, *89*, 10,087–10,101, doi:10.1029/JB089iB12p10087.

DeMets, C., R. Gordon, D. Argus, and S. Stein (1990), Current plate motions, *Geophys. J. Int.*, *101*, 425–478, doi:10.1111/j.1365-246X.1990.tb06579.x.

England, P., and G. Houseman (1986), Finite strain calculations of continental deformation: 2. Comparisons with the India-Asia collision zone, *J. Geophys. Res.*, *91*, 3664–3676, doi:10.1029/JB091iB03p03664.

England, P., and D. McKenzie (1982), A thin viscous sheet model for continental deformation, *Geophys. J. R. Astron. Soc.*, *70*, 295–321.

England, P., L. Sonder, and G. Houseman (1985), Length scales for continental deformation in convergent, divergent, and strike-slip environments: Analytical and approximate solutions for a thin viscous sheet model, *J. Geophys. Res.*, *90*, 3551–3557, doi:10.1029/JB090iB05p03551.

Gan, W., P. Zhang, Z. Shen, Z. Niu, M. Wang, Y. Wan, D. Zhou, and J. Cheng (2007), Present-day crustal motion within the Tibetan Plateau inferred from GPS measurements, *J. Geophys. Res.*, *112*, B08416, doi:10.1029/2005JB004120.

Guseva, T. G. (1986), Contemporary Movements of the Earth's Crust in the Transition Zone From the Pamir to the Tien Shan (in Russian), 171 pp., Inst. of Phys. of the Earth, Acad. Nauk, Moscow.

Herring, T., R. King, and S. McClusky (2006), Introduction to GAMIT/GLOBK Release 10.3, Mass. Inst. of Technol., Cambridge.

Jade, S., B. Bhatt, Z. Yang, R. Bendick, V. Gaur, P. Molnar, M. Anand, and D. Kumar (2004), GPS measurements from the Ladakh Himalaya: Preliminary tests of plate-like or continuous deformation in Tibet, *Geol. Soc. Am. Bull.*, *116*, 1385–1391, doi:10.1130/B25357.1.

Kirby, E., N. Harkins, E. Wang, X. Shi, C. Fan, and D. Burbank (2007), Slip rate gradients along the eastern Kunlun Fault, *Tectonics*, *26*, TC2010, doi:10.1029/2006TC002033.

Konopaltsev, I. M. (1971), Measurements of crustal movements in the Garm area, 1948–1970 (in Russian), *Geotektonika*, *5*, 111–116.

Kuchai, V. K., and V. G. Trifonov (1977), Young left-lateral strike slip along the zone of the Darvaz-Karakul Fault (in Russian), *Geotektonika*, *3*, 91–105.

Lawrence, R., S. Khan, and T. Nakata (1992), Chaman Fault, Pakistan-Afghanistan, in *Major Active Faults of the World: Results of IGCP Project 206*, edited by Buckham, R. C. and P. L. Hancock, *Ann. Tecton.*, Suppl. 6, 196–223.

Legler, B., and I. Przhiyalgovskaya (1979), The interaction of the Indian and Asian lithospheric plates and tectonics of the Tadjik Depression (in Russian), in *Structure of Lithospheric Plates: Institute of Oceanology*, pp. 125–188, Akad. Nauk, Moscow.

Molnar, P., and H. Lyon-Caen (1989), Fault plane solutions of earthquakes and active tectonics of the Tibetan Plateau and its margins, *Geophys. J. R. Astron. Soc.*, *99*, 123–153.

Nikonov, A. A. (1970), Differential analysis of the Quaternary tectonics of the Afghan-Tajik Depression (in Russian), *Geotektonika*, *1*, 101–107.

Nikonov, A. A., A. V. Vakov, and I. A. Veselov (1983), Seismotectonics and Earthquakes in the Convergent Zone Between the Pamir and Tien Shan (in Russian), 240 pp., Nauka, Moscow.

Okada, Y. (1985), Surface deformation due to shear and tensile faults in a half-space, *Bull. Seismol. Soc. Am.*, *75*, 1135–1154.

Reigber, C., G. Michel, R. Galas, D. Angermann, J. Klotz, J. Chen, A. Papschev, R. Arslanov, V. Tzurkov, and M. Ishanov (2001), New space geodetic constraints on the distribution of deformation in central Asia, *Earth Planet. Sci. Lett.*, *191*, 157–165, doi:10.1016/S0012-821X(01)00414-9.

Ruleman, C., A. Crone, M. Machette, K. Haller, and K. Rukstales (2007), Map and database of probable and possible Quaternary faults in Afghanistan, *U.S. Geol. Surv. Open File Rep., 2007–1103*.

Sborshchikov, I., L. Savostin, and L. Zonenchayn (1981), Present plate tectonics between Turkey and Tibet, *Tectonophysics*, *79*, 45–73, doi:10.1016/0040-1951(81)90232-8.

Shareq, A., and V. Chmyriov (1977), Map of mineral resources of Afghanistan, scale 1:500,000, Dep. of Geol. and Mineral Surv., Minist. of Mines and Ind., Kabul.

Strecker, M., M. Frisch, M. Hamburger, L. Ratschbacher, S. Semiletkin, A. Zamoruyev, and N. Sturchio (1995), Quaternary deformation in the eastern Pamirs, Tadzhikistan and Kyrgyzstan, *Tectonics*, *14*, 1061–1079, doi:10.1029/95TC00927.

Tapponnier, P., M. Mattauer, F. Proust, and C. Cassaigneau (1981), Mesozoic ophiolites, sutures, and large-scale tectonic movements in Afghanistan, *Earth Planet. Sci. Lett.*, *52*, 355–371, doi:10.1016/0012-821X(81)90189-8.

Trifonov, V. G. (1978), Late Quaternary tectonic movement of western and central Asia, *Geol. Soc. Am. Bull.*, 89, 1059–1072, doi:10.1130/0016-7606(1978)89<1059:LQTMOW>2.0.CO;2.

Wellman, H. (1966), Active wrench faults in Iran, Afghanistan and Pakistan, *Geol. Rundsch.*, *55*, 716–735, doi:10.1007/BF02029650.

Wolfart, R., and H. Wittekindt (1980), Geologie von Afghanistan, 500 pp., Gebrüder Borntraeger, Berlin.

Wright, T., B. Parsons, P. England, and E. Fielding (2004), InSAR observations of low slip rates on the major faults of western Tibet, *Science*, *305*, 236–239, doi:10.1126/science.1096388.

Zhang, P.-Z., et al. (2004), Continuous deformation of the Tibetan Plateau from global positioning system data, *Geology*, *32*, 809–812, doi:10.1130/G20554.1.

Zhang, P.-Z., P. Molnar, and X. Xu (2007), Late Quaternary and present-day rates of slip along the Altyn Tagh Fault, northern margin of the Tibetan Plateau, *Tectonics*, *26*, TC5010, doi:10.1029/2006TC002014.

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