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Tectonic geomorphology of the eastern extent of the Kashmir Basin Fault (KBF) zone

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Abstract: *The Kashmir Basin Fault (KBF) is exposed as a train of discontinuous active fault traces for a strike length of ~120 km (Shah, 2013), in Kashmir, Himalayas. However, its eastern extent was not mapped previously and therefore, this study demonstrates that the active fault trace extends further east, where the geomorphic expression of active faulting is clear for a distance of ~43 km. The fault shows a very prominent dextral strike-slip motion with little to no dip-slip component associated with it, particularly, on the easternmost portion. Further west it mainly shows dip-slip motion with a slight indication of dextral strike-slip. This new active fault trace extends the total strike length of the KBF zone to ~163 km, which has implications for seismic hazard and the distribution of deformation along the NW portion of the Himalayas.*

Key words*: Kashmir Basin Fault, Distributed deformation, NW Himalayas, Active faults*

INTRODUCTION

A number of previous studies have mapped traces of active thrust faults in the Kashmir Basin, Himalayas (e.g. Madden et al., 2010, 2011; Shabir and Bhat, 2012; Shah, 2013). These faults are formed in response to the active continent–continent collision of the Indian and Eurasian plate. These two tectonic plates collide at geologic and geodetic convergence rates of 30–50 mm/yr (Ader et al., 2012). The presence of active deformation in Kashmir basin suggests that the ongoing collision deformation along the ~2,000-km long Himalayan orogenic belt is distributed differently along the central and western portions of the belt (e.g. Madden et al., 2010, 2011; Shah, 2013).). Thus the bulk shortening along the central part is mainly accommodated along the Himalayan Frontal Thrust (HFT) system (e.g. Ader et al., 2012 as a latest reference) and along the NW Himalayas, the convergent deformation is not concentrated on the front but is distributed across the width of the belt (e.g. Kaneda et al., 2008; Meigs et al., 2010; Shah, 2013). The present study further demonstrates the active nature of the eastern extent of the KBF (Shah, 2013) and its tectonic significance.

KASHMIR BASIN

The strike length of the Kashmir Basin is ~150 km and is ~50 km across (Fig. 1). It is located on the north-western

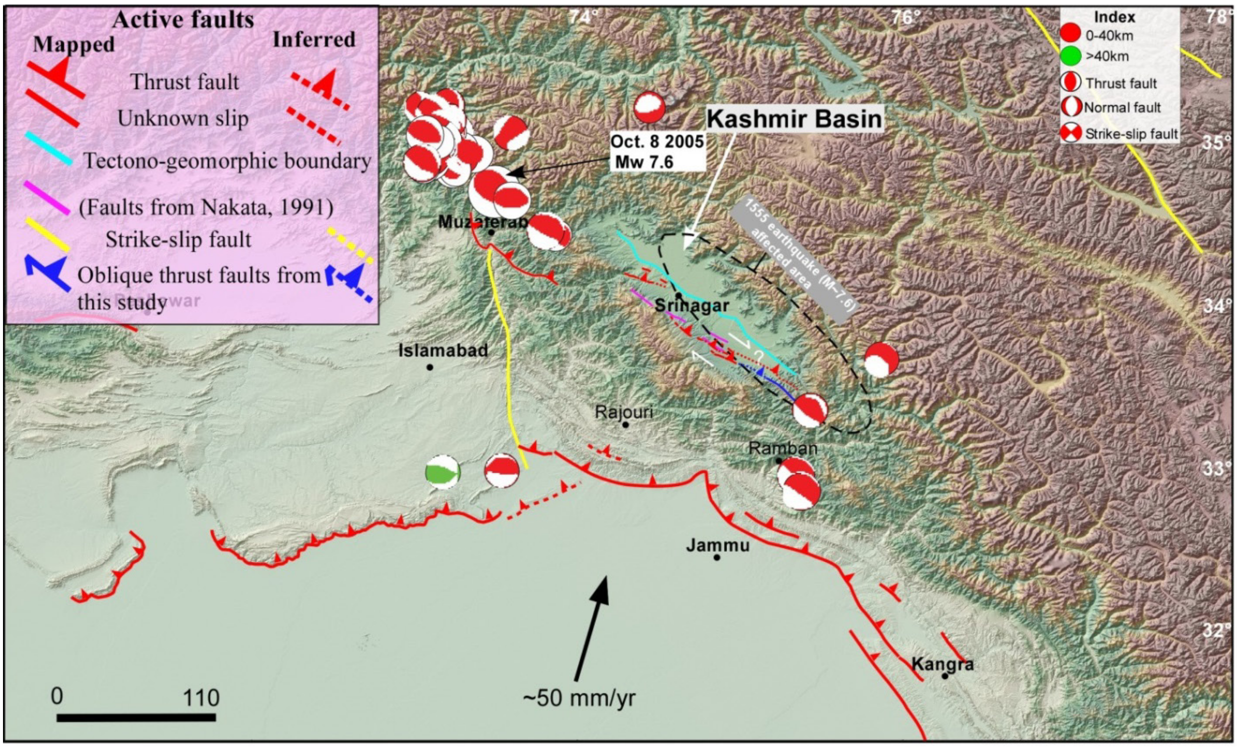

Fig. 1: Regional tectonic setting of the Kashmir Basin and CMT catalogue data (1976–2012), modified after Shah, 2013.

portion of the Himalayan orogenic system, about ~100 km away from the actively growing frontal part of the Himalaya. It is classified as one of the Neogene–Quaternary intermontane basins (Burbank & Johnson, 1983) of the Himalayas and contains strata, which are equivalent in age and similar in lithology to the Upper Siwalik Group (Burbank & Johnson, 1982). The basal part of the sequence is slightly older ~5 Ma, but much of the succession is of late Pliocene-Pleistocene age, with deposition continuing locally into the Holocene age (Burbank & Johnson, 1983).

TECTONIC GEOMORPHOLOGY

The oval-shaped KB, which stretches ~NW–SE,is surrounded by fold and thrust mountainous (Fig. 1). A quick look at the regional topography suggests that the regions on the NE of the valley are drowned, while those on the SW are uplifted. The geomorphic expression of the active faults vary along the strike, where it mostly crops out as discontinues traces and pierces through some of the young deposits(Shah, 2013; Fig. 1), which are ~50–100 ka old (e.g. Jaiswal et al., 2009; Meigs et al., 2010; Madden et al., 2011).The eastern extent of this fault shows a clear right-lateral strike-slip motion for a distance of ~1km and is demonstrated by young stream channels, some of which have captured the lateral motion. For example the Figure 2 shows that offset along some of the streams varies from ~20 to ~40 m. The fault has caused characteristic stream captures along the

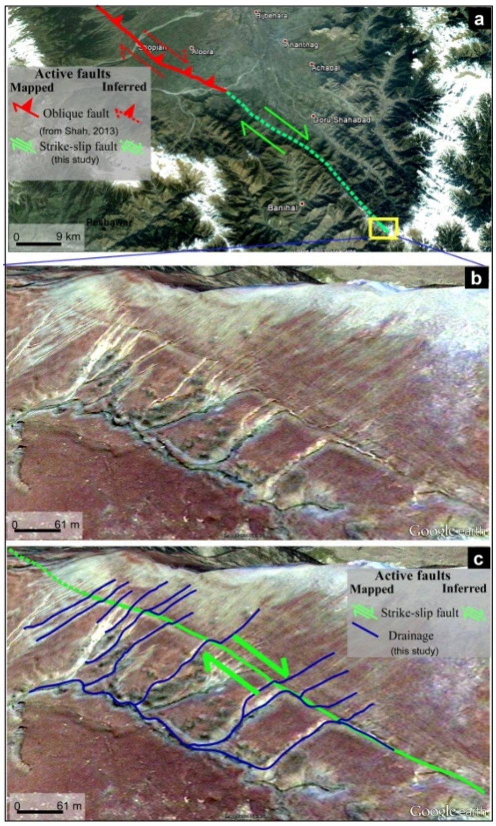

Fig. 2: 3D Google images show the eastern extent of the newly identified trace of the KBF.(a) Shows the total extent of the fault. (b) Shows an un-interpreted image and in (c) the active dextral strike-slip faults are interpreted.

strike. Some portion of the fault is not very clear from the available resolution of the Google images, thus, that portion of the trace is inferred (Fig. 1). If we assume the displaced deposits are of ~50 ka year old, then the estimated strike-slip rate will be around 0.08cm/year. However, this could be higher or lower, depending on the exact ages of deposits.

RESULTS AND INTERPRETATIONS

The KBF traces trend ~ NW–SE and preserve geomorphic evidences of recent activity, wherein they cut across the ~ 50–100 ka old deposits (e.g. Jaiswal et al., 2009; Meigs et al., 2010; Madden et al., 2011).

Some of these fault traces show an indication of an oblique motion, however, the dip-slip component is more prominent on the west and the evidences presented here suggest that dextral strike-slip motion is more prominent on further east. The KBF faults dip towards NE and uplift the young deposits on the SW of the basin thereby drowning everything to the NE portion of the basin, as suggested previously, the geomorphic expression of the Kashmir Valley is modified due to these faults and has therefore roughly divide the valley into two major tectono-geomorphic terranes. These are: (1) north-eastern terrane (NET) and (2) south-western terrane (SWT). The former is a low-relief area, with sediment-filled sluggish streams. The latter is an uplifted region, with actively flowing streams (Shah, 2013). This suggests that the south- west side of the valley is climbing a ramp on the Main Himalayan Thrust (MHT), uplifting the SW side and drowning everything to the NE (e.g. Madden et al., 2011; Shah, 2013). However, the evidences presented here suggest that the deformation on the KBF partitions along two more splays of the major fault. Also, the fault is clearly an oblique fault with a dextral strike-slip component associated with thrusting. The dip-slip component is more towards the west, because of an oblique dextral slip motion. This could be because of the regional stress distribution, wherein the flow of the bulk of the GPS vectors show a more prominent clockwise rotation (dextral slip) on the east than west (Figs. 1 and 2), which is because of the extrusion along the strike-slip faults on the east (Yin, 2000, 2006; Ader et al., 2012).

Table 1. modified after Bilham et al., 2010.

Historical earthquakes of Kashmir (primarily reported in Srinagar)			
	Date	Maximum estimated intensities	
		Lyengar and Sharma (1998); Lyenger et al. (1999)	Bashir et al. (2009)
1.	1123	VII	VII
2.	24 September 1501	XII	VIII
3.	1 September 1555	-	VII
4.	ca. 1560/1561	-	VII
5.	1569-1577	IV	
6.	23 June 1669	VII	
7.	ca. 1678/1979	VIII	
8.	1683	VII	
9.	24 March 1736	VIII	
10.	1779		
11.	ca. 1784/1785		
12.	1803		
13.	26 June 1828		
14.	1863		
15.	30 May 1885		
16.	8-Oct-05		

DISCUSSION AND CONCLUSION

The ongoing collision deformation along the ~2,000-km-long Himalayan orogenic belt is distributed differently along the central and western portions of the belt. For example, the bulk shortening along the central part is mainly accommodated along the Himalayan Frontal Thrust (HFT) system (e.g. Wesnousky et al., 1999; Lave & Avouac 2000; Ader et al. 2012). In contrast, along the NW Himalayas, the convergent deformation is not concentrated on the front and is distributed across the width of the belt (e.g. Meigs et al., 2010; Kaneda et al., 2008). Distributed deformation is also supported by the active geomorphic observations within the Kashmir Basin (e.g. Madden et al., 2010, 2011; Shabir & Bhat, 2012; Shah, 2013 and this study). The ~N130°E strike of the mapped thrust faults is consistent with the regional ~NE–SW convergence along the collision zone (Fig. 1). Therefore, it is more likely that the Kashmir Basin fault is an independent thrust, a possible ramp on the MHT, which has uplifting the SW portion of the KB and drowning everything to the NE (e.g. Madden et al., 2011; Shah, 2013). The evidences presented here further suggest that the deformation on the KBF shows an oblique motion, where the total deformation partitions along two more splays from the major fault and these faults clearly show an oblique faulting with a dextral strike-slip component associated with thrusting. This, thus, suggests that KBF is a broad zone of an oblique faulting pattern, where deformation is mainly concentrated along the major trend of the fault, which is around 163 km long (Fig. 1).

Further, since the dip-slip component is more towards the west, it suggests that the regional stress distribution is responsible for this deformation pattern. This is primarily, because the flow of the bulk of the GPS vectors show a more prominent clockwise rotation (dextral slip) on the east than west, which is because of the extrusion takes place along the major strike-slip faults on the east (Yin 2006; Ader et al., 2012) and thus, deformation is primarily consumed by motion along the strike-slip faults.

SIZE OF EARTHQUAKE ON KBF

The future earthquake potential of a fault is commonly evaluated from the estimates of fault rupture parameters that are in turn related to earthquake magnitude (e.g. Wells & Coppersmith, 1994). Therefore, using the strike length of the mapped fault, which is ~81 km, plus the length from the inferred portion, which is ~82 km, the total strike length of the fault would be ~163 km. Further, by assuming a dip of 29 (Avouac et al., 2006) and a down-dip limit of 20 km, a Mw of 7.7 is possible on this fault. Further, a historical record of 13 earthquakes in the valley over the last millennium, which includes the damaging earthquakes of 1555 and 1885, indicates that the Kashmir Valley is a locus of active deformation (e.g. Madden et al., 2011; Table 1). Therefore, the active geomorphic evidences presented here suggest that these historical events must have ruptured the surface, which are now preserved as active fault scarps (Figs. 1 and 2). Therefore, the on-going paleoseismic work (e.g. Madden et al. 2011) and the proposed investigations will further unravel the earthquake chronology of the KB. This will be an extremely useful step towards the hazard mitigation of the region.

FUTURE WORK

Further, I think that the past events on the KBF were not blind and must have ruptured the surface, therefore, our proposed investigations will answer this question and it will be a very significant quest, primarily, because, none of the historical earthquakes is reported to have produced primary surface rupture and it has generally been assumed on the basis of isoseismals and location, that the earthquakes are the result of slip on the Himalayan Frontal Thrust (Wesnousky et al., 1999). However, since this long-standing consensus was finally challenged by Sapkota et al. (2013) by providing strong evidences that the *M*w 8.2 Bihar–Nepal earthquake on 15 January1934 did break the surface. Therefore, in Kashmir, since the geomorphic expression of the surface rupture is well expressed, it thus, potentially suggests that the rupture has reached surface. Hence, it will be a key location to investigate the timing of the fault activity and will provide data about the supposedly blind great earthquakes in the Himalayan history.

Further, earthquake researchers have learnt from the past experience that most of the faults behave differently and in a unique pattern, which is often characteristic of a particular fault, thus, each fault needs to be investigated in much more details. Kashmir Basin is very unique in its shape and the deformation pattern is also uniquely different from the frontal Himalayas, thus, serious efforts are required to investigate the active faults in the valley, which could be achieved through this a comprehensive study.

SIGNIFICANCE OF THE PROPOSED WORK

The significance of my proposed work lies in the fact that the surface rupture of earthquakes in the Kashmir, which are reportedly said to have occurred on the blind great Himalayan events, might exist and thus, evidences need to be recollected. This will be useful to understandthe historical earthquakes and to re-evaluate the seismic risk along the NW Himalayas and the frontal portions. Thus, it will suggest reassessing the earthquake potential of the Himalayan faults, which might have ruptured in the past historical events.

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