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Active tectonics, October 8, 2005 earthquake deformation, active uplift, scarp morphology and seismic geohazards microzonation, Hazara-Kashmir Syntaxis, Northwest Himalayas, Pakistan

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The Hazara-Kashmir Syntaxis (HKS) is an active antiformal synclinal structure. It is formed by the folding of Himalayan thrust sheets in the northeast Himalayas of Pakistan. It is convex to the hinterland and concave to the foreland. The northern HKS is a tight antiformal structure whereas the southern HKS is an open structure (Fig. 1). The thin skin faults those bend around the HKS are the Main Boundary Thrust (MBT), Panjal Thrust (PT) and Barian Thrust (BT) (Wadia, 1931; Calkins et al., 1975; Baig and Lawrence 1987; Khan and Ali, 1994)). The active Jhelum left-lateral strike slip reverse fault truncates the thin skin Main Boundary Thrust (MBT), Panjal Thrust (PT), Barian Thrust {BT), Himalayan Frontal Thrust (HFT) or Muzaffarabad Fault (MF), Riasi Fault (RF}, Shahdara Thrust (ST), Hazara Thrust (HT), Nar Thrust (NT), Shah Khaki Fault (SKF), Pir Gali Fault (PF), Samwal Fault (SF) and Ratial Fault (RF). The local newly recognized faults in Shahdara, Plandri, Panjara, Sarsawa and Kotli areas are the splays of the Riasi Fault. These include Dhalian Fault, Shahdara Thrust, Manoor Fault, Nuhisarhota Fault, Godri Badshah-Kotli Fault, Chak Nasru Fault and Mandi Fault.

The active faults along the eastern limb of the HKS in Azad Kashmir-Potwar are the Muzaffarabad Fault, Riasi Fault, Shahdara Fault, Shaheed Gala Fault, Riasi Fault, Godri Badshah-Kotli Fault, Pirgali Fault and Samwal Fault (SM). However, the active faults along the western limb of the HKS are the Salt Range Thrust (SRT), Shah Khaki Fault (SKF) or Diljaba Fault (DF), Main Boundary Thrust and Chail Sar Thrust (CST). The northwest-trending and northeast-dipping Chail Sar Thrust (CST) is the extension of the Indus-Kohistan Seismic Zone in Alai Kohistan (Baig, 1990). These faults show the evidence for Quaternary deformation, deflected or offset streams, nick points, uplifted and tilted terraces and seismicity. North of Kohala, the MBT offsets Berot Nala left laterally more than I km. This indicates that the MBT is an active fault.

The thrust/reverse faults along the eastern and western limbs of the HKS are the result of southwest-and southeast-directed thin/thick skin imbricate thrusting and southwest-and southeast-verging open to tight folds respectively. The most of the thin skin faults are along the limb or core of anticlines.

The Jhelum fault runs parallel or sub-parallel to river Jhelum or along the crest or western limb of the Jhelum River anticline. The seismicity, old linear landslides, dissected spurs, nick points, deflected drainage and tilted and uplifted river terraces or nala fans show that the Jhelum Fault is an active tectonic feature (Baig and Lawrence, 1987; Baig, 2006). The northwest-southeast-trending and northeast dipping thick skin active faults in the HKS are the Chail Sar Thsust (Baig, 1990), Indus-Kohistan Seismic Zone (IKSZ) blind reverse faults wedge (Armbruster et al., 1978; Seeber and Armbruster, 1979), Bagh Basement Fault (BBF; Khan and Ali, 1994) and new October 8th 2005 earthquake associated reverse Kawai-Dewalian Basement Fault (KDBF). The fault on which magnitude 7.6 earthquake occurred has reverse and some right-lateral strike slip fault motion (Yeats et al., 2006; Monalisa et al., 2007). The movement on northwest-trending and northeast-dipping KDBF reactivated the pre-existing northeast-dipping active Muzaffarabad Fault and Indus-Kohistan Seismic Zone (Baig 2006; Baig *et al.*, 2008). The KDBF marks back stepping or northeast jump of Indus Kohistan Fault Zone during active Himalayan strain buildup.

The BBF is a normal passive margin fault or bending moment normal fault on the Indian plate. The BBF reactivated as reverse fault during the Himalayan collision. The reverse Shaheed Gala Fault is the exposed extension of the BBF on surface. The most of the BBF in northwest is under the thin skin thrust sheets of the HKS. The fault is between the Murree Formation and the Nagri Formation. The 10 meter thick breccia and gouge are present along the fault. The shallow earthquakes in HKS are associated with these thin and thick skin active faults.

The Muzaffarabad fault was recognized along the overturned limb of the Balakot-Muzaffarabad anticline (Calkins *et al.*, 1975; Ghazanfar *et al.*, 1986). The Muzaffarabad Fault was also called as Himalayan Frontal Thrust (Baig and Lawrence, 1987), Tanda Fault (Nakata and Kumahara, 2006) and Balakot-Bagh Fault (Yeats *et al.*, 2006). The fault was the known active fault before October 8th 2005 earthquake. The thrust/reverse right lateral Muzaffarabad Fault extends northwest-southeast 120 Km from Balakot to Punch, Indian occupied Kashmir (Baig et al., 2008). The fault branches into Balakot, Garalat and Sangal Bohr terminal splay faults in Balakot area. In the southeastern segment, the Muzaffarabad Fault splays into the Berpani Fault and Raikot Fault. The fault terminates into overlapping rupture zone near Chrikot and Punch areas. The Balakot Fault cuts the MBT in the northwest. The Muzaffarabad fault formed the extensive active rupture zone varying from 1-3 km. The rupture zone has normal and reveres ruptures, landslides, breccia and gouge.

The scarp morphology along Muzaffarabad Fault is controlled by warps or folded scarps, fault-related fold scarps (Nisar camp and Balakot hanging wall anticlines Baig *et al.*, 2008), imbricate scarp, compressional arc scarp, vertical scarp and overhang scarp. The local pop ups, triangle zones, pressure ridges, horst and grabben, bending movement normal faults and back thrusts at places are present along the fault. The fault forms significant pre-earthquake degraded scarp topographic front which was reactivated and uplifted along Muzaffarabad Fault up to 7.5 m during October 8th 2005 Kashmir earthquake (Baig et al., 2008). The minimum and maximum terrace uplift is measured across Muzaffarabad Fault through detail mapping of river terraces. The minimum uplift across the fault is 50 m whereas the maximum uplift is 120 m. The 120 m uplift across Muzaffarabad Fault is the result of strong multiple earthquake uplifts in Holocene.

The Institute of Geology after October 8th 2005 earthquake started seismic geohazard microzonation along Muzaffarabad Fault during 2005-2007 for the rehabilitation of the earthquake affected people of Hazara and Kashmir. However, Institute of Geology Azad Jammu and Kashmir University, Muzaffarabad voluntarily coordinated and supervised NESPAK (2006) in Seismic Hazard Microzonation of Muzaffarabad, Bagh and Rawalakot areas on the request of AJ&K government. The other areas mapped for seismic geohazard microzonation along the Muzaffarabad Fault include Balakot-Garhi Habibulla, Jhelum valley, Chikar-Bagh and Bagh-Lasdana.

The seismic geohazard microzonation along Muzaffarabad Fault is based on hazard parameters such as active faults, active rupture zone, unstable steep slopes, brittle shear zone, active old and new landslides, ground shaking, earthquake deformation, seismic amplification, seismicity and flood. The areas are classified into highly hazard, high hazard and moderate hazard zones. It was recommended that the highly hazard zone (red zone) areas be avoided for any type of construction. However, the high hazard and moderate hazard zones be used subject to geotechnical studies and earthquake resistant building codes. The active fault lines, active ruptures, active landslides, steep slopes, river-nala banks, nala courses and flood zone areas should be avoided. The seismic amplification, ground shaking, slope failure, liquefaction, structural collapse, basement failure, old buildings, structural design, asymmetric structures and building material are the causes for the damage of civil structures and loss of human lives during earthquakes. The detailed study of slip rates, uplift rates, strain buildup, hazard zonation, recurrence intervals, seismicity, seismic hazard assessment, geohazard and earthquake monitoring is needed to avoid major human loss along active faults in Azad Kashmir and Pakistan.

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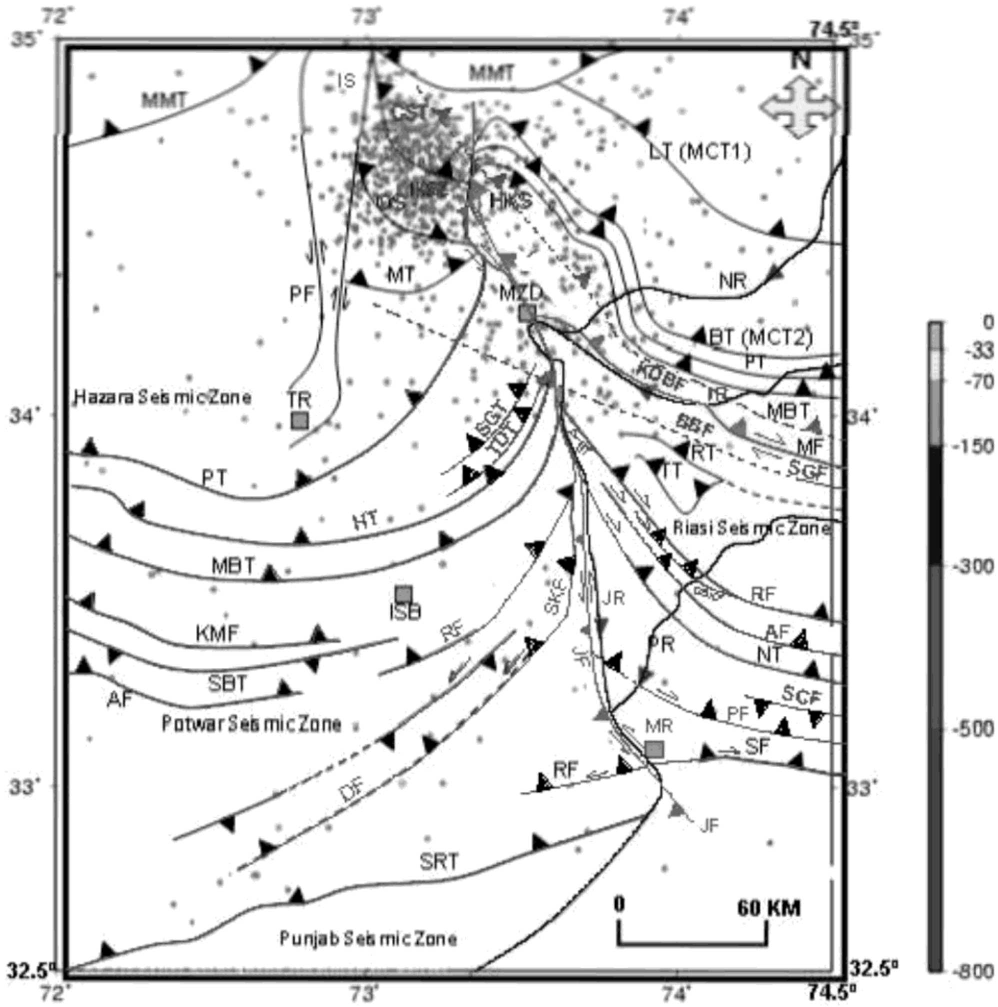

Fig. 1. Seismotectonic map of the Hazara Kashmir Syntaxis. Map shows seismicity from 1900 to present (Seismic data from U SGS 2007; modified after Baig and Lawrance, 1987; Baig 2006; Baig et al., 2008)

HKS = Hazara Kashmir Syntaxis, MMT = Main Mantle Thrust, BT = Barian Thrust, LT = Luat Thrust, MBT = Main Boundary Thrust, PT = Punjal Thrust, MF = Muzaffarabad Fault, RF = Riasi Fault, AF = Ajor Fault, NT = Nar Thrust, SF = Samwal Fault, RF = Ratial Fault, SGT = Sangar Gali Thrust, TDT = Thandiani Thrust, PF = Pir Gali Fault, SCF = Samani-Choki Fault, ST = Shahdara Thrust, SGF = Shaheed Gala Fault, BBF = Bagh Basement Fault, KDBF = Kawai-Devian Basement Fault, GBKF = Godri Badshah-Kotli Fault, SRT = Salt Range Thrust, AF = Ahmadwal Fault, SBT = Soan Back Thrust, KMF = Kheri-i-Murat Fault, RF = Rawat Fault, JF = Jhelum Fault, HT = Hazara Thrust, MT = Mansehra Thrust, OS = Ogi Shear, CST = Chail Sar Thrust, TF = Thakot Fault, PF = Puran Fault, IKSZ = Indus Kohistan Siesmic Zone, IS = Indus Syntaxis, TR = Terbela Reservoir, MR = Mangla Reservoir, ISB = Islamabad, MZD = Muzaffarabad, NR = Neelum River, JR = Jhelum River, PR = Punch River