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Active Fault System and the Related Seismicity in Pakistan

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Abstract：Earthquakes in Pakistan are generated along the active fault system due to neo-tectonic process, emerged from the colliding plate boundaries of the Indian, Eurasian and Arabian plates. Based on this progression many active seismic zones in Pakistan, e.g., the Hindu Kush-Karakoram and Indus-Kohistan seismic zones emerged. Consequently, the 8th October 2005 earthquake occurred along the Indus-Kohistan active seismic zone that killed more than 80000 people. The subsequent studies revealed that he causative faults for earthquakes are mainly active thrust faults with a strike slip component and purely the strike slip faults. Based on the seismic hazard zones, prepared after 8th October 2005 earthquake, Islamabad, the capital of Pakistan has been up-graded from Zone 2 to Zone 3 having “g” factor between 0.1-0.3 with moderate to severe damage.

Keywords：Active Fault, Seismicity, Earthquake, Hazard Zones, Pakistan

Ⅰ．Introduction

Earthquakes are normally assumed to originate from the hypocenter which is located always within about 700 km of the earth’s surface, however, in reality the focal region extends to several kilometers after most earthquakes when originated along a fault plane (e.g., Kearey *et al*., 2009). The mechanism of the earthquakes is related to the plate tectonics. Earth’s crust is composed of a number of rigid and heterogeneous plates, called tectonic plates, which move very slowly on top of a weaker homogeneous layer, the asthenosphere of the mantle within the Earth. The two colliding plates when slide pass each other, build pressure within the Earth’s crust. Earthquakes occur when pressure within the Earth’s crust increases slowly with times and finally exceeds the strength of the rocks with sudden release in the form of strain energy.

Pakistan lies in the realm of tectonic plates and frequently receives earthquakes (Fig. 1). These earthquakes occur along the active transpressional and strike slip faults (e.g., Armbruster *et al*., 1978; Kazmi 1979; Kazmi and Rana, 1982; MonaLisa and Khwaja, 2005; Rafi *et al*., 2011; Shah, 2013). According to Nakata *et al*. (1991), the nature of the Recent and Subrecent tectonic conditions of the colliding plate boundaries in Pakistan generated the active fault system in Pakistan. This manuscript highlights the causes of the October 8, 2005 Kashmir Earthquake and share the information about the seismicity in Pakistan.

Ⅱ．The October 8, 2005 Earthquake in Pakistan

Magnitude 7.6 earthquake followed by a number of aftershocks ranging between 6.0 and 5.2 magnitude hit Azad Jammu & Kashmir (AJ&K), Hazara Division, Shangla and Kohistan Districts and Peshawar, Islamabad-Rawalpindi, Lahore and other parts of the country as well as Afghanistan and the Indian held Kashmir on Saturday the October 8, 2005 at 8:52:38 AM PST at the epicenter. The depth of earthquake was 10 km. The epicenter of the earthquake was located 90 km NNE of Islamabad (Fig. 2). This earthquake killed more than 80,000 and injured more than 100,000 people with millions people rendered homeless.

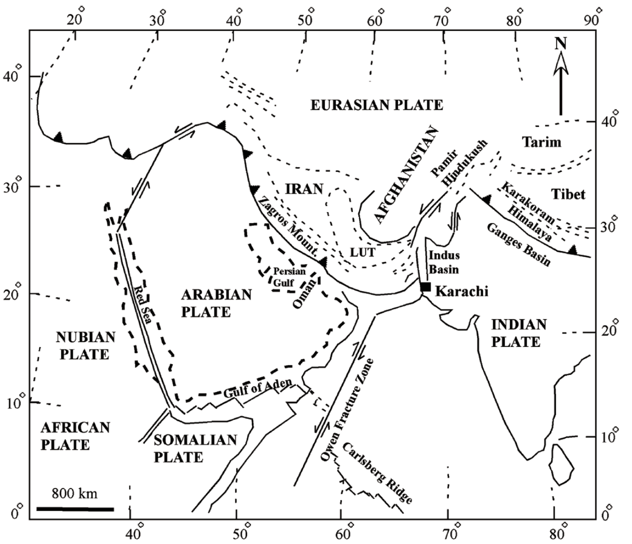


Figure 1. Map showing tectonic configuration of the Indian, Eurasian, Arabian and African plates. Also seen Karakoram-Himalaya -Pamir and Hindukush Mountain Ranges.

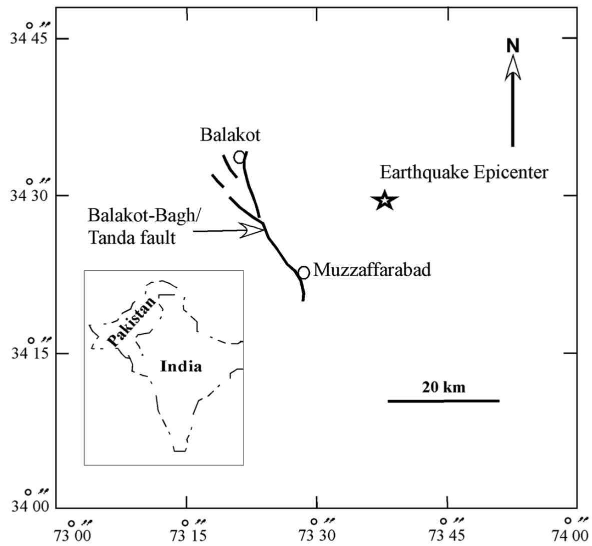


Figure 2. Simplified map, drawn from CORONA satellite photo, shows the causative faults of 8th October 2005 Kashmir earthquake after (Nakata and Kumahara, 2006). The inset shows location of Pakistan.

Ⅲ. The causative faults

The northwestern margin of the South Asian subcontinent is characterized by all kinds of earthquake events. These seismic activities are the result of movement along various active faults and tectonic processes associated with deep crustal-mantle changes in the region. The major active fault structures, particularly the peripheral fault systems have moved repeatedly during the recent geological times. The global distribution of destructive earthquakes and nature of tectonic elements indicate that a major part of Pakistan lies in an active zone of significant seismicity because of its tectonic location (Fig. 2).

In North Pakistan, Kohistan paleo-island arc-back-arc system covers about 40000 km^2 area and squeezed between the collided Indian and Karakoram-Asian continental plates (Khan *et al*., 2011). Both the tectonic contacts are marked with suture zones, namely the Main Karakoram Thrust (MKT) in the north and Main Mantle Thrust (MMT) in the south, which are seismically active (e.g., Tahirkheli *et al*., 1979; Yuhei *et al*., 1996; Kazmi and Jan, 1997; Fig. 3). The collision of the Indian continental plate with Eurasian plate took place about 40-55 million years ago, producing a tectonic pile. This tectonic pile is composed of three main elements (Subhimalaya, Lesser Himalaya and Higher Himalaya), each having characteristic stratigraphic, structural and metamorphic features and which are further separated by three main thrust faults namely the Main Central Thrust (MCT), the Main Boundary Thrust (MBT), and the Main Frontal Thrust (e.g., Keirry *et al*., 2009; Fig. 3). The large-scale structure is dominated by the 160° bending of geological lineaments around a central lower most core (Hazara-Kashmir Syntaxis) and by northeast continuation of this syntaxial structure towards the uppermost tectonic element (Nanga Parbat Syntaxis) and the collision margin (MMT).

The Subhimalayan element forms the core of the Hazara-Kashmir Syntaxis with the molassic, Miocene aged ~20 million years old Murree Formation. Older Cambrian ~560 million years and Paleocene (~65-53 million years old rocks are exposed along the ridge of Muzaffarabad anticline, which is the main structural feature of this element. The Lesser Himalaya is composed of a stack of thrust units. Characteristically, the age and the metamorphic grade of these units increase northwards, where by the highest tectonic position is occupied by the oldest rocks the Salkhala Formation (Fig. 4). A multi-phased folded basement and cover sequence belonging to the Higher Himalaya lies above an important discontinuity, which represents the continuation of the Main Central Thrust in northeast of Pakistan (Greco 1989).

The structures associated with thrust tectonics in the area are imbricate faults and isoclinals and recumbent folds. This deformation is due to northwest-southeast oriented compression forming the Hazara-Kashmir Syntaxis (Greco 1989) (Fig. 3). Seismic activity has been noticed with these thrust faults and the area has been subjected to recent active faulting, particularly the Raikot and Astore Earthquakes of 2002 that occurred along the Raikot-Sassi-Astore strike slip active fault. The Main Boundary Thrust (MBT) passes

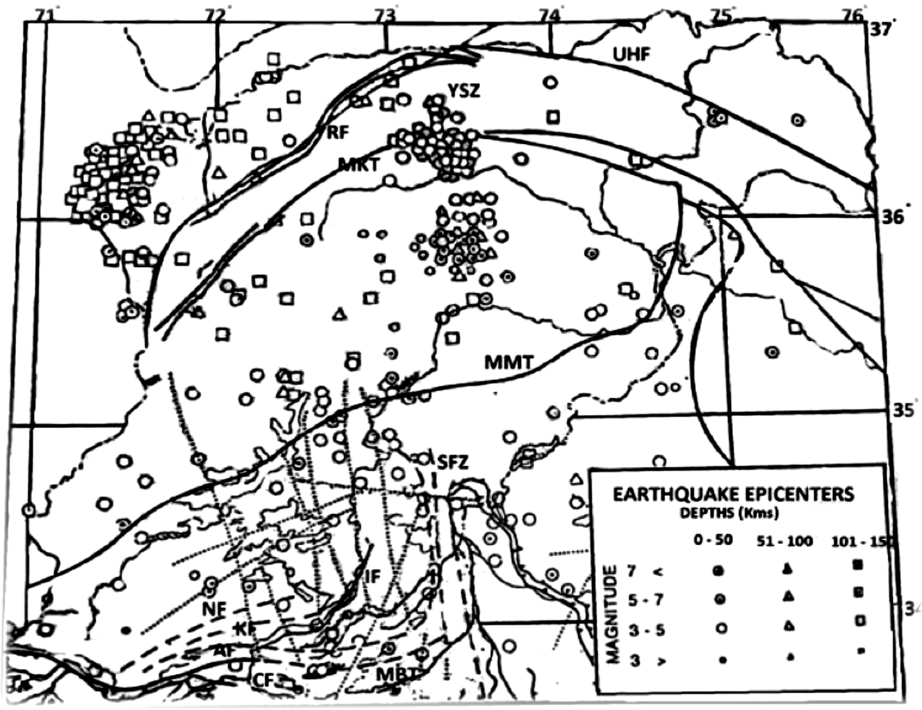
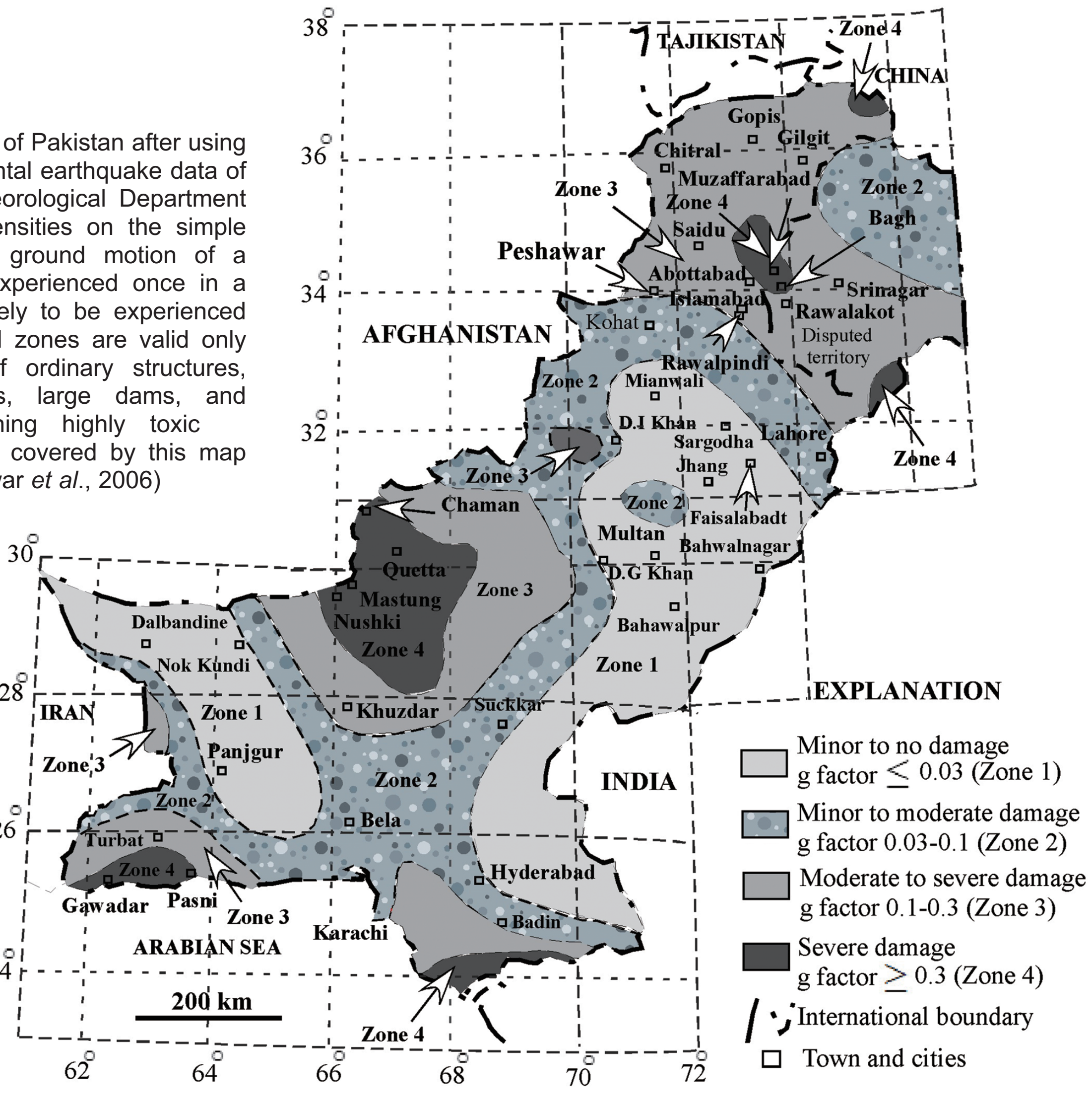


Figure 3.
Seismotectonic map showing the locations of Yasin (YSN) and Hamran (HSZ) seismic zones and faults. UHF=Upper Hunza Fault, RF=Reshun Fault, MKT=Main Karakoram Thrust, MMT=Main Mantle Thrust, NF=Noushera Fault.

Figure 4.
Seismic zone map of Pakistan after using historical instrumental earthquake data of the Pakistan Meteorological Department and observed intensities on the simple premise that the ground motion of a certain intensity experienced once in a certain area is likely to be experienced again. The hazard zones are valid only for the design of ordinary structures, nuclear structures, large dams, and structures containing highly toxic chemicals are not covered by this map (redrawn after Anwar *et al*., 2006)



through Islamabad, Murree, Muzaffarabad, Balakot, and Indian held Kashmir and to the west, in Kohat and Parachinar. A number of active faults are associated with the MBT, which already generated earthquakes, particularly in Mansehra and the adjoining areas of the Hazara Division, Kohistan and the Northern Areas of Pakistan.

The recent earthquake of 8th October 2005 links to the Balakot-Bagh active fault and/or Tanda fault of Nakata and Kumahara (2006), the offshoot of the MBT, which lies in the Indus-Kohistan active seismic zone. The fault extends for a strike length of about 65 km and passes through Balakot, Muzaffarabad, and Bagh areas. The fault between Balakot and Muzaffarabad runs between the dolomitic limestone and carbonaceous shale of the Muzaffarabad Formation of Precambrian age and the Murree Formation of Miocene age. Further in the southeast, the fault mostly extends within Murree Formation. In Muzaffarabad area, the fault dips to the northeast at moderate to steep angle coinciding with the earthquake epicenter. The field evidences indicate a thrust fault with strike slip movement, a transpressional fault. The rupture is traceable on the surface illustrating uplift of the area on the northeastern side of the fault.

Ⅳ. Seismicity in Pakistan

The documented record of seismicity consists of mainly earthquake epicenters located on the basis of instrumental recordings. Kazmi and Jan (1997) reported active seismic zones of Pakistan which include the Hindu Kush-Western Karakoram seismic zone with frequent earthquakes of magnitude 5-7 at focal depths of 100-200 km (Fig. 5). Other active seismic zones are the Yasin and Hamran seismic zones in the Gilgit-Baltistan province where frequent earthquakes of 3-5 magnitude and focal depth up to 100 km encounter. The Tarbela-Hazara and the Indus-Kohistan seismic zones depict shallow for Tarbela from 8-18 km depth to deeper for

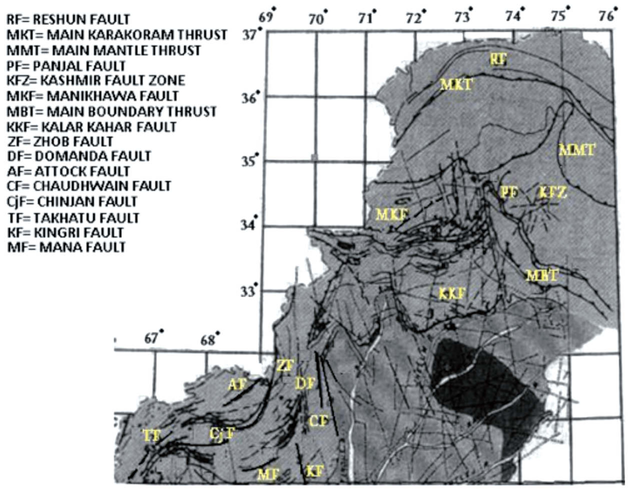


Figure 5. Seismotectonic map showing the locations of various faults (after Kazmi and Jan, 1997).

the Hazara region where the seismicity encounter more than 18 km along the steeply dipping basement fault with reverse and strike slip motion (Kazmi and Jan, 1997). The Punjab seismic zone comprises a region of relatively high seismicity. Strike slip active faults and a number of lineaments traverse this region. Other seismic zones include (1) the Sulaiman seismic zone which covers the entire Sulaiman fold-and-thrust belt characterized by shallow earthquakes of moderate to high magnitude (5 to 7). Within this zone there is Harnai-Kohlu high seismicity belt.

The high seismicity belt contains a number of large NE, EW and NW trending faults. Earthquake activity in the region is due to strike slip faulting, (2) the North Kirthar seismic zone comprising the northern portion of the Kirthar fold-and-thrust belt lying between Quetta and Kalat and bounded to the east by the Kachhii plain and to the west by the Ghazaband fault. Seismic events and associated ground ruptures at various locations indicate that the seismicity of this region is centered around a few NS trending faults, (3) Chaman fault seismic zone forms a narrow seismic strip around the 900 km long Chaman Fault, along which small to

Table 1. Revised seismic hazard zones of Pakistan (after Anwar et al., 2006).

Zones	Impact	Intensity	g Factor	Cities
Zone 1	Minor to no damage	≦6	≦0.03	Mianwali, Sargodha, Jhang, Multan, DG Khan, Dalbandine, Nokundi, Panjgur
Zone 2	Minor to moderate damage	6-7.5	0.03-0.1	Gujranwala, DI Khan, Bannu, Kohat, Lahore, Dera Bugti, Sukkur, Bela, Hyderabad, Badin, Karachi
Zone 3	Moderate to severe damage	7.5-9	0.1-0.3	Gopis, Chitral, Gilgit, Patan, Rawalakot, Abottabad, Saidu, Sialkot, Kohlu, Khuzdar, Jacobabad, Turbat, Peshawar, Rawalpindi, Islamabad, Jhelum
Zone 4	Severe damage	>9	≥ 0.3	Muzaffarabad, Bagh, Mansehra, Chaman, Pishin, Quetta, Mastung, Nushki, Kalat, Gowader, Pasni

large earthquakes occurred in the past. Focal mechanism and field evidences indicate left lateral strike slip motion (e.g. Rehman *et al*., 2011) and (4) the Makran Coast seismic zone comprising a region of active subduction and is characterized by shallow seismicity (e.g. Hussain *et al*., 2002). Most of the earthquakes are located off the coast. The 1945 earthquake generated Tsunami along the Makran coastal area. After the 8th October 2005 earthquake Ahmad *et al*. (2006) published revised seismic hazard zones of Pakistan on the basis of "g" factor (Table 1).

V. Seismicity in other regions of the country

In other parts of the country, namely Chaghai, Bannu, Potwar, Bela-Kuzdar and Southern Kirthar fold belt, the level of seismicity is relatively low and diffused. The central and southern parts of the Indus Platform zone are devoid of any modern teleseismic activity except in the Sulaiman and Kirthar foredeeps and in the Rann of Kutch and the adjacent areas. Two large earthquakes namely the 1901 Kachhi and the 1819 Alla Band have already occurred in the Rann of Kutch.

There are many other active faults in Pakistan which include: Reshun Thrust Fault; Upper Hunza Fault; Karakoram Fault; Main Karakoram Thrust; Main Mantle Thrust; Raikot-Sassi-Astore Fault; Harban and Sassi-Dassu Fault; Shinkiari Fault; Indus Fault System; Darband Fault; Nowshera and Kund Faults; Main Boundary Thrust (composed of a series of parallel and echelon faults) also known as the Parachinar-Murree Fault; Muzaffarabad-Balkot Fault; Jhelum Fault; Dil Jaba Thrust Fault; Hissartang Fault; Attock and Campbellpur Faults; Kaller Kahar and Uchalli Faults; Salt Range Thrust Fault; Surghar Thrust Fault: Kalabagh Fault (Kazmi and Jan, 1997).

VI. Conclusions

Earthquakes in Pakistan are generated along the active fault system due to neotectonic process emerged from the colliding plate boundaries of the Indian, Eurasian and Arabian plates. Based on this tectonic process many active seismic zones in Pakistan such as the Hindu Kush-Karakoram and Indus-Kohistan seismic zones have been emerged. The 8th October 2005 earthquake occurred along the Indus-Kohistan active seismic zone that killed more than 80,000 people. The causative faults for earthquakes are mainly active thrust faults with strike slip component and purely the strike slip faults. Based on the seismic hazard zones, Islamabad, the capital of Pakistan has been up-graded from Zone 2 after the 8th October 2005 earthquake to Zone 3 having "g" factor between 0.1-0.3 with moderate to severe damage.

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