

## BALAKOT, MUZAFFARABAD EARTHQUAKE OF 8 OCTOBER 2005, Mw 7.6; FIELD OBSERVATIONS ON GEOLOGICAL ASPECTS

M. Zaré<sup>1</sup> and S. Karimi-Paridari<sup>2</sup>

<sup>1</sup>Associate Professor, Dept. of Engineering Seismology, International Institute of Earthquake Engineering and Seismology (IIEES), Tehran, Iran, e-mail:mzare@iiees.ac.ir

<sup>2</sup>PhD Candidate; Dept. of Engineering Seismology, International Institute of Earthquake Engineering and Seismology (IIEES), Tehran, Iran, e-mail:s.karimi.p@gmail.com

### ABSTRACT :

This article is focused on the geological observations in the meizoseismal region in Muzaffarabad earthquake, Oct.8 2005, Mw 7.6. The major damaged area (the valley elongated between Balakot, Muzaffarabad and and Bagh) was elongated parallel to the reactivated Muzaffarabad fault and the attenuation is high in the direction normal to the fault comparing with the direction parallel to it. The high intensity values were assessed in the localities where some huge landslides are observed.

**KEYWORDS:** Muzaffarabad, Pakistan, Reconnaissance, Geology, Intensity, Attenuation

### 1. INTRODUCTION

An earthquake of magnitude Mw=7.6 occurred in the NE of Pakistan on Oct. 8, 2005, at 8:50:40 a.m. local time, (3:50:40 GMT). Its epicenter was located at about 10 km in the east of Balakot and 19 km in the north-east of Muzaffarabad in Pakistan administered Kashmir. The earthquake caused heavy life and property losses in Pakistan-administered Kashmir, Pakistan's North-West Frontier Province (NWFP), western and southern parts of Kashmir on Indian side and eastern parts of Afghanistan. More than 80,000 persons were killed according to the official report. The affected region is a mountainous area with high landslide potential. A series of landslides were triggered by the earthquake, which blocked and damaged roads and power transport lines. Small houses located in the slopes were buried under the debris of landslides. This article is concentrated to review the geological aspects of the earthquakes observed in the epicentral region. This mission was headed by Dr Sassan Eshghi (IIEES) and funded by the International Institute of Earthquake Engineering and Seismology.

### 2. TECTONIC SETTING

The study area is a part of the NW Himalayan Fold and Thrust Belt (Kazmi and Jan, 1997), seismically very active. Some researchers (e.g. Verma, 1986; Sercombe et al., 1998; MonaLisa et al., 2002; MonaLisa et al., 2004) have contributed to the seismicity/tectonics understanding of this seismically very active region of the world and studied the ongoing collisional processes of Indian plate with Kohistan Island Arc. The affected zone (north east of Pakistan) shows different geological structures (Figure 1). The region is known to be a tectonic syntax, changing the major tectonic trends from NNW-SSE to NNE-SSW in the NE of Islamabad (Figure 2).

#### 2.1. Seismotectonic

The epicentral location of this earthquake lies in the northwestern part of Himalayan Frontal Arc, between 1897 and 1952, along the Himalayan convergent plate margin, 14 major earthquakes ( $M \geq 7.5$ ), including 5 great earthquakes of  $M \geq 8$  occurred.

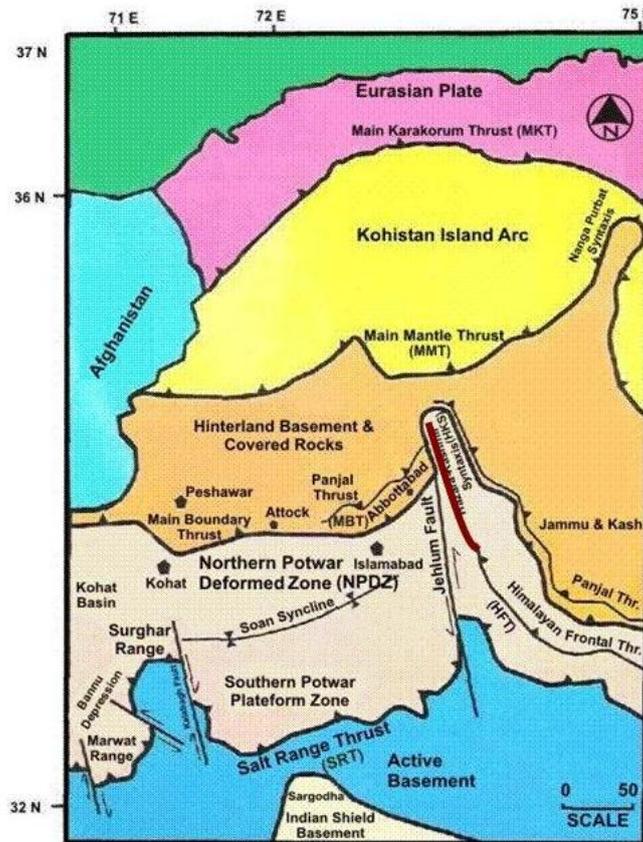


Figure 1: Major tectonic unites of NE Pakistan (source: Geological survey of Pakistan web site).

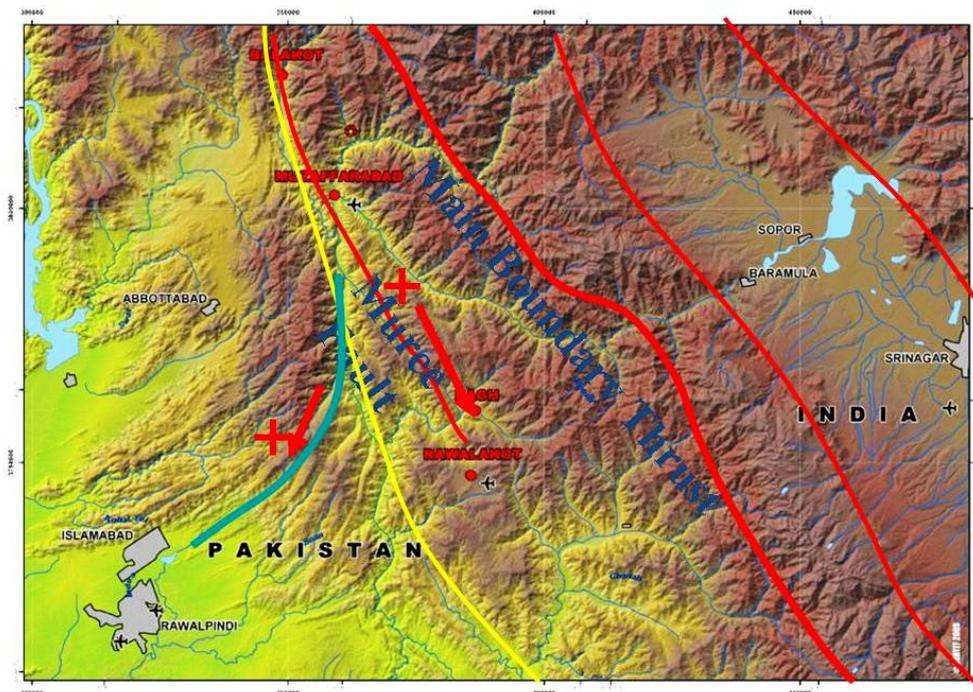


Figure 2: Major faults in the epicentral region of 8 October 2005 earthquake.

### 3. SPOURCE PARAMETERS

The epicenter of Balakot, Muzaffarabad earthquake- 8 Oct. 2005, was located at 110 km in the north of Islamabad and 175 km north-west of Sehrinagar. The focal mechanism determined by Avouac et al., (2006) using sub-pixel correlation of ASTER images, indicates thrust faulting on a N138° striking fault having dip towards NE with significant strike-slip component of slip. Similar focal mechanism was obtained by Parsons et al. (2006).

47 aftershocks of  $m_b \geq 5.0$  occurred in the first month after the event. The fault plane solutions of these aftershocks show thrust motions similar to the mainshock.

The aftershocks distribution shows a concentration in the north and north-west of the epicentral zone. The earthquake rupture, 8 Oct. 2005, reached the surface in many places, being referred to as “Muzaffarabad fault” and in the name of “Murree Fault” in geological map of the area (Geological Survey of Pakistan, 1:50000 scale; Figure 3);. Furthermore, most surface ruptures are marked by landslides. The estimated focal depth is less than 10 km (Parsons et al., 2006).

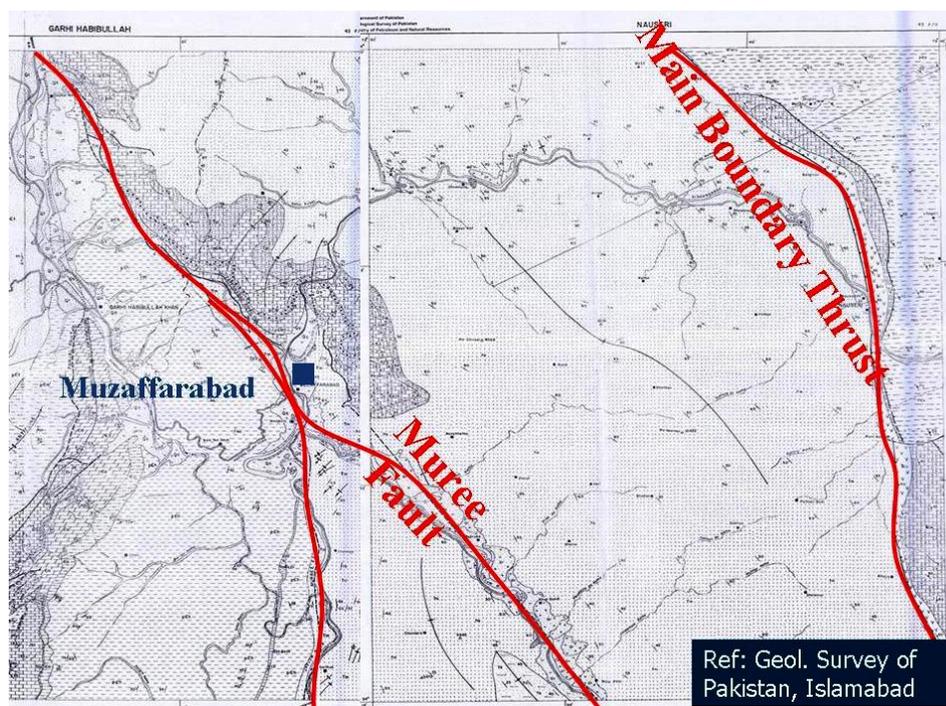


Figure 3: Muzaffarabad fault zone (draft prepared by Dr Kausar and his group, GSP)

### 4. SLOPE MOVEMENTS

The earthquake occurrence accompanied by landslides made a lot of dust specially in Darebagh, Muzaffarabad and Balakot. Such phenomena with huge stones falling the destroyed the roads in different places and blocked the traffic leading to extreme congestion.

Numerous landslides occurred in the meisoseismal region and most of them were associated with the fault scarp where the rupture reached the surface. The landslides mostly occurred from the eastern parts of Darebagh to Muzaffarabad and Balakot (Figure 4) which damaged or blocked roads and also induced some damages to the

transport facilities such as tunnels, having no halter or cover, and bridges in the south of Muzaffarabad. Some vertical and horizontal cracks and fissures have been observed on the south Muzaffarabad bridge.

## 5. INTENSITY DISTRIBUTION

The city of Balakot was destroyed by a intensity of X (EMS98 scale). Many buildings were destroyed in Muzaffarabad (Figures 5 and 6). The isoseismal map for 8 Oct 2005 earthquake (Figure 7) is prepared based on the total destruction of epicentral zone (Balakot and Muzaffarabad) and studying the reports of remote places such as Srinagar in India and Lahore in Pakistan. This map is essentially based on field visits of IIEES reconnaissance team. The visits were taken place in less than three weeks after the epicentral mainshock . The maximum intensity was estimated to be around Balakot and along Muzaffarabad fault, with a width of 10-15 km around fault.



Figure 4: landslides in southern Balakot (the white color patches on the slops).

The greatest damage was observed in Balakot representing complete destruction (i.e. more than 1 meter dislocation of the concrete bridge over Balakot River). Balakot region is assigned intensity X (according to EMS-98 scale). All buildings in this valley city were destroyed totally. Many landslides on the north and south sides of valley took place and they were more concentrated in the eastern hillsides And all buildings, facilities and roads around Balakot were seriously damaged.

The city of Muzaffarabad is located on a river terrace. Based on damages seen in Ijaz Golab military hospital, an intensity of IX on EMS98 scale is estimated. There are many large earthquake inducing landslides along the hills around the city. The retaining walls were collapsed in some roads. In Ijaz Golab hospital, the northern block fell down due to the first floor collapse (soft story; Figure 5) but other parts of the hospital show less damage. The daily life had returned to normal 18 days after the event when IIEES reconnaissance team visited the epicentral region.,



Figure 5: Crunched Hospital building (Ijaz Golab Hospital), in Muzaffarabad.



Figure 6: Collapsed Sangam Hotel building (in Muzaffarabad).

Intensity in Abbottabad was estimated to be VIII (EMS-98 scale) derived from a hotel collapse. Due to the observed residential buildings damage VIII intensity is assigned to Mansehra. No damage was observed on the dam and the facilities upon the inspection of Tarbela earth-rock fill dam. However, mud was reported in the dam's reservoir due to the landslides. To the SW of the epicenter, the landslides were observed in the region between Punjab and Jammu and Kashmir (India). This region is assigned an intensity of about VI.

While there wasn't as much damage in Islamabad, a Margala tower collapsed in the north west of Islamabad

because of its structural engineering and also the type of soil (grain alluvium with clay matrix).

## 6. DISCUSSION

The meiseisomal region is located in the Muzaffarabad valley and the most devastated area, Balakot city, was totally demolished. The observed damage was nearer to the southeast end of the fault (towards Bagh) that could be due to directivity effect along the fault towards northwest. The upward progress of the rupture plane might be the source of heavier damage in the hanging wall of the fault.

The attenuation of strong ground motions was faster in the fault normal direction and therefore, the damage diminished rapidly towards the east and west of the meiseisomal region,

This earthquake has shown the importance of the landslides in the determination of earthquake intensities in the remote and sparsely populated mountainous areas. The great landslides, specially along Muzaffarabad valley and near Bagh city, were major indicators of inferring isoseismal intensity.

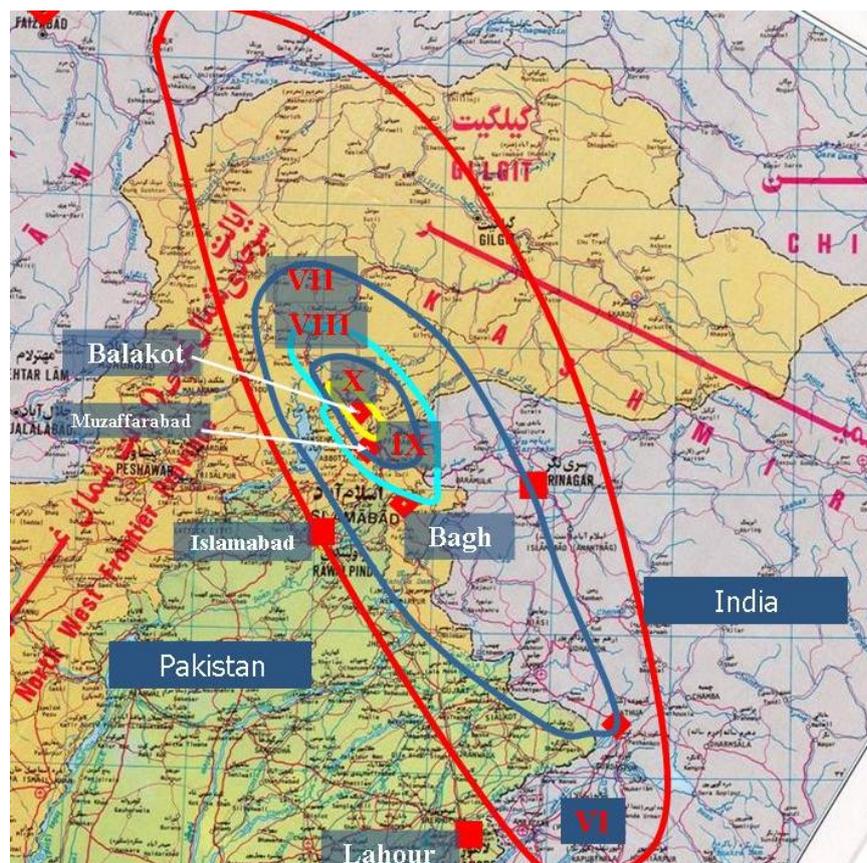


Figure 7: Iso-seismal map of Balakot, Muzaffarabad earthquake of 8 October 2008 (developed by S. Eshghi and M. Zare, October 2008, IIEES).

## 8. CONCLUSION

Balakot, Muzaffarabad earthquake, of 8 Oct. 2005, with the magnitude  $M_w=7.6$ , occurred along

Muzaffarabad fault, and most likely a part of the fault between Bagh and Balakot was reactivated. Strong ground motion caused severe damage especially in the east and northeast part of the epicenter. The direction of the strong movement mostly were northwest-southeast. As the occurrence time of the previous event on this fault segment is unknown, paleoseismological studies are required to infer the recurrence interval.

Islamabad city is located near the syntaxial bend where the tectonic processes are more intense and complex. Therefore, the region has very high potential seismic hazard. The seismic hazard zonation map of Pakistan, produced by Geological Survey of Pakistan before 8 Oct. 2005, represented moderate hazard level in Balakot region (Figure 8) . After Balakot earthquake, the seismic hazard map of Pakistan has been revised. Balakot and Muzaffarabad zones now lie in high seismic hazard zones. However, in order to update the seismic hazard zoning maps for Pakistan, incorporating major active tectonic units and assuming proper seismicity parameter are proposed for the input of seismic hazard map.

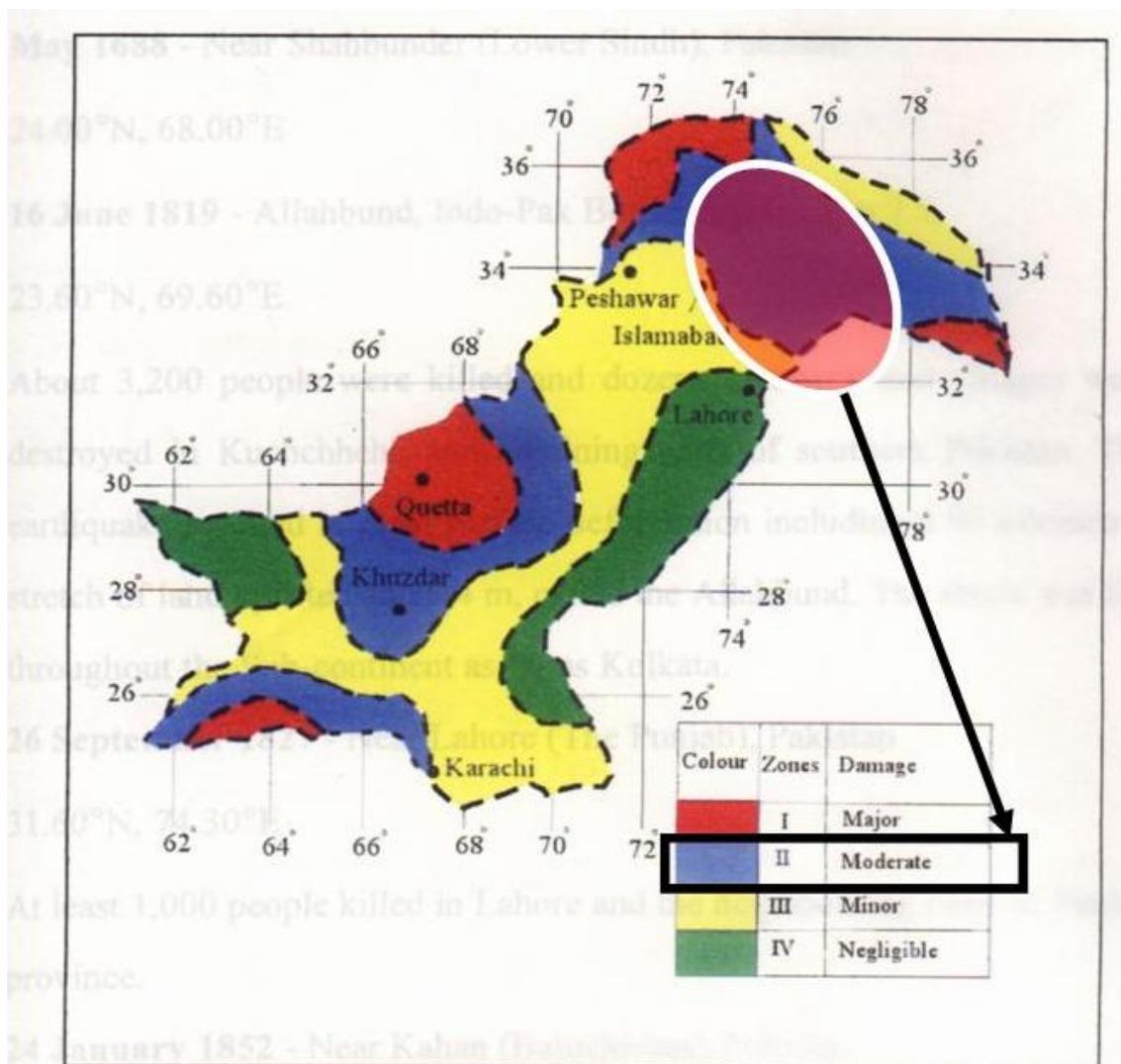


Figure 8: Seismic hazard zoning map of Pakistan, prepared before 2005 earthquake (GSP web site).

## Acknowledgment

Special thanks should be addressed to Dr. Sassan Eshghi, the team leader of IIEES reconnaissance team dispatched to the earthquake affected area. The financial support for this study is provided by IIEES which is greatly acknowledged. The support provided by the Geological Survey of Pakistan (GSI), the technical advices given by Mr Mirza Talib Hassan (General Director of Geological Survey of Pakistan), Dr. Kausar (GSI General Director in Islamabad) and Dr. Ahmad Hossein (Chief Geologist, retired from GSI) were very useful in these studies.

## **REFERENCES**

Avouac, J.P., Ayoub, F., Leprince, S., Konca, O., Helmberger, D.V., (2006) The 2005, Mw 7.6 Kashmir earthquake: Sub-pixel correlation of ASTER images and seismic waveforms analysis, *Earth and Planetary Science Letters*, 249: 516-528.

Geological Survey of Pakistan (GSP), web site; <http://www.gsp.gov.pk/>, October 2005 to December 2005.

Grunthal G [ed.], (1998) *European Macroseismic Scale 1998*, [http://www.gfz-potsdam.de/pb1/pg2/ems\\_new/INDEX.HTM](http://www.gfz-potsdam.de/pb1/pg2/ems_new/INDEX.HTM).

Kazmi, A.H. and Jan, M.Q., (1997) *Geology and tectonics of Pakistan*, Graphic Publishers, Karachi, Pakistan.

MonaLisa., Khwaja. A.A. and Qaiser, M., (2002) Focal Mechanism Studies of Kohat and Northern Potwar Deformed Zone. *Geological Bulletin, University of Peshawar* 35: 85-95.

MonaLisa., Khan, S.A. and Khwaja, A.A., (2004) Focal mechanism studies of North Potwar deformed zone (NPDZ), Pakistan. *Acta Seismologica Sinica, China* 17:255-261.

National Earthquake Information Centre (NEIC), web site: <http://neic.usgs.gov/>, October 2005.

Parsons, T., Yeats, R.S., Yagi, Y., (2006) Static stress change from the 8 October, 2005 M=7.6 Kashmir earthquake, *Geophys. Res. Lett.* 33 (2006) LO6304, doi:10.1029/2005GL025429.

Verma, R.K. and ChandraSekhar, Ch., (1986) Focal mechanism solutions and nature of plate movements in Pakistan. *Jour. Geodyn.* 5:331-351.