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THE TECTONIC SETTING OF THE OCTOBER 8TH 2005 EARTHQUAKE IN KASHMIR, NORTH PAKISTAN

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Abstract

On the 8th of October 2005 an earthquake of magnitude 7.6 occurred in northern Pakistan. The earthquake epicenter was located in Pakistan Kashmir, 90 km north of Islamabad, the capital of Pakistan. The focal depth was 26 km triggered by a thrust fault striking NW-SE and of 40o dip angle towards the NE. The mean fault slip was estimated as 4 m. The aftershocks epicenters were located northeastwards of the Indus – Kohistan Seismic Zone. The structures that trace the activated fault were distributed along the southwestern limb of the Muzaffarabad anticline and grouped as structures of flexural-slip folding, structures that are correlated to folding and normal faults. The latter may represent overturned segments of the seismic fault on the high-angle limb of the Muzaffarrabad anticline. This anticline is located on the hanging wall of a thrust fault with geometry and kinematics characteristics similar to those of the Indus – Kohistan Seismic Zone. This zone, from the Hazara – Kashmir Syntaxis to the Swat River represents a blind thrust under the metamorphosed rocks of the Lower Himalayas, while in the region of Sub– Himalayas becomes a distinct structure. This thrust fault is linked in depth to the Main Himalaya Thrust through which. the cratonic basement of India is subducting under its sedimentary cover.

Key words: *Himalayan, main boundary thrust, thrust fault, Kashmir, flexural slip structures, #Muzaffarabad fault.*

Περίληψη

Την 8η Οκτωβρίου 2005 σεισμός μεγέθους 7.6 έλαβε χώρα στο βόρειο Πακιστάν. Το επίκεντρό του τοποθετείται στο Κασμίρ, 90 km βόρεια του Islamabad, πρωτεύουσας του Πακιστάν. Το εστιακό βάθος του ήταν 26 km και οφείλεται στη δράση ενός επωθητικού ρήγματος διεύθυνσης ΒΔ-ΝΑ και κλίσης 40ο προς τα ΒΑ, ενώ η μέση ολίσθηση ήταν 4 m. Τα επίκεντρα της μετασεισμικής ακολουθίας εντοπίστηκαν βορειοανατολικά της Σεισμικής Ζώνης Ινδού – Κοχιστάν. Οι δομές που σχετίζονται με το ρήγμα παρατηρήθηκαν κατά μήκος του νοτιοδυτικού σκέλους του αντικλίνου του Muzaffarabad και επρόκειτο για πτυχωσιγενείς δομές ολίσθησης, παραμόρφωση των παλαιών πλευρικών κορημάτων και αλλουβιακών ριπιδίων με ταυτόχρονη δημιουργία νέων και κανονικά ρήγματα μεγάλης κλίσης, τα οποία πιθανά να αντιπροσωπεύουν ανεστραμμένα ή κατακόρυφα τμήματα του σεισμικού ρήγματος στο μεγάλης κλίσης σκέλος του αντικλίνου του Muzaffarabad. Το αντίκλινο αυτό βρίσκεται στο πάνω τέμαχος ενός

επωθητικού ρήγματος με γεωμετρία και κινηματική συγκρίσιμη με αυτή της Σεισμικής Ζώνης Ινδού – Κοχιστάν. Η τελευταία συνιστά από τη Hazara – Kashmir Syntaxis μέχρι τον Ποταμό Swat ένα τυφλό επωθητικό ρήγμα κάτω από τα μεταμορφωμένα πετρώματα των Χαμηλών Ιμαλάϊων, ενώ στην περιοχή των Υπο-Ιμαλάϊων είναι μία διακριτή δομή. Στο βάθος συνδέεται με την Κύρια Επώθηση των Ιμαλάϊων, όπου το κρατονικό υπόβαθρο της Ινδίας υποβυθίζεται κάτω από το ιζηματογενές επικάλυμμά του.
Λέξεις κλειδιά: *Ιμαλάια, κύρια περιθωριακή επώθηση, Κασμίρ, δομές πτυχωσιγενούς ολίσθησης, ρήγμα Muzaffarabad.*

1. Introduction

On the 8th of October 2005 and at 8:50 AM local time (03:50:38 UTC), an earthquake of magnitude 7.6 R hit northern Pakistan. The earthquake epicenter, which is the strongest earthquake in the history of the country since 1935, was located near the capital of the Kashmir, Muzaffarabad, and except northern Pakistan, the earthquake also affected northern India and northeastern Afghanistan. The local authorities of Pakistan recorded over 87,000 casualties and at least a fivefold number of injuries, while according to the United Nations the homeless were estimated to nearly four million. Important damages and at least 1,300 casualties were also recorded in northwestern India.

Although it is not the first time that the Himalayas generate such earthquakes – many earthquakes of magnitude >8 R have been recorded in the past – this was the most catastrophic earthquake recorded on the Himalayan Arc. Major earthquake events recorded during the past century include the Kanga earthquake in 1905 with 19,000 casualties, the Bihar earthquake with 11,000 casualties and the Quetta earthquake with 30,000 casualties (Khattri 1987, Billham 2004). An interesting element is that for the aforementioned earthquakes but also for other historical earthquakes, no primary surface ruptures were recorded, a fact that led Seeber and Ambruster (1981) to suggest that those earthquakes were occurred by the activation of blind thrust faults and that the stresses were released through fold growth of anticline structures rather than primary surface rupturing (Kumar *et al.* 2006 and references therein). However, recent research is controversial to the above suggestions presenting new data on the surface expression of large thrust structures during earthquake events of significant magnitude (Kumar *et al.* 2006).

Similar suggestions were also derived from the first reports on the 8th October 2005 earthquake, which mention large scale landslides along a zone that must correspond to the activated fault and accept that the propagation of the fault rupture have stopped before reaching the earth surface, (e.g. EERI reports, http://www.eeri.org/lfe/clearinghouse/kashmir/observ1.php), as in previous earthquakes.

In this paper, besides the tectonic setting of October 8th 2005 earthquake, we present field data indicative of the surface expression of the activated fault. We believe that these data will provide important information for the behaviour of thrust faults on the earth surface, not only for the Himalayan mountain belt but for similar tectonic settings around the world.

2. Tectonic Setting

2.1. The Himalayas

The Kashmir region represents a section of the Himalayan orogenic chain. This orogen extends from central Afghanistan to the west and to southeastern China to the east, with a length approaching 4,000 km and width varying from 500 to 2,000 km (Fig. 1). It comprises a complex tectonic structure formed by multiple thrusting and stacking of continental terrains and island arcs on the southern margin of Eurasia, a procedure that was initiated during the Upper Paleozoic and continues in our days with the increment of the Indian tectonic plate (Hodges 2000).

This orogenic chain comprises of six tectonic zones that can be observed along its length (Fig. 1a). From north to south these zones are the following (Butter *et al.* 1989, Hodges 2000, Najman *et al.* 2000, 2001. 2002, 2004) (Figs 1, 2): The Trans-Himalayan with batholiths that it is suggested that they represent an Andean type north Tethyan margin. 2) The Indus Suture Zone that comprises of marine sediments, ophiolites, volcanic rocks and mélange. It represents the collision trace between the Indian and the Eurasian plates. 3) The North Himalaya or Tethyan Himalaya or Tibetan Himalaya, comprising of sedimentary and post- sedimentary rocks, of Upper Precambrian – Lower Paleozoic age and of Permian – Cretaceous thick marginal sequences. 4) The crystalline rocks of the Greater Himalaya that comprise of Upper Proterozoic – Lower Cambrian sedimentary, granite and volcanic rocks, metamorphosed during the Tertiary. 5). The Lower Himalaya that represents the lower tectonic nappe and comprises of post-sedimentary, sedimentary and volcanic rocks of Middle Proterozoic and granite rocks of Cambrian – Ordovician age. 6) The Thrust and Fold Belt also referred to as Sub-Himalaya. It represents the Neogene and Quaternary forearc basin section between the Lower Himalaya and the active thrust front of the orogen, the Main Frontal Thrust – MFT, (Fig. 2). This belt is the result of the subduction of the Indian cratonic block under its Phanerozoic sedimentary cover (Najman *et al.* 2001, 2002).

The aforementioned zones are bounded by great Cenozoic normal or thrust faults with a general dip direction towards the north (Figs 1b, 2): (i) the Main Frontal Thrust – MFT or Himalayan Frontal Thrust – HFT, (ii) the Main Boundary Thrust – MBT, (iii) the Main Central Thrust – MCT and (iv) the South Tibetan Detachment System – STDS, (Najman *et al.* 2004 and references therein). All the thrust structures can be observed throughout the mountain chain and it is believed that are linked to a large scale detachment the Main Himalayan Thrust – MHT.

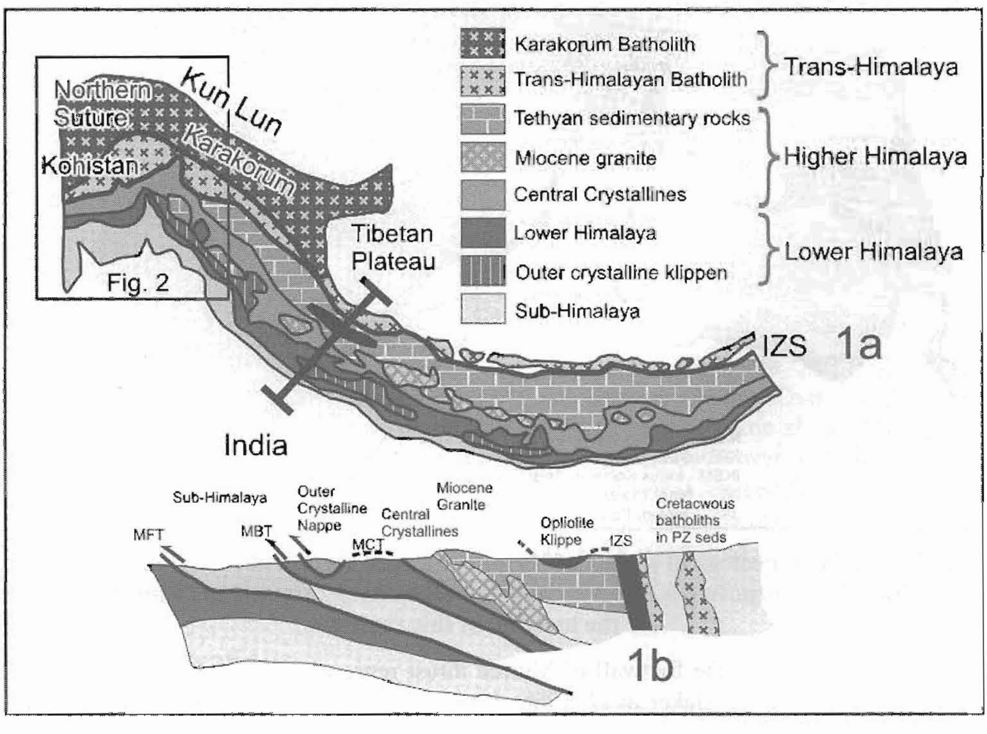

Figure 1 – Geotectonic map of Himalaya orogenic belt (1a) and representative geological section of the belt (1b)

It is estimated that since the Upper Cretaceous approximately 2000–3000 km of convergence has been leveled along this margin (Molnar and Tapponier 1977). GPS measurements indicate that the convergence between India and Eurasia continues in our days with a rate that approaches 40–50 mm/year (DeMets *et al.* 1994, Banerjee and Bürgmann 2002). The 10–20 mm/year are attributed to the sliding on the HFT (Wesnousky *et al.* 1999). Seeber and Ambruster (1981) observed that most of the earthquake epicenters and disasters related to historical earthquakes were concentrated in a region that is bounded to the north by the MCT and to the south by the HFT and suggested that these large earthquakes have caused the activation of the Main Himalayan Thrust south of the Greater Himalaya up to the HFT.

2.2. The Hazara – Kashmir Syntaxis

The earthquake epicenter of the October 8th 2005 was located in Pakistan Himalayas and specifically within the Hazara – Kashmir Syntaxis (Figs 2, 3). The latter represents a tectonic structure that was formed during the progressive penetration of the northwestern end of Indian plate in Asia which caused right lateral rotation of the thrust direction by 75° relative to the India cratonic block, (Critelli and Garzanti 1994, Najman *et al.* 2001, 2002).

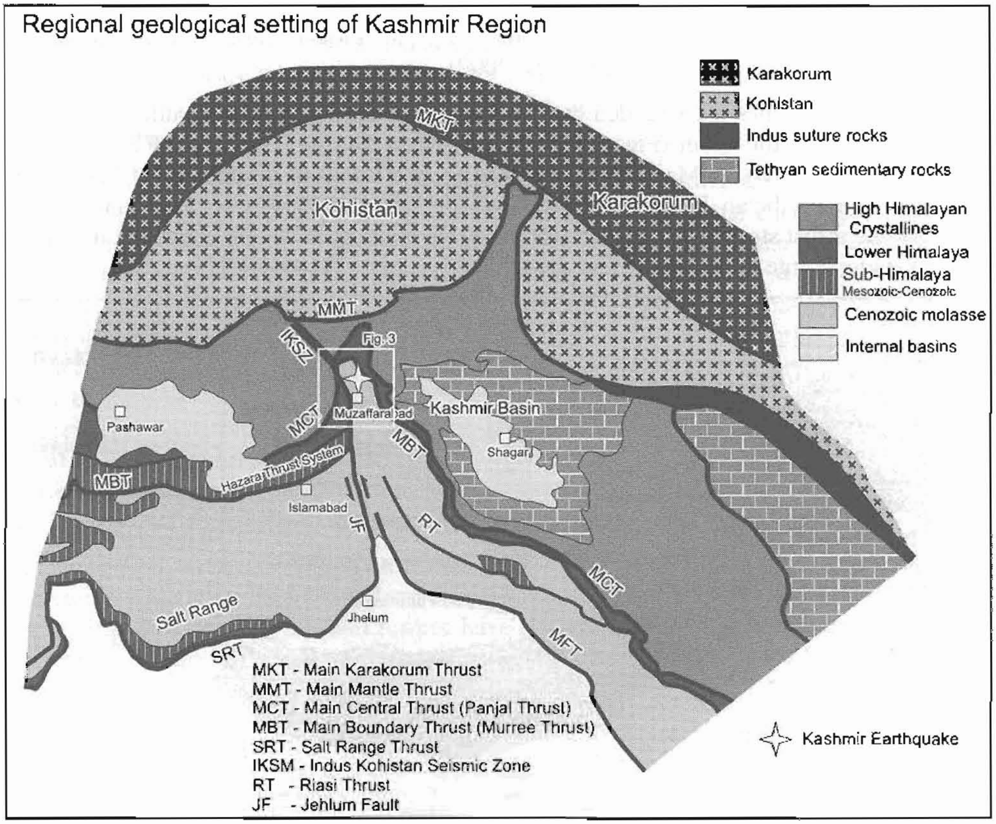

Figure 2 – Regional geological setting of Kasmir, western section of the Himalaya orogenic belt (modified from http://www.albany.edu/geosciences/nangap/paksuc97.html). See figure 1 for the location of this region

The formations located on the footwall of Murree thrust represent a part of the Thrust and Fold belt of the Indian foreland (Baker *et al.* 1988, Jaune and Lillie 1988, Bossart *et al.* 1990). The stratigraphy of the belt is the following from older to younger: (i) The Precambrian basement of metamorphosed and volcanic rocks of the Indian shield, (ii) the Cambrian Salt Range formation of evaporates and sediments with a dominant hyalite phase, that compose the detachment zone of the Fold and Thrust Belt, (iii) Cambrian to Eocene platform sediments with large unconformities at the base of Permian and Paleocene and finally (iv) Miocene - Pleistocene molassic sediments laying unconformably over the platform sediments that can be distinguished in two groups, the

Rawalpindi Group and the Siwalik Group. The Murree formation is considered as part the Rawalpindi Group.

The footwall of the Murree thrust which corresponds to the MBT of India is characterized by the Muzaffarabad anticline (Fig. 3). In the core of the anticline between Balakot and Muzaffarabad, the Abbottabad formation outcrops which comprises of carbonate rocks with chert intercalations and of Upper Precambrian – Cambrian stromatolithic limestones (Bossart *et al.* 1988). This formation is underlying unconformably the 400 m thick Paleocene, shallow water, Lockhart limestones. The latter is grading to the Patala formation which consists of clastic sediments with marly limestone intercalations of Paleocene – Lower Eocene age. These beds are grading to the Murree formation of red clayish beds, with biolclastic limestones and benthic fossils of Lower Eocene age at its base. Latest data from the Balakot formation, the stratigraphic base of Murree formation, indicate that these beds are younger than 37 Ma and that the aforementioned contacts are of tectonic origin and more specifically are thrust faults with a sense of shear "the top to the southwest" (Najman *et al.* 2002). The thrust that emplaces the carbonate rocks over the molassic sediments is known as the Muzaffarabad Fault or Balakot – Bagh Fault (Avouac *et al.* 2006 and reference therein).

3. The October 8th 2005 Earthquake

3.1. Seismological Analysis

The earthquake epicenter of the 8th of October event is located in Pakistan Kashmir, 10 km northeast of Muzaffarabad, the capital of Pakistan Kashmir, and approximately 105 km north of the capital of Pakistan, Islamabad. The earthquake magnitude was recorded as 7.6 R and was located in geographical latitude of 34,493 and longitude of 73,629 (Figs 2, 3). The focal depth of the earthquake was only 26 km, the activated thrust fault had a NW-SE strike (N333^{o}), with 29^{o} dip towards the NE and with a rake of 140^{o} (USGS 2005). The Harvard CMT solution indicates a fault with a N133^{o}E strike, 40^{o} dip towards the NE and a rake of 123^{o} (http://www.seismology.harvard.edu/CMTsearch). The fault displacement was originally estimated that was ranging from 1-6 m, while the displacement dimensions were estimated as 90-100 km X 35-50 km (Chen 2005). Avouac *et al.* (2006) used sub-pixel correlation of ASTER images to calculate the ground deformation and seismic waveforms modeling to suggest that the ground rupturing was continuous for a distance of 75 km with mean offset of 4 m and maximum offset of 7 m to the northwest of Muzaffarabad. The corresponding seismic moment was estimated as 2.94 x 1020 N m.

The main seismic event was followed by a large number of aftershocks. Over a 100 aftershocks had a magnitude that exceeded 5.0 during the first 20 days after the main shock. During the first day, 147 aftershocks were recorded while during the first 15 days over 12 aftershocks had a magnitude that exceeded 5.5 and three had a magnitude that exceeded 6.0. The strongest aftershock had a 6.3 magnitude and was recorded three days after the main shock. Furthermore, 978 aftershocks had a magnitude over 4.0 (USGS 2005). An interesting element of the aftershock sequence is that its concentration is located approximately 50 km northwest of the main shock epicenter.

3.2. Field Observations

A series of structures that are directly related to the activated fault were recorded throughout a distance of 70 km, between the towns of Balakot and Bagh (Fig. 3). This region is characterized by steep slopes with many small and a few large valleys and many alluvial fans and river terraces, overlying by an unconformity the Murree formation and the foreland carbonate rocks. The observed structures are distributed within a zone of width of several tenths of meters along the west – southwestern limb of the Muzaffarabad anticline. The structures include flexural slip folding observed in alluvial fans and river terraces, where sufficient deposits unconformably cover the alpine basement, tension cracks most of which are located on the crests of the flexural-slip folding structures, landslides and normal faults. The latter were distributed in a zone, a few tenths of meters wide, where the southwest limb of the Muzaffarabad anticline joins the MBT (Fig. 3).

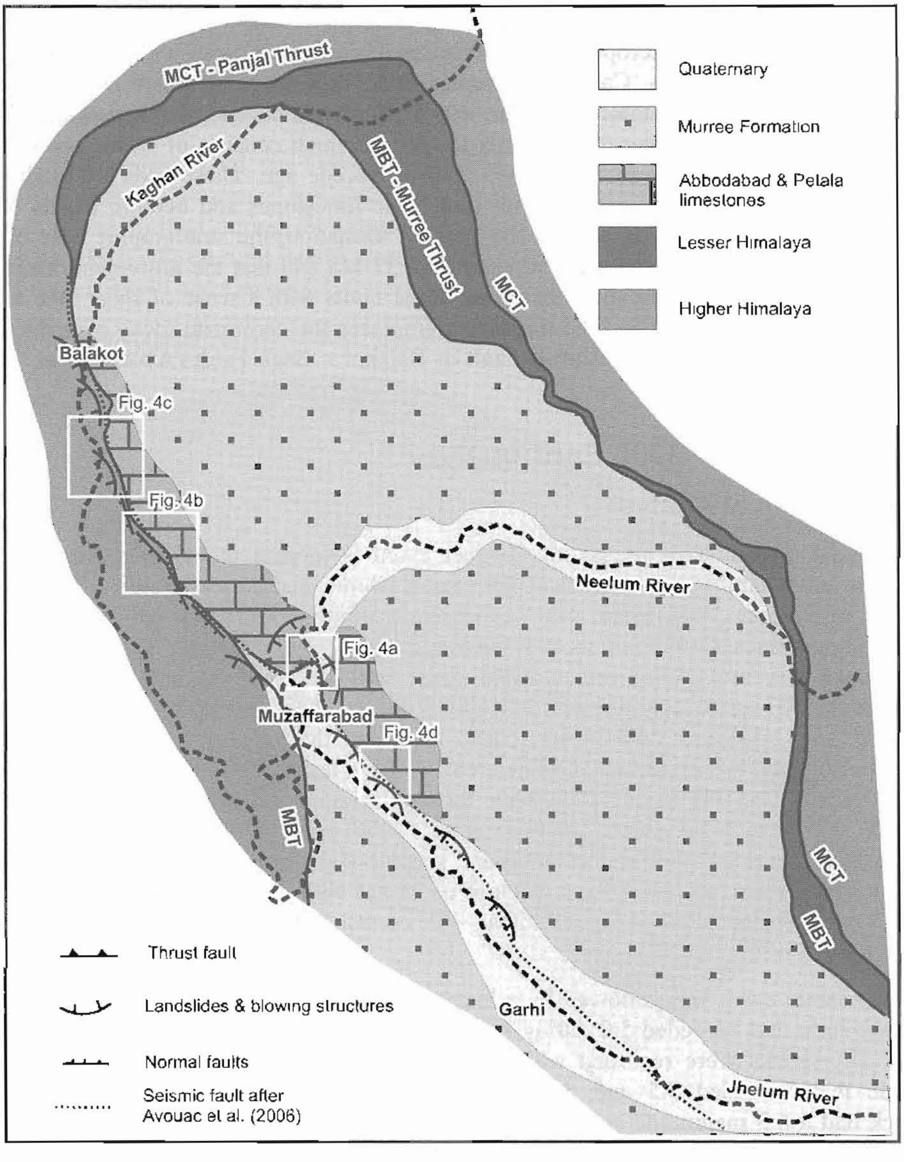

Figure 3 – Geological map of the Hazara – Kasmir Syntaxis modified from Bossart aud Ottiger (1990), where we have add our field observations. Notice that between Balakot and Muzaffarabad the seismic fault is identified with the MBT

Between the towns of Balakot and Bagh and along the western and southwestern slopes of the mountains, many new alluvial fans were recorded, formed by depris flow during the main earthquake. Many of these fans were still evolving for days after the main event. The mature fans on the contrary, present deformational characteristics of folding to a buckling extent. The alluvial fans body exhibits extensional faults many of which have listric geometry (Figs 3, 4c). The majority follows the slope geometry and has displacements up to 2 m, while the rest of them develop laterally or at an angle to the aforementioned (Fig. 4c).

Moreover, extensional faults of high dip angles towards the SW were also recorded in this region having a strike similar to that of the activated fault and offset ranging between 0.5 – 4.5 m (Figs 4d, e). Most of these faults develop along the contact between the carbonate rocks and the red pelites of the Murree formation. These faults could be interpreted as slumps but could also represent a surface expression of the seismic fault. Since the geological formations are folded, local stresses develop on their convex surfaces and these formations are lengthened. On the other hand, their concave surfaces are shortened. This has as a result the formation of normal faults on the convex surfaces and reverse faults on the concave surfaces. In the case of Muzaffarabad anticline, the southwestern limb present high dip angles towards the SW and the rupture of the activated fault could have propagated towards the contact between the two aforementioned geological formations resulting in an overturned structure. This led to the surface expression of the reverse fault as a normal fault and not as a thrust fault. It is interesting that this expression is running along the southwestern segment of the MBT of the Hazara – Kashmir Syntaxis which has high-angle dips to the SW (Fig. 3).

To the northern limits of Muzaffarabad town, the homonymous fault caused serious damages on the road network, which is parallel to the Jhalum River. More specifically, the road followed the deformation of the geological basement and was uplifted approximately 2.0 m (Fig. 4b). The uplift can be observed in a 30-35 m wide zone. For the first 20 m the deformation takes place without surface rupturing while for the rest 15 m, tension cracks with N100°E strike was recorded. These cracks are open with a width of 15-40 cm, vertical to the road, are parallel to one another and have a vertical throw of 20-40 cm. They formed on the crest of the flexural-folding of the road asphalt and its geological basement and reach 1m in depth. On the western slope of the road fractured Cambrian limestones were observed with recent fractures having NW to WNW strike and a 50-65° dip towards the NE, that do not always accompanied by slip. In front of this exposure, an unfinished building of concrete pillars was noted. The base of the construction in its southern part was detached from the rest of the building, with a southward sense of motion, suggesting a simultaneous extension in an NE-SW direction and uplift. This section of the building was located on the trace of the extensional cracks of the road towards the west.

Similar structures to those observed on the road, were recorded further to the east on terraces of the Jhelum River, which are significantly more impressive (Fig. 4a). In this area two river terraces can be distinguished, separated by a 12- 15 m high morphological discontinuity. The lower one develops nearly 1-4 m over the present river level while the second one develops 20 m higher from the river level. The morphological discontinuity that separates those two terraces is located on the eastern projection of the extensional cracks described in the previous paragraph and therefore we believe that this discontinuity can be a fault scarp attributed to the Muzaffarabad fault. Along the fault trace, the terrace is interrupted by a 12-15 m high morphological escarpment. The resulting structures exhibit clear characteristics of flexural slip folding. The clasts that compose the terrace have undergone rotation and sliding, while the existing vegetation in this area has followed the folding pattern of the geological basement. The crest sections of the structure are dominated by open tension cracks responsible for the total collapse of the constructions founded on the terrace to a southward direction. The length of these cracks is ranging from 3-30 m, while the width is measured to 5 -30 cm and the depth exceeds one meter. The fact that the height of the morphological discontinuity of the terrace is nearly three times the throw observed on the road and of the calculated throw generated by the earthquake indicates that the fault must have been reactivated during the recent past, since the terrace has a Holocene age. This indication is also supported by the existence of two smaller morphological breaks, in front of the fault front with a height of approximately 1.5 m suggesting past reactivations.

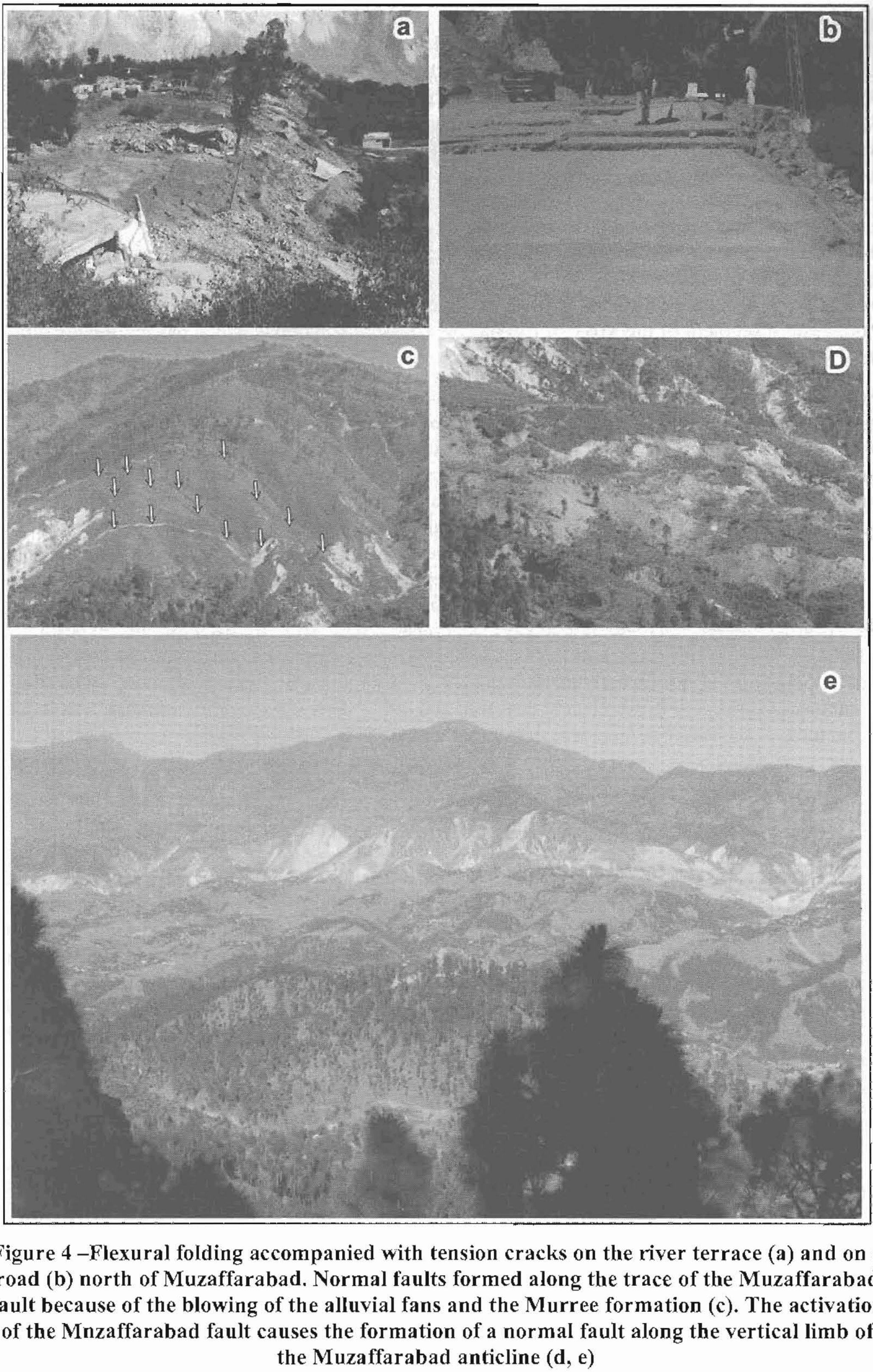

Figure 4 –Flexural folding accompanied with tension cracks on the river terrace (a) and on a road (b) north of Muzaffarabad. Normal faults formed along the trace of the Muzaffarabad fault because of the blowing of the alluvial fans and the Murree formation (c). The activation of the Mnzaffarabad fault causes the formation of a normal fault along the vertical limb of the Muzaffarabad anticline (d, e)

4. Discussion

The continuous convergence between India and Eurasia, besides the uplift of Himalaya, has also resulted in the development of great earthquakes along the orogeneic front. Based on previous and historical earthquakes it was suggested that some sections of the Main Himalayan Thrust have not generated large earthquakes till now (Khattri 1987). Such sections are referred to as seismicity gaps. At the western end of the mountain front, the Kashmir area located west of the 1905 earthquake epicenter in Kangra area is considered as a seismicity gap, (Seeber and Ambruster 1981, Khatri 1987, Gahalout 2005).

Based on the aforementioned data it is suggested that the seismically active region of the Himalaya is a 100 km wide zone along the mountain front, bounded by MCT to the north and HFT to the south. To the west, that is in Kashmir area, this zone becomes significantly uarrower since both MCT and MBT thrusts are verging close to one another. Additionally, Seeber and Gornitz (1983) studied the stream gradient of the main rivers in the region and concluded that the values were relatively high and could be attributed to the short distance between those active structures.

Since the epicenter of the main shock of October 8th 2005 was located near MBT and important controversies existed regarding its location (e.g. USGS 2005 and Harvard), the first reports on the seismic fault were suggesting that MBT was responsible for the earthquake (e.g. Galahaut 2005). However, the epicenter is located on the Syntaxis core and the focal solution of the earthquake, as given by USGS and Harvard, correspond to a NW direction reverse fault, that dips towards the NE and presents right lateral slip suggesting that the earthquake cannot be attributed to the main fault systems of the region, that is MBT and MCT, since the epicenter area belongs to the Sub – Himalaya, that constitutes the footwall of the MBT.

Furthermore, the aftershock epicenters are located to the northwest of the Syntaxis and to the northeast of a seismic zone indicated by Armbruster *et al.* (1978) during a microseismic research known as the Indus – Kohistan Seismic Zone (Fig. 2). The Indus – Kohistan Seismic Zone has a width of 20 – 40 km and a length of 100 km extending from the Kagar River to the southeast, to the Swat River to the northwest. This zone runs through Indus River, forming a kink towards the east and a deep gorge within mountains that approach 3,000 m in altitude. These mountains are part of a linear topographic front that forms the Pir Panjal mountain chain extending from Kashmir to Swat River. The topographic front coincides to the uplifted block of MBT along Kasmir and to the Indus – Kohistan Seismic Zone to the northwest of the Syntaxis. This seismic zone along with the high mountains, form a linear projection of the MBT to the northwest of Kashmir which develops around of the Syntaxis and is coupled to the Hazara Thrust Fault System. However, these two structures cannot be correlated since their tectonic evolutions are completely different (Armbruster *et al.* 1978).

Various earthquakes of intermediate depth have been recorded in the Seismic Zone, the most disastrous being that of the 28th of December 1974, with a magnitude 6.0 near Pattan, at its northern end (Gahalaut 2005). The earthquake generation mechanism and other six intermediate magnitude earthquakes since 1976, indicate a reverse motion character on a surface that dips towards the northeast, with a slight right lateral slip, a mechanism relative to that of the 8th of October 2005 seismic event. This seismic zone is characterized by dip angles of the order of 30-50^{o}.

From the distribution of the damages, the greatest percentage of disasters is located along a zone striking NW-SE, from Uri at the borders of India – Pakistan to the eastern end of the Indus – Kohistan Seismic Zone where it correlates to the aftershock epicenters. This is indicative that the ruptures dnring the main event were distributed along the southwestern limb of the Muzaffarabad anticline, in an area where carbonate rocks of the foreland are outcropping, while the seismic activity migrated to the northwest towards the Indns – Kohistan Seismic Zone. Practically, this means either tbat the south-eastward extension of the Indus – Kohistan Seismic Zone is not the

MBT but the Muzaffarabad fault or that the main earthquake of the 8th of October 2005 caused the activation of the Indus – Kohistan Seismic Zone. If the first suggestion is true then this zone, from the Syntaxis to the Swat River, appears to constitute a blind thrust under the metamorphosed rocks of the Lower Himalayas while in the Sub-Himalayas ceases to be blind and represents a distinct structure responsible for the formation and the growth of the Muzaffarabad anticline. The second case supposes a strong structural control between those two tectonic structures.

Bendick *et al.* (2007) presented a kinematic model combined the main rupture with a wedge thrust. Based on the data of Seeber and Armbruster (1979), aftershock distributions, and aftershock focal mechanisms infer that the 8 October 2005 earthquake appears to have ruptured the surface between Balakot and Bagh in a reverse fault with strike 331° and dip 29° and mean slip of ~5.1 m, with an additional 1.8 m of slip on the dipping plane of a wedge thrust in the northwest, and centimeters of slip on parts of its weak flat-roof detachment.

We believe that because the geometry and the kinematics of the dipping segment of the Bendick *et al.* (2007) thrust wedge and the Muzaffarabad fault are the same; it confirms the suggestion that the Indus – Kohistan Seismic Zone is the north-westwards extension of the Muzaffarabad fault. The flat segment of the thrust wedge may corresponds either to the detachment of the Murree Formation from their carbonate substratum or to the MBT that is now works as a normal fault because of the deformation and the uplift of its footwall.

We also suggest that the Muzaffarabad thrust fault is linked to the Seeber et al (1981) detachment which seems to extend under and to the north of the Hazara – Kashmir Syntaxis. Seeber *et al.* (1981) proposed the existence of a main thrust, which separates the low-angle and seismically active detachment under the External and Lower Himalaya, from the high-angle and seismically inactive thrust under the Greater Himalaya. Further to the north, under the Himalaya, it extends under the Syntaxis and links to the Indus – Kohistan Seismic Zone.

5. Conclusion

The 8th of October 2005 earthquake in Pakistan Kashmir, was located in the core of the Hazara – Kashmir Syntaxis and was caused by a fault that its hanging wall is represented by the Muzaffarabad anticline. In the core of the anticline, Pre – Cambrian and Paleocene limestones outcrop, while on either side red molassic sediments of the Murree formation are observed. The fault on its deepest projection is linked to a primary thrust comprising a large detachment surface where the sedimentary cover of the Indian foreland is sliding over its metamorphic basement. This blind fault aligns with the Indus – Kohistan Seismic Zone to the northwest which also exhibits similar characteristics.

The surface expression of the fault is not that of a thrust fault. In most locations along its trace, landslides of alluvial debris were recorded. Debris flows, buckling and fractural deformation of older alluvial fans, flexnral slip strnctures in river terraces and frequently normal faults along the contact of Abbotabad and Murree formations were observed. The latter conld be the expression of the thrust fault responsible for the 8th of October 2005 earthqnake, which near the surface became overturned following the geometric characteristics of the contact between the carbonate rocks and the molassic sediments or the geometry of the MBT.

The earthquake was the result of the progressive movement of the continental plate of India towards the north and its collision with the Eurasian plate. This collision, besides the nplift of Himalaya has as a result catastrophic earthquakes, developed mainly along the mountain chain front that extends for over 2,500 km. This earthquake is suggested to have filled a section of the seismic gaps that have been recorded on this front (Gahalaut 2005). According to recent studies (Billham *et al.* 2001, Billham and Ambraseys 2004), in the following years similar or greater magnitude earthquakes should be expected in this region. This suggestion in combination to the population increase observed in neighbouring to the Himalaya countries and the insufficient seismic hazard education, iucrease significantly the earthquake vulnerability of the Himalayan region.

6. Acknowledgments

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