2005 Kashmir earthquake: not a Kashmir Himalaya seismic gap event

Continuing convergence between the Indian and Eurasian plates has given rise to the mighty Himalaya. It has also led to the occurrence of major and great earthquakes in the Himalaya, important among them being the great 1905 Kangra, 1934 Bihar–Nepal and 1950 Assam earthquakes. Great earthquakes occur on the detachment under the Outer and Lesser Himalaya, which separates the overlying Himalayan wedge rocks from the underthrusting Indian shield rocks. Based on instrumentally recorded and historical earthquake data, it has been suggested that some segments of the detachment under the Himalayan mountain chain have not experienced major and great earthquakes in the past 100 years or so, though these segments have the potential to generate large earthquakes. Such segments are referred to as seismic gaps. A seismic gap is defined as a section of a fault that has produced large earthquakes in the past but has been quiet at present[1–4], and has been experiencing strain accumulation. Three main seismic gaps have been identified in the Himalaya: the gap between the 1950 Assam and 1934 Bihar–Nepal earthquakes, known as the Assam gap; the gap between the 1905 Kangra and 1934 Bihar–Nepal earthquakes, known as the Central gap, and the Kashmir gap which lies west of the 1905 Kangra earthquake rupture[5,6]. These gaps are considered as the future locale of major and great earthquakes. Here we focus on Kashmir Himalaya seismic gap (hereafter referred to as Kashmir gap). Though historical records are poor, it appears that the last great earthquake in this region occurred in September 1555. Yet another major earthquake occurred in 1885 near Srinagar[7]. Seeber and Armbruster[5], and Gahalaut and Chander[8] found evidence of strain accumulation in the region. The gap region lies southeast of the NW Himalayan Syntaxis (Figure 1), which is interpreted as a resistant spur of the underthrusting Indian shield rocks below the Himalaya, with the Himalayan structures moulded around it on three sides. Many stratigraphic and structural units are traced around the spur from the Main Boundary Thrust (MBT), Murree and Panjal thrusts in the Kashmir Himalaya to the Hazara Thrust System (HTS) in the Sulaiman Kirthar ranges[5]. The Murree Thrust along with the HTS is considered to be equivalent to the MBT[5,9]. Thus the MBT forms a continuous boundary of all postcollisional rocks along the entire Himalaya[5]. The structures in the region are complex due to its proximity to the NW Himalayan Syntaxis and the presence of salt and anhydrites in the syntaxial region. The rate of convergence, accommodated in the Himalaya, is low (about 10–14 mm/yr) compared to the high rate of 20 mm/yr in the central Himalayan region[7,8].

Geographically, the recent earthquake of 8 October 2005 (*Mw* 7.6) occurred in the Kashmir region, but whether it occurred in the Kashmir gap region, is debatable. United States Geological Survey (USGS) and European–Mediterranean Seismological Centre (EMSC) have reported the epicentre of this earthquake in the Syntaxis, while India Meteorological Department (IMD) has reported it further west of the Syntaxis. Aftershocks of the earthquakes, as reported by USGS, lie further NW of the main shock epicentre and beyond the Syntaxial bend in the Indus–Kohistan Seismic Zone (IKSZ) (Figure 1) and coincide with the main shock epicentre location of IMD. Aftershocks reported by IMD also lie NW of Syntaxis, but are quite scattered. The IKSZ was first identified by Armbruster *et al.*[10] during a microearthquake survey in that region during 1973–74. The NW–SE trending IKSZ is geologically unmapped but seismically the most active structure in the region and is considered to be capable of generating large events. It is predominantly a thrust fault with its strike parallel and aligned with the MBT. However, it is not appropriate to equate the IKSZ with the MBT, because the tectonic history of these two structures, as evident from the surface geology, is quite different. The conventional definition of the MBT as the northern boundary of the clastic deposits in the frontal trough certainly does not apply to the IKSZ, but it does apply to HTS. The activity along the

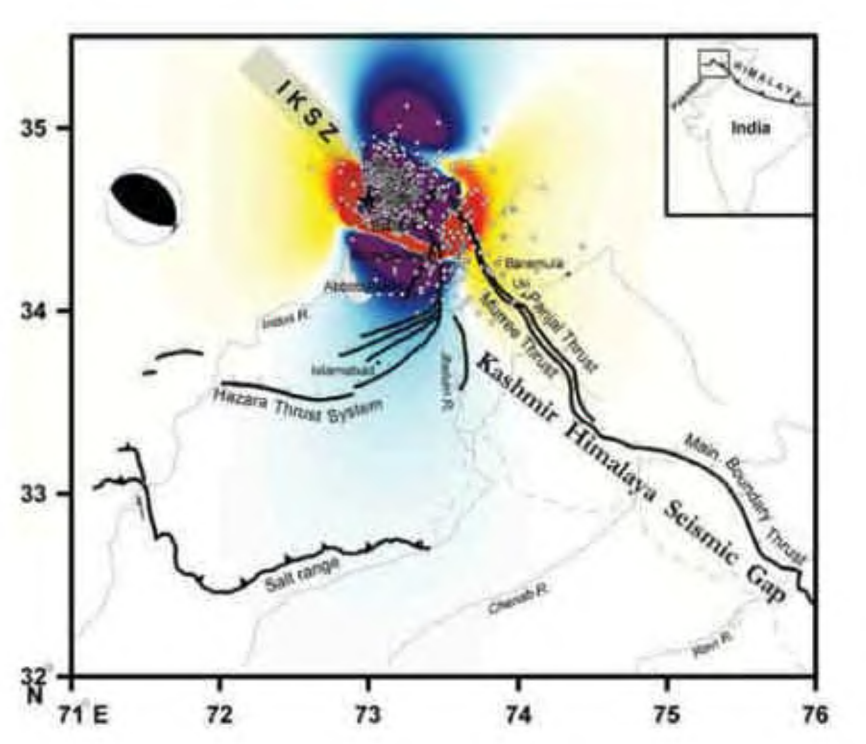

Figure 1. Simplified tectonic map in the region of NW Himalayan Syntaxis[5]. Aftershocks that occurred in the following one-month period of the 8 October 2005 earthquake are also shown. Stars denote estimates of epicentre by IMD, USGS and EMSC. Focal mechanism (EMSC) of the mainshock is also shown. IKSZ, Indus–Kohistan Seismic Zone. Change in Coulomb stress[14] due to the mainshock on the optimally oriented thrust faults in the vicinity of the rupture is also shown. Cool colours show decrease in stress and hot colours show increase in stress. The mainshock appears to have increased the stress in the two regions, namely in the IKSZ and in regions of Panjal and Murree thrusts in Kashmir Gap region.

IKSZ is much more intense than the MBT and HTS. Armbruster *et al.*[10] argued that if it is assumed that MBT extends past the Syntaxis and joins IKSZ, then HTS should have been less active or inactive. However, both the regions of MBT and HTS have experienced major historic earthquakes, e.g. 1555 and 1905 Kangra in the MBT region and AD 25 Taxila earthquake in the HTS region. The 20–40 km wide and about 100 km long NW–SE trending IKSZ crosses the Indus river, where the latter deviates in a conspicuous eastern excursion from its otherwise north-south directed flow, and cuts a deep gorge through 3000 m high mountains. Seeber *et al.*[11] postulated that the Basement Thrust Front (BTF), which separates the shallow-dipping seismically active detachment under Outer and Lesser Himalaya from the steeper and mostly aseismic basement thrust under Higher Himalaya and further north, under the Himalaya, extends past the Syntaxis and joins the IKSZ. They suggested that the shallow angle thrust at the base of the Salt Range is extended northward and is connected with the decoupling layer deduced from the seismicity north of the Hazara thrust forming a major detachment under the region. This detachment of about 200–300 km width joins the IKSZ and extends northward beyond it. They suggested that the presence of salt in the region caused the syntaxial bend and the larger width of the detachment. A few moderate magnitude earthquakes have occurred in the IKSZ, the most destructive being the 28 December 1974 earthquake (m_b 6) near Pattan, at its northern edge[10]. The focal mechanisms of this and other six moderate magnitude earthquakes since 1976 show consistent reverse motion on a plane dipping towards northeast, with slight right lateral motion. The focal mechanism solutions of the 8 October 2005 earthquake and its aftershocks are consistent with those of the previous earthquakes of the IKSZ. The IKSZ is characterized by steep dip (30–50°), whereas earthquakes in the Himalaya occur on a gently dipping thrust fault whose dip is less than 25°.

Though isoseismal map of the earthquake is not available yet, it appears that maximum damage occurred in the epicentral region and NW of it, which coincides with the aftershock locations. It appears that majority of the earthquake rupture occurred on the eastern part of the IKSZ and probably involved only a small part of the Syntaxial bend. This is supported by the fact that IMD located this earthquake further WNW of the epicentre located by USGS into the zone of intense aftershock activities. This suggests that the two regions on either side of the Syntaxis may be distinct[10]. However, Armbruster *et al.*[10] and Seeber *et al.*[11] suggested that the IKSZ does not extend to the surface and remains buried at a depth of about 10 km, whereas this earthquake probably involved shallow faulting also. Nevertheless, it appears from the above that this earthquake did not occur in the Kashmir gap that lies east of the Syntaxis.

It implies that the threat due to future major earthquake in the Kashmir gap has not decreased, as this earthquake either occurred entirely in the shallow updip part of the IKSZ or involved some part of the detachment under the Kashmir Himalaya across the NW Syntaxis. In fact, this earthquake might have increased the stress in the abutting region of Kashmir Himalaya (Figure 1) akin to the case of the giant 2004 and great 2005 Sumatra earthquakes[12,13].

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