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The 14 February 2006 Sikkim earthquake of magnitude 5.3

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On 14 February 2006, an earthquake of magnitude 5.3 struck to the west of Phodong, a small town in the Himalayan State of Sikkim. The earthquake was followed by a large number of aftershocks that were recorded by a network of digital seismic stations operated by the National Geophysical Research Institute, Hyderabad. The study indicates an east-west trend of the epicentral distribution of earthquakes, which is correlated with the decollement plane of the Main Boundary Thrust dipping northward in Sikkim Himalaya. The Sikkim region is surrounded by several damaging earthquakes of the past, although it has not experienced a magnitude 8.0 earthquake so far. However, it remains to be seen whether the Sikkim region is a potentially less hazardous zone or there is likelihood of occurrence of a great earthquake in the near future.

Keywords: Main Boundary Thrust, Main Central Thrust, Sikkim earthquakes, Tista and Gangtok lineaments.

A moderate earthquake of magnitude (M) 5.3 occurred in the early hours (00 : 55 UTC) of 14 February 2006, west of the small town of Phodong in Sikkim with lat. 27.415°N, long. 88.551°E and a focal depth of 20 km. The earthquake was located by the National Geophysical Research Institute (NGRI), Hyderabad as well as other agencies, namely the United States Geological Survey and the India Meteorology Department, Pune. Most of the damage was observed in Phodong and Theng. In the capital city of Gangtok, maximum damage was reported for government establishments like the Police Headquarters, school buildings and some old constructions. The Raj Bhavan, which is one of the oldest constructions in Gangtok, was severely damaged. Even some modern RCC buildings in Gangtok developed multiple cracks.

The Sikkim region falls between Nepal and Bhutan and comprises the lesser active part of the 2500 km stretch of the active Himalayan belt (Figure 1). The region has only experienced moderate seismicity in the past. The most significant earthquake that occurred in its neighbourhood is the 1934 Bihar–Nepal border earthquake of M 8.3 to the west, that caused intensity VIII damage in Sikkim Himalaya[1]. Earlier, an earthquake of M 7.7 was reported to its west in 1833. More recently, in 1988 the region again witnessed an M 6.6 earthquake with intensity VII in Gangtok.

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The major tectonic features traversing the Sikkim Himalaya are the well-defined Main Boundary Thrust (MBT) and the circular overturned Main Central Thrust (MCT) to the north. This circular overturned feature of the MCT has a striking similarity with that observed in the western Himalaya, the site of the recent devastating earthquake of 8 October 2005 of magnitude 7.6 in Muzaffarabad region[2].

Interestingly, seismic activity in the Sikkim Himalaya is confined between the MBT and MCT, above the plane of detachment[3]. Earlier studies[3–5] suggested that the MBT in this region is deep-seated, reaching mantle depths. The earthquakes here generally have a thrust fault mechanism, with the preferred plane coinciding with the detachment plane of the MBT. On the other hand, earthquakes to the east in the Bhutan Himalaya show strike-slip mechanism along NW–SE trending transverse lineaments.

NGRI is operating seismic stations in the Sikkim region, along a roughly NS-trending profile from Mungpoo in West Bengal to Thangu in northern Sikkim. These stations established in 2003, are equipped with broadband seismometers and high dynamic range Reftek digital data acquisition systems. Data are recorded in continuous mode at 20 samples/s. The main shock of 14 February 2006 was well recorded by the local digital seismic stations. Using data from seven local stations (Peshok, Gangtok, Phodong, Mangan, Theng, Rabom and Thangu), the earthquake of 14 February 2006 was located using the Hypo71 program in the SEISAN software[6]. The velocity model of Kayal[5] for the Sikkim region based on microearthquake studies was used to estimate the hypocentral location. In view of the close proximity of the main shock to our seismic stations, the location accuracy is much better than that of the other agencies, with an uncertainty of 1.4 km in latitude, 2.8 km in longitude and 3.3 km in depth. In spite of a roughly linear distribution of stations, the earthquake has a good azimuthal coverage of stations covering three quadrants, enabling precise location by the network (Figure 2). The focal mechanism of the 14 February 2006 earthquake as reported by Harvard University, was a thrust fault event with strike 287°, dip 27° and rake 126° (Figure 2). This is quite typical of the Himalayan earthquakes with EW-trending strike and shallow eastward-dipping fault plane. About hundred aftershocks were recorded immediately after the mainshock. On the first day itself there were many small aftershocks recorded at the nearest seismic station (Phodong). It was possible to locate about 73 of these tremors with reasonable errors, using data recorded at seven seismic stations. The magnitudes of these aftershocks lie within a range of 0.1–3.0. Prior to the occurrence of the M 5.3 earthquake of 14 February 2006, a small tremor of magnitude 2.7 occurred on 13 February 2006 at 02 : 37 UTC in this region. The data recorded by the network stations were analysed and the epicentre of this earthquake was located close to the main shock, indicating the possible occurrence of a foreshock. However, there was no other noticeable or anomalous precursory activity before the main shock. It is important to note that most of the aftershocks follow the trend of the MBT. This is evident from the EW trend of the epicentral distribution in the map view as well as the along-detachment distribution in a NS depth section (Figure 3). Even, the fault plane derived from the focal mechanism solution conforms to the spatial distribution of aftershock locations.

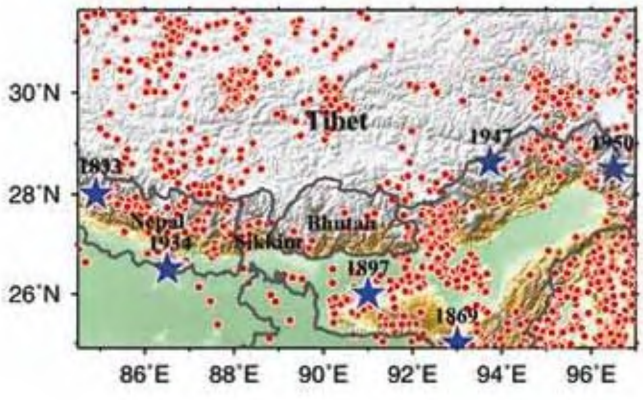

Figure 1. Seismicity map of the eastern Himalaya region indicating historical seismicity around Sikkim.

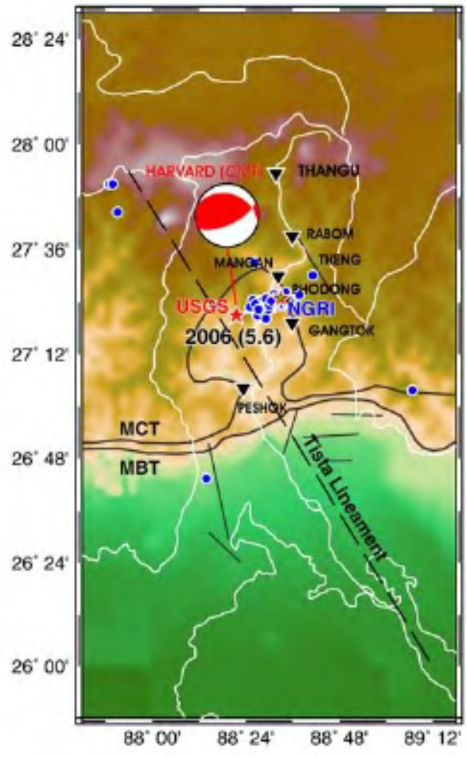

Figure 2. The 14 February 2006 mainshock (red star), its foreshock (green star) and aftershocks (circles), amidst the NGRI station network (triangles), along with the major tectonic features – Main Boundary Thrust (MBT), Main Central Thrust (MCT) and the Tista lineament. Also shown for comparison is the mainshock location by the United States Geological Survey (black star). The focal mechanism solution of the mainshock given by the Harvard University is also indicated.

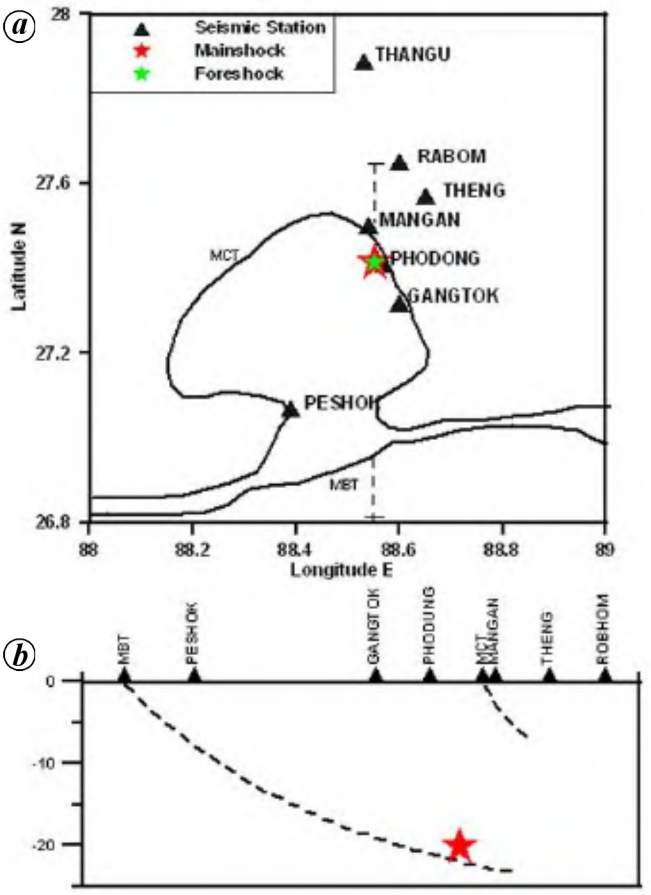

Figure 3. ***a***, Map showing epicentral distribution of the 14 February 2006 earthquake, its foreshock and aftershocks, following the EW trend of the MBT. ***b***, NS section indicating depth disposition of the 14 February 2006 Sikkim earthquake along a projection of the MBT fault. The dip angle is also in agreement with the shallow north-dipping fault plane of the Harvard CMT solution.

The seismic hazard scenario of Sikkim Himalaya appears to be quite underestimated considering its zone IV status in the seismic zonation map of India[7], unlike zone V for most of the Himalayan front. One cannot overlook the fact that this region is surrounded by Great earthquake occurrences during the past, namely the 1934 Bihar–Nepal earthquake (M 8.3) to the west, the 1897 Shillong earthquake (M 8.7) to the southeast and the 1950 Assam earthquake (M 8.7) to the east. Seismic hazard in the Sikkim region is further accentuated due to the presence of sedimentary rocks and loose soil in the region, which tend to amplify the seismic ground motion. Nath *et al.*[8] have indicated that, in general, site amplification in the Sikkim region increases from northeast to southwest along the Tista and Gangtok lineaments, peaking to a maximum of 1.6 at Singtam, southwest of Gangtok. This is attributed to the presence of thick sedimentary rocks to the south, at the Himalayan foothills. Based on calculation of strains along different segments of the Himalayan front, Bilham *et al.*[9] have indicated the strong possibility of occurrence of an $M \geq 8.0$ earthquake in the Sikkim Himalaya, among other segments. It was also pointed out that Great earthquakes ($M \geq 8.0$) tend to cluster towards the eastern Himalayan syntaxis, in comparison to the western and central Himalayas[2,10]. It is not clear whether the Sikkim region is a potentially less hazardous zone as suggested by the Seismic Zonation Map of India[7], or whether there is likelihood of occurrence of a Great earthquake in the near future. In this regard, a critical review of the existing Seismic Zonation Map of India is essential. Considering the increasing population and industrialization in and around the Gangtok city, detailed microzonation studies need to be undertaken to comprehend and mitigate the imminent earthquake hazard in Sikkim Himalaya in the future.

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