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Preliminary observations from the 3 January 2017, M_W 5.6 Manu, Tripura (India) earthquake

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ABSTRACT

On 3 January 2017, a M_W 5.6 earthquake occurred in Dhalai district in Tripura (India), at 14:39:03 IST (09:09:03 UTC) with an epicentre at 24.018°N ± 4.9 km and 91.964°E ± 4.4 km, and a focal depth of 31 ± 6.0 km. The focal mechanism solution determined after evaluating data from seismological observatories in India indicated a predominantly strike-slip motion on a steeply dipping plane. The estimated focal depth and focal mechanism solution places this earthquake in the Indian plate that lies beneath the overlying Indo-Burmese wedge. As in the 2016 Manipur earthquake, a strong motion record from Shillong, India, appears to suggest site amplification possibly due to topographic effects. In the epicentral region in Tripura, damage assessed from a field survey and from media reports indicated that the macroseismic intensity approached 6–7 EMS with damage also reported in adjacent parts of Bangladesh. A striking feature of this earthquake were the numerous reports of liquefaction that were forthcoming from fluvial locales in the epicentral region in Tripura, and at anomalous distances farther north in Bangladesh. The occurrence of the 2017 Manu earthquake emphasises the hazard posed by intraplate earthquakes in Tripura and in the neighbouring Bengal basin region where records of past earthquakes are scanty or vague, and where the presence of unconsolidated deltaic sediments and poor implementation of building codes pose a significant societal and economic threat during larger earthquakes in the future.

1. Introduction

The state of Tripura in north-eastern India is located within the Indo-Burmese wedge where crustal deformation and associated seismicity occur in response to the interaction of the Indian and Sunda plates (Le Dain et al., 1984; Guzman-Speziale et al., 1989; Guzman-Speciale and Ni, 1996). Tectonic features in this area were discussed by Le Dain et al. (1984), Maurin and Rangin (2009), Gahalaut et al. (2013) and Wang et al. (2014). The geodetically determined motion of ≈36 mm/year between the two plates (Socquet et al., 2006) is partitioned by slip along the Churachandpur Mao Fault (CMF) in the Indo-Burmese wedge (Gahalaut et al., 2013), and by motion on the Sagaing Fault (Vigny et al., 2003; Maurin et al., 2010) in Myanmar (Fig. 1). Earthquakes on the Sagaing Fault have shallow foci with predominantly strike-slip focal mechanisms on steep planes (Le Dain et al., 1984; Guzman-Speziale et al., 1989; Guzman-Speciale and Ni, 1996, Maurin et al., 2010). In the Indo-Burmese wedge region, the majority of earthquakes occur on steep planes within the Indian plate that lies below the Indo Burmese wedge (Rao and Kalpna, 2005; Kundu and Gahalaut, 2012; Russo, 2012; Gahalaut and Kundu, 2016). An important implication of the latter is the status of the dipping décollement surface between the overriding Indo-Burmese wedge and the underlying Indian lithospheric slab. Using a model supported by geodetic measurements from India and Myanmar, Gahalaut et al. (2013) suggested that the motion between the Indian and the Burma plate in the wedge occurs primarily on the Churachandpur-Mao fault that separates the outer wedge to the west from the inner wedge and its core to the east, and that this structure is a splay from an eastward extending décollement. Steckler et al. (2016) supplemented data from India and Myanmar with geodetic observations from Bangladesh to propose an alternative model that suggests the décollement surface under the outer wedge is also seismically active, and accommodates strain that could be released in future interface rupturing earthquakes. We note that the 2017 Manu, Tripura earthquake occurred beneath the outer wedge of the Indo-Burmese arc, which has an apparently lower seismic moment release during the historical and instrumental eras in contrast to adjacent regions. Therefore the preliminary analysis of observations from the 2017 Manu, Tripura earthquake presented in this article offer a

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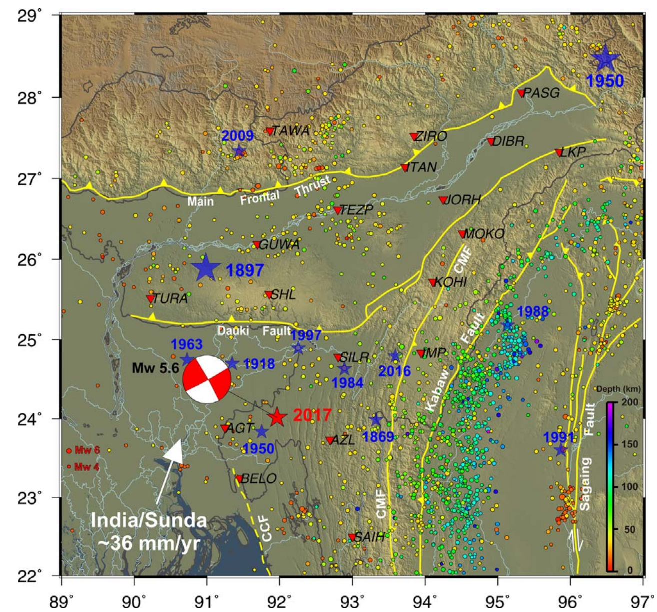

Fig. 1. Regional tectonics, seismological stations (red inverted triangles), along with earthquakes from 1973 to 2016 (ISC and USGS). CCF- Chittagong Coastal Fault, CMF- Churachandpur Mao Fault. A beachball representation of the 2017 Manu earthquake using parameters determined in this study is also shown. Stars represent events discussed in the text, or regionally significant earthquakes. The 1897 Shillong Plateau and 1950 Assam earthquakes are also shown. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

crucial opportunity to contribute to the ongoing efforts (e.g. Ahsan et al., 2015) to understand the seismic hazard potential of a region that lies in close proximity to the densely populated Ganga-Brahmaputra basin, vulnerable to amplification of ground motion in unconsolidated, or reworked deltaic sediments (e.g. Islam et al., 2010; Asad et al., 2015; Khan, 2015).

2. Seismicity of Tripura

The 2017 Manu, Tripura earthquake is one of the strongest instrumentally recorded earthquakes within the state borders of Tripura in at least half a century. Prior to 2017, the largest known earthquake occurred on 29 December 1950 with a local magnitude (M_L) of 6.3 which was located by Tandon (1954) in the central Balisera Valley (24.39°N, 91.74°E) (Fig. 1). The location and magnitude of this event were revised by Storchak et al. (2013) who relocated it in central Tripura (23.85°N, 91.84°E) and calculated M_W 5.9 ± 0.26. We did not find additional information for this earthquake. Sohoni (1951) reports it was felt at Aizawl (23.72°N, 92.71°E), Karimganj (24.86°N, 92.34°E) and Silchar (24.83°N, 92.77°E).

In the 19th century, the Cachar earthquake on 10 January 1869 caused heavy damage in the Silchar area of lower Assam (Oldham, 1883a) but its effects in Tripura are unknown. The 12 June 1897 Shillong earthquake, on the other hand, severely damaged the Maharaja's palace (*Friend of India*, 22–29 June 1897) and destroyed many buildings and shrines in Agartala (Hunter et al., 1909). It also raised the beds of many rivers notably that of the Manu (Hunter et al., 1909). The most significant earthquake in the immediate vicinity of the 2017 Manu earthquake during this period is the 8 July 1918 Sreemangal (also Srimangal or Srimongal) earthquake in the Balisera Valley with a moment magnitude (M_W) 7.4 (Pacheco and Sykes, 1992) and an intensity magnitude (M_I) between 6.8 and 7.1 (Ambraseys and Douglas, 2004; Szeliga et al., 2010). Within the Balisera Valley, severe shaking rendered it difficult to stand and people were thrown to the ground (Stuart, 1919, 1920). Single-storied, steel framed buildings with masonry infill walls suffered Grade 4 or greater damage, effects determined to be approximately equivalent to 8 EMS by Martin and Szeliga (2010). Hilly and forested tracts in Tripura, and regions of Sylhet flooded at the time, were not surveyed (Stuart, 1919) leaving the southern and northern extents of the meizoseismal zone poorly defined. However, in Agartala sand blows occurred and cracks were observed in roads (*Englishman*, 15 July 1918, repeated in Stuart, 1920). The upper storey of the Kunjabon Palace was badly damaged and had to be dismantled, and four domes of the Lakshminarayan temple collapsed (*Englishman*, 15 July 1918). Regionally, damage and fatalities occurred as far as Dhaka where, among other structures, the walls and *chhattris* of the Hossaini Dalan mosque needed repair or reconstruction (Anonymous, 1920). Varying grades of building damage also occurred in the large urban centres of Chittagong, Jamalpur, Mymensingh, Kolkata and Shillong (*Englishman*, 9–12 July 1918). As many as 53 fatalities were recorded in Sylhet district (Anonymous, 1919). Liquefaction features were reported from numerous locations within the mapped meizoseismal area as well as in Sylhet division (Stuart, 1920).

We would also like to draw attention to two earthquakes on 19 June 1963 and 21 June 1963 (M_W 5.6 ± 0.2 and M_W 5.7 ± 0.2 respectively) that were instrumentally located in Mymensingh division, Bangladesh (Storchak et al., 2013). Focal mechanisms for both earthquakes were computed and discussed by Chen and Molnar (1990). However, Modified Mercalli Intensities (MMI) reported by Tandon (1963), and repeated by Rothé (1969, p.188) for both earthquakes, appear to indicate that the highest intensities (MMI VII) were reported from further south at Kailashahar (24.32°N, 92.00°E) in Tripura, more than 60 km from the instrumented locations. Shaking from both earthquakes was widely perceived in Assam and Bengal: the first earthquake was felt as far as Bagdogra (26.69°N, 88.31°E) and Jorhat (26.74°N, 94.21°E). Although we rely on MMI assignments made by Tandon (1963) because first-hand accounts were unavailable to us, the spatial distribution of intensities, particularly for the 19 June 1963 earthquake, appear to suggest they both produced significantly higher ground motions away from their instrumentally determined epicentral locations, or more plausibly, that they were located closer to the region of the 2017 Manu earthquake.

3. Instrumental parameters

The 2017 Manu earthquake is one of the largest well instrumented earthquakes in the state of Tripura, since the establishment of the worldwide network of standardised seismographic stations (WWSSN) in the 1960s (Oliver and Murphy, 1971). It was well recorded by the broadband seismograph network operated by the National Centre for Seismology (NCS). The NCS has 84 seismological observatories that are part of the Indian national network connected to a central recording station at NCS in Delhi through VSAT. For the 2017 Manu earthquake, automatic preliminary earthquake parameters were determined within three minutes of the earthquake. We subsequently re-analysed the data from the closest 16 seismological stations (< 500 km) in north-eastern India, and more than 50 stations in the rest of the country. This allowed us to refine the epicentral location to 24.018°N ± 4.9 km and 91.964°E ± 4.4 km (Fig. 1) with a focal depth of 31 ± 6 km. Our estimate of the hypocentral depth was also constrained by sPn-Pn observations at nearby stations.

The seismic moment (M_o) of the earthquake is estimated to be 3.0×10^{24} dyne cm which corresponds to M_W 5.6 (Fig. 2). The estimated stress drop for the event is 20 MPa which is in the range of stress drops determined for other earthquakes in the immediate region (Allmann and Shearer, 2009; Raghukanth and Somala, 2009). Two aftershocks of magnitude (mb) 3.4 and 3.9 that occurred at 13:40:32 UTC on 4 January and at 15:03:52 UTC on 6 January respectively were also recorded by the national network. The parameters determined for the mainshock using data available to us from Indian observatories, show good correspondence with similar parameters determined by the United States Geological Survey (USGS), the European-Mediterranean