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The 4 January 2016 Manipur earthquake in the Indo-Burmese wedge, an intra-slab event

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ABSTRACT

Earthquakes in the Indo-Burmese wedge occur due to India-Sunda plate motion. These earthquakes generally occur at depth between 25 and 150 km and define an eastward gently dipping seismicity trend surface that coincides with the Indian slab. Although this feature mimics the subduction zone, the relative motion of Indian plate predominantly towards north, earthquake focal mechanisms suggest that these earthquakes are of intra-slab type which occur on steep plane within the Indian plate. The relative motion between the India and Sunda plates is accommodated at the Churachandpur-Mao fault (CMF) and Sagaing Fault. The 4 January 2016 Manipur earthquake (M 6.7) is one such earthquake which occurred 20 km west of the CMF at ~60 km depth. Fortunately, this earthquake occurred in a very sparse population region with very traditional wooden frame houses and hence, the damage caused by the earthquake in the source region was very minimal. However, in the neighbouring Imphal valley, it caused some damage to the buildings and loss of eight lives. The damage in Imphal valley due to this and historical earthquakes in the region emphasizes the role of local site effect in the Imphal valley.

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Indo-Burmese wedge; sagaing fault; seismogenesis; earthquake focal mechanisms; intra-slab earthquakes

1. Introduction

The north-eastern part of the Indian subcontinent is one of most active regions of the world. It consists of mainly three units, approximately E-W extending eastern Himalaya, which marks the collisional boundary between the underthrusting Indian plate beneath the Eurasia plate, approximately N-S extending Indo-Burmese Arc (IBA), which extends further southward to join the Andaman Arc, and the eastern Himalayan syntaxis (EHS) which lies at the junction of the above two. Subduction surely occurs along the Andaman Arc, but whether it is still active in the IBA is debated (Kundu & Gahalaut 2012; Gahalaut et al. 2013). The 4 January 2016 Manipur earthquake (M_w 6.7) occurred in the wedge part of the IBA, about 30 km west of Imphal with its epicentre at 24.85°N latitude and 93.55°E longitude (figure 1). There are three estimates of the focal depth (17 km initial estimate and then revised to 59 km by National Centre for Seismology, NCS; 50 km by European-Mediterranean Seismological Centre, EMSC; and 55 km by United State Geological Survey, USGS). The earthquake focal mechanism (USGS) shows predominantly strike slip (reverse connected) motion on steep

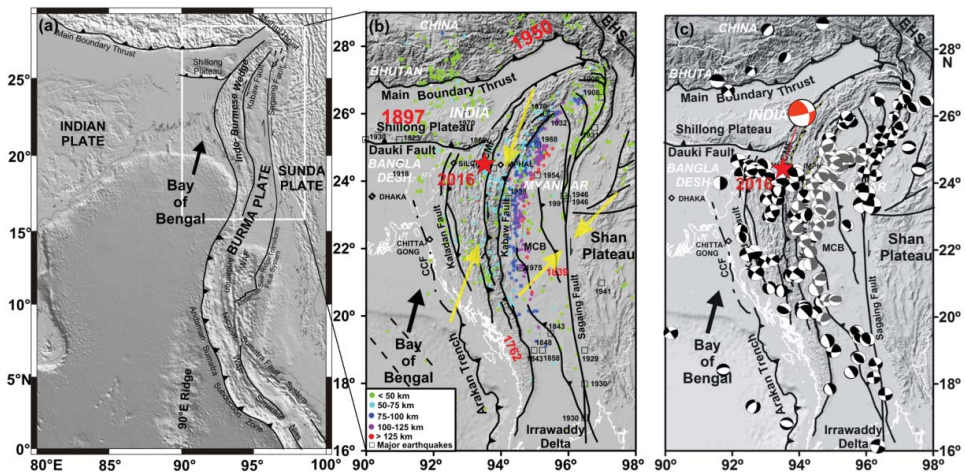


Figure 1. Past earthquakes (with focal depth and focal mechanisms) in the Indo-Burmese arc region and the 4 Jan 2016 earthquake. Arrows (star) show the India Sunda relative motion (36 mm/year). All historical great and major earthquakes are also shown.

Note: CCF- Chittagong Coastal fault, MCB- Myanmar Central Basin, KBF- Kabaw fault, CMF- Churachandpur Mao fault, EHS- eastern Himalayan syntaxis.

planes; predominantly, dextral motion on the approximately N-S oriented plane (strike 345° , dip 52° , rake 168°) or oblique sinistral motion on E-W steep plane (strike 83° , dip 81° , rake 38°). In this letter, we discuss general geology, tectonics, seismicity of the region which is followed by the earthquake damage in the source and neighbouring regions.

2. Geology and tectonics of the Indo-Burma region

The IBA consists of Indo-Burman Wedge (Arakan Yoma, Chin Hills and Naga Hills, from south to north), the Myanmar Central Basin (MCB) and the eastern highlands of Shan Plateau (figure 1). IBW is an arcuate sedimentary belt with N-S trend of folded mountain chain, formed by Cenozoic rocks with Triassic metamorphic basement (LeDain et al. 1984). It is considered as an active aerial accretionary wedge linked to eastward subduction of the Bengal basin oceanic crust. This wedge is composed of Cretaceous ophiolite, Cretaceous to Eocene pelagic sediments and a section of Eocene to Oligocene flysch overlain by Neogene shallow water sediments. MCB is separated from the IBW by Eastern Boundary Thrust, which is also known as Kabaw fault. The basin is actually a series of Cenozoic basins presently affected by an active tectonic inversion. Sagaing fault separates the MCB from the Shan plateau and joins into the Andaman sea rift system. Shan plateau with an elevation of 1000 m is considered as western edge of the rigid Sundaland block. The estimates of magnitude of dextral movement across the Sagaing fault vary from 250 to 460 km since Miocene.

3. Earthquakes in the IBA region

Earthquakes in the IBA and Sagaing fault regions occur in response to partitioning of the India-Sunda motion along these two distinct boundaries. Under the accretionary wedge of the Indo-Burmese arc, majority of the earthquakes occur in the depth range of 30–60 km and define an eastward gently dipping seismicity trend surface that coincides with the Indian slab.

The dip of the slab steepens in the east direction and earthquakes occur down to a depth of 150 km (Kundu & Gahalaut 2012), though the slab can be traced up to the 660 km discontinuity (Pesicek et al. 2010). Frequency of earthquakes increases as the dip of the slab increases. Although these features are similar to a subduction zone, the nature of the earthquakes, including the 4 January 2016 earthquake, and their focal mechanisms suggest that the earthquakes are of intra-slab type which occur on steep plane within the Indian plate and the sense of motion implies a northward relative motion. Thus, these earthquakes and the stress state do not support active subduction across the IBA which is also consistent with the relative motion of India-Sunda plates. In the Sagaing fault region, earthquakes occur through dextral strike slip motion along the N-S oriented plane and the stress state is consistent with the plate motion across the Sagaing fault (Kundu & Gahalaut 2012).

The region has experienced a few great earthquakes. The great Assam earthquake of 1897 (M8.1) occurred in the Shillong plateau region (Bilham & England 2001). Another great earthquake (Mw 8.6) in 1950 occurred in the Indian Tibet region, close to the EHS (Molnar 1990). Large earthquakes in Bengal basin have occurred in 1885, 1918, 1923 and 1930. In the IBA region, a few notable major earthquakes are the 2 April 1762 and 24 August 1858 Arakan earthquakes, and the 10 January 1869 Cachar earthquake (figure 1). Other than these earthquakes, several instances of damage due to earthquakes are reported from Chittagong, Sylhet, Manipur valley and Cachar regions. However, it is possible that the high damage in these regions was due to relatively large population, local site effects, as these places are located in the valley with thick sediment cover. The 10 January 1869 Cachar–Manipur earthquake was probably the most severe earthquake in the available 2000 years of written historical records of Manipur. Manipur, now a state of India, was an independent kingdom which was ruled by Meitei kings since 35 CE, at least. Kangla (now Imphal) in the Manipur valley was the capital of the princely state and the historical records were maintained in the ‘The Cheitharol Kumpapa, The Court Chronicle of the Kings of Manipur’. The sediment-filled valley region has remained the centre of inhabitation since historical times. The valley is located at the centre of the Indo-Burmese arc. Thus, this region could not have escaped from the damage due to any great earthquake in the Indo-Burmese arc. Hence, it may be appropriate to state that no larger earthquake than the 10 January 1869 earthquake occurred in the IBA during the period of written historical records. The 1869 earthquake caused severe damage in the Cachar valley, near Silchar and Manipur valley, near Imphal. Five deaths were reported from Silchar while three from Imphal. Extensive liquefaction, wide cracks appeared in the Silchar region, near the Barak river and in Imphal, near the Imphal river. In Imphal, a few bridges and the palace of the king, the Kangla Palace, and a temple within it were damaged. The earthquake was followed by more than 15 aftershocks in the following two-day period which were strongly felt in Imphal. Ambraseys and Douglas (2004) estimated the magnitude of this earthquake as 7.4. Oldham (1882) described the damage caused by this earthquake in the Cachar valley near Silchar and at far off places but did not visit the Manipur valley due to security reasons, where the damage was equally severe.

4. Plate motion in the region GPS measurements in the IBW region

GPS measurements have been undertaken in the IBA (Gahalaut et al. 2013). These results suggest that though subduction of Indian plate occurred in geological past, currently the motion between the Indian and Burmese plate occurs through dextral slip motion. The predominant northward motion of 35 mm/year between the India and Sunda plate occurs through dextral motion along the Sagaing fault at the rate of about 20 mm/a and the remaining motion of 16 mm/year is accommodated in the IBA region. The motion in the IBA is accommodated

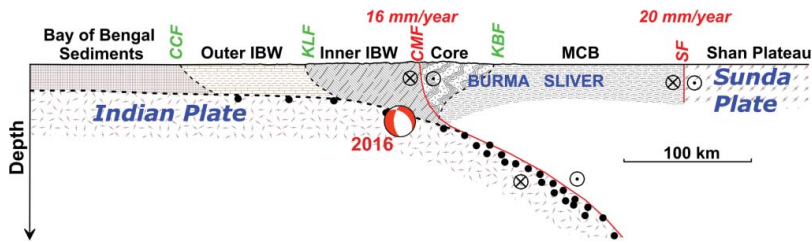


Figure 2. Generalized west to east cross section showing the depth of the earthquake with past earthquakes.

Note: CCF- Chittagong Coastal fault, KLF- Kaladan fault, KBF- Kabaw fault, IBW- Indo-Burmes wedge, MCB- Myanmar Central Basin, CMF- Churachandpur Mao fault, SF- Sagaing fault.

across the Churachandpur-Mao fault (CMF) through predominant dextral strike slip motion (figure 2).

5. Damage due to the earthquake

We undertook a damage and earthquake effect survey in the earthquake source region and visited a few places in the earthquake source region, near None in Tamenglong district of Manipur and Imphal, the state capital.

5.1. Damage in earthquake source region

We visited Kabuikhullen village of Tamenglong district, where the maximum shaking and a spectacular crack were reported (figure 3). All the houses are light weight wooden structures. It appears that the shaking in this village was very intense as the people could not stand or even sit during the earthquake. Most of the houses suffered damage. The walls got detached from the foundation frame and in some cases, the foundation shifted by $\sim 1/3$ m due to intense shaking. A few huts got tilted. A spectacular crack appeared in the village. We could trace this up to a distance of ~ 2 km. The crack is N-S oriented and has some oblique motion (1–2 cm) across it. The crack at some places was as deep as 2 m. Although the strike of the crack and motion across it matched with the N-S plane of the earthquake focal mechanism, in a most likely case, it is a secondary feature of the earthquake as the reported depth of the earthquake is ~ 50 km. The intensity of the earthquake at this place is about VI to VII on Modified Mercalli scale.

5.2. Damage in Imphal city

The Imphal city is located about 30 km east of the earthquake epicentre. Damage in the Imphal city (figure 4) appears to be primarily driven by site response. The Imphal valley is filled with thick sediments and damage was mostly confined in either the marshy land region or regions close to rivers. Four rivers, namely the Nambul, Imphal, Kongba and Iril rivers, flow through the Imphal city. The damage was sporadic and was confined to some structures either on the river banks or on marshy land. The three women markets, Ima and Lakshmi markets, on the banks of Nambul river were structurally damaged. Damage was also seen in the Central Agricultural University (west of Imphal) campus where the land is quite marshy. It appears that the damage in Imphal is primarily because of improper construction and local site effect.

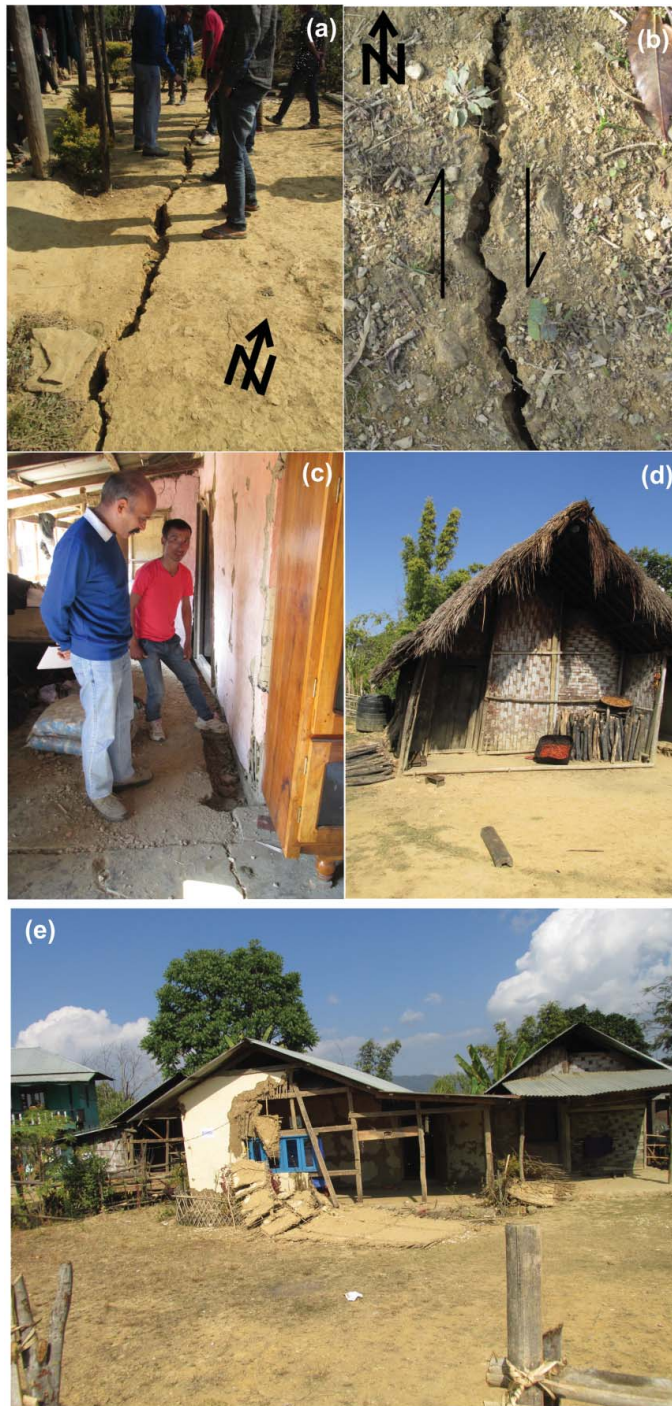


Figure 3. Photographs showing damage in Kabaikhullen village: (a) a N-S crack, (b) dextral motion across the crack, (c) a house shifted from its original foundation, (d) tilted hut and (e) damaged house.



Figure 4. Photographs showing damage in Imphal: (a) Agricultural University gate, (b) and (c) damage to the pillars of Ima women market through crushing and shear cracks.

6. Conclusion

The 4 January 2016 earthquake (M 6.7) occurred on a steep plane at depth of ~ 59 km and is about 15 km west of the CMF (the fault coinciding with the western edge of the Imphal valley), which is considered to be accommodating some of the India-Sunda plate motion. This event is not related with the CMF. The earthquake is a typical intra-slab earthquake which occurred within the predominantly northward moving subducted Indian plate. It occurred in the remote hilly region with very sparse population living in traditional wooden houses and hence it did not cause much damage in the source region. The damage in Imphal was mainly because of local site response and poor construction.

Acknowledgments

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Disclosure statement

No potential conflict of interest was reported by the authors.

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