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Seismotectonics and its Implications on Intra-crustal Seismicity Triggering in Shillong Plateau (India).

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Abstract--
Shillong plateau in the Northeast India having almost a vertical plunge in its Bangladesh facing southern margin was treated as a kind of craton that was presumed to follow an orogeny mechanism different from the adjacent thrust belts like the eastern Himalayas or the Indo-Burman ranges. Spatio-temporal distribution of triggering zones of different earthquakes inside the plateau since 1966 suggests distinctly variable depth-ranges of seismicity within the crust. Predominantly shallow regime of seismicity triggering in the Shillong massif infers the constrained neo-tectonism of the plateau up-to a depth of 40km. Above all, the present study incorporates both qualitative as well as quantitative approach while understanding the types of recent seismicity pattern in the Shillong massif.

Keywords: geodynamics, seismicity, depth-section plot.

1. Introduction:

The Northeast India is one of the most seismically active zones in the world; the region is jawed between the two great arcs, the Himalayan mountain range to the north and the Indo-Burmese arc to the east. The region bounded by latitude 22-29^{0}N and longitude 90-98^{0}E, produced two great earthquakes (M>8.0) and about 20 large earthquakes (7.0≤M<8) since 1897. The Shillong Plateau was the source area for the 1897 great earthquake M_s~8.7, and the Assam syntaxis zone or more precisely Lohit Himalayas (Mishmi Hills) for the 1950 great earthquake M_s~8.6 [1],[2]. Several large earthquakes occurred along the Indo-Burma ranges [3].

Chedrang valley and its vicinity of Shillong massif was the main rupture area aftermath the great Assam earthquake of 1897. Highest ever recorded ground motion was reported in the valley with the attribution of intensity X on the Rossi-Forel scale to the 1897 earthquake in the Shillong plateau [4]. The major seismotectonic elements influencing the study area are referred in Figure 1. In the present study, the detail analysis of the seismicity for 1098 numbers of seismic events recorded during 1966-2013 has been done, which infers the type of seismicity pattern occurred in and around the Shillong massif. Further, receiver function analysis for the determination of Moho-depth beneath Shillong massif has also been added up in the present study to get insight of the sub-crustal deformation in the Shillong massif.

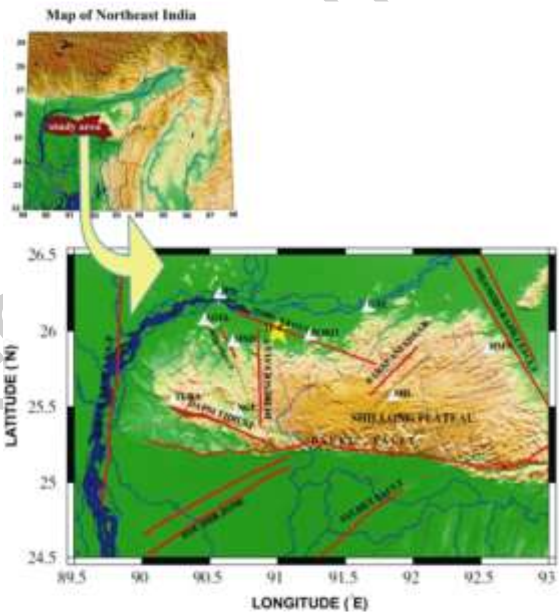

Figure 1: Map showing major tectonic features in the study area with latitude-longitude bound of 24.5°-26.5°N and 89.5°-93°E. Triangles indicate seismic stations and the star mark indicates the great Assam earthquake of 12th June, 1897.

2. Tectonic setting:

The Northeast India represents a complex tectonic province portraying juxtaposition of two mobile belts, the E-W trending Eastern Himalayas and the N-S trending arcuate Arakan-Yoma belt. The geological settings in this part of India comprised of complex topographic features with age dating from Archean to young Quaternary [5], [6], [7]. Indian plate undergoes subduction beneath the Eurasian plate to the north, and towards east the Indian plate is colliding with the Burmese plate and undergoes subduction [8]. The great Himalayan mountain ranges are lead by the northern subduction zone; whereas eastern collision-

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subduction zone marked the existence of Indo-Burma ranges [9]. The North-eastern region of India is thus characterized as a zone of convergence by the aforesaid mountain ranges due to ongoing tectonic movements.

The complex tectonic setting of the Shillong massif, and ongoing crustal plate movement lead to a significant number of large to great earthquakes, out of which 1869 Cachar earthquake (M_W~7.5), 1897 the great Assam Earthquake (M_W~8.1), 1923 Meghalaya Earthquake (M_S~7.1), 1930 Dhubri Earthquake (M_S~7.1), 1943 Assam Earthquake (M_S~7.2), 1947 Arunachal Pradesh Earthquake (M_S~7.7), 1950 Assam Earthquake (M_S~8.6), 1988 Manipur Earthquake (M_S~7.3), 2009 Assam Earthquake (M_W~5.1) [[9]Anjelier et.al., (2009)] and the very recent 2011 Sikkim Earthquake (M_W~6.9) are remarkable. The tectonic regime of Shillong plateau is governed by a number of faults in and around the plateau. In the south, Dauki fault separates the Plateau from the Bengal basin. The Dauki fault is an E-W trending, approximately 320km long north dipping reverse fault [10]. According to Kayal and De (1991) [11], the NW-SE trending Dapsi thrust which is considered to be the northwest extension of the Dauki fault for nearly 90-100km stretch separates the sediments of the Bengal basin to the southwest of Shillong plateau from the rocks of the plateau itself in the northeast. Towards the northeast of Shillong plateau is the Mikir massif. A NNW-SSE trended Kopili lineament separates the Mikir massif from the Shillong plateau, which is nearly 300-400 km long and 50 km wide extending in the north up-to MBT (Main Boundary Thrust) in the Himalayas and the area is considered to be major earthquake source zone as evaluated in the seismicity study by Kayal et al. (2006) [12]; in the same study the depth of the seismogenic zone in the Kopili fault region is found to be ~50 km. The Kopili fault is considered to be normal fault with strike-slip component having dip in N-E direction. Further to the north of the Shillong plateau is the Brahmaputra River which separates the plateau from the Himalayas. The N-S trending Dhubri fault lies to the west of the plateau separating the plateau from the Chotanagpur craton. Other faults in and around Shillong plateau include Oldham fault, Chedrang fault, Samin fault, Dudhnoi fault and Barapani shear zone. All these faults are prominent seismic sources for intense seismicity in the area.

3. Data and Methodology:

3.1 Seismicity analysis:

The complex tectonic regime in the study area inhibits variable stress pattern in different parts of the Shillong massif. Detail seismicity analysis for the study area, which is confined in between latitude 24.5°-26.5°N and longitude 89.5°-93°E has been performed based on 1098 seismic events recorded during 1966-2013, including 1897 the great Assam earthquake. The seismicity data has been collected from ISC, NEIC, CSIR-NEIST, CSIR-NGRI and some past earthquakes information available on literature. The database has been calibrated using moment magnitude scale M_w, for the purpose different magnitude formats like m_b, M_s and M_0 has been converted to one moment magnitude scale using Borman, et al. (2010) and Scordilis (2006) [13], [14].

For the pursuit of seismicity plot of the study region, GMT (Generic Mapping Tool), a command based program has been used for analysis of 1098 seismic events. The seismic database has been sorted according to their origin time, geographical configuration, moment magnitude (M_w) and depth of focus. Further, the events have been grouped under certain magnitude ranges, to depict the zones of high to low tremor activities with specific color codes and legend types.

4. Results and Discussion:

The seismicity scenario in the Shillong plateau is quite fascinating due to geodynamics of the region. The recorded 1098 seismic events for the study area have been processed in GMT environment to prepare the seismicity map. The entire database has been grouped into certain slots for assessing their magnitudes. The slots are considered to be, 0-2.99, 3-4.99, 5-7.99 in moment magnitude scale M_w. The gross distribution of seismicity is shown in Figure 2, which nicely depicts different ranges of earthquake events inferring the zone to a highly vulnerable to earthquakes of variable intensities. From Figure2, it is obvious that a large numbers of earthquakes are concentrated mainly in the Chedrang valley and its vicinity, where the dominant earthquakes are of the order of ≤4.99$M_{w.}$ By observing the seismicity pattern, it can be inferred that the earthquake stress release is more in western and central part of the plateau than its surroundings, which might be due to the active nature of the faults lying within the area.

'Pop-Up' structure/Upliftment of Shillong plateau is a matter of concern for geoscientists; many a researchers opined differently for the upliftment of the plateau. According to [15] and [16], the Shillong plateau is a Horst which evolved due to thermal disturbance in the upper mantle. According to [17] suggested that the plateau upliftment might be due to isostasy.

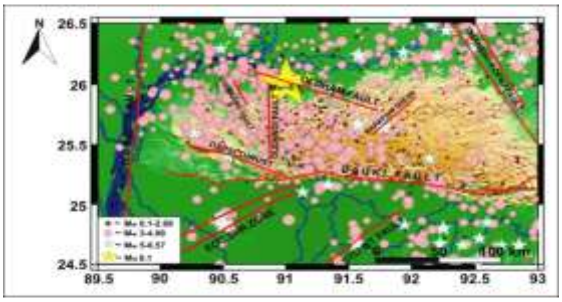

Figure2: Seismicity Map of the study area for the period 1966-2013 showing 1098 earthquakes, including M_w~8.1 the great Assam earthquake.

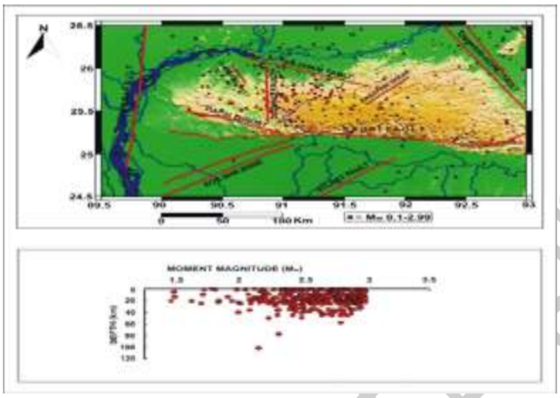

Figure 3(a): Seismicity plot in Shillong plateau with depth section counterparts for 1098 number of earthquakes with moment magnitude ranging from 0.1-2.99 M_w.

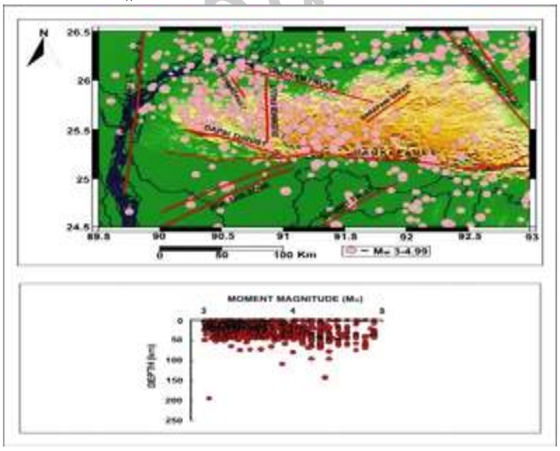

Figure 3(b): Seismicity plot in Shillong plateau with depth section counterparts for 1098 number of earthquakes with moment magnitude ranging from 3-4.99 M_w.

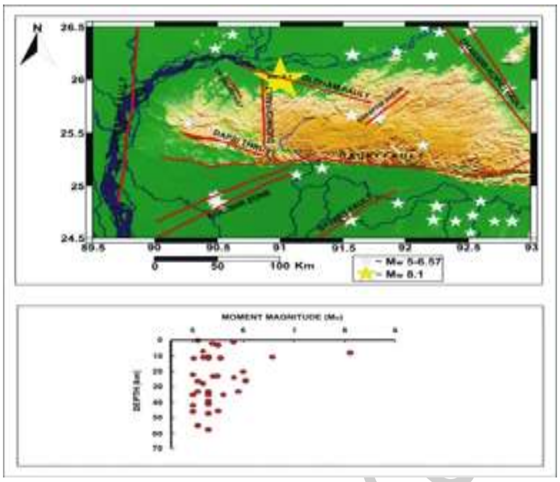

Figure 3(c): Seismicity plot in Shillong plateau with depth section counterparts for 1098 number of earthquakes with moment magnitude ranging from 5-6.57 M_w alongwith the earthquake of 1897, M_w~8.1.

From the study of seismicity distribution pattern as in Figure: 3(a), (b), (c) it is evident that moderate intensity earthquakes are predominant within the plateau at different depth ranges, whereas high magnitude earthquakes i.e. >5M_w are dominant only in the peripheral part of the Shillong plateau with moderate distribution rate, leading thereby the fact that intra-crustal seismicity triggering in the Shillong plateau deciphers the activeness of faults present within the massif pertaining to high frequency of earthquake distribution.

However other researchers [18], [11], [1], [19] proposed the theory of plateau 'Pop-Up' mechanism, where the faults bounding the plateau region are held responsible owing to different magnitudes of stresses involved. From the study of seismicity distribution pattern as in Figure: 3(a), (b), (c) it is evident that moderate intensity earthquakes are predominant within the plateau at different depth ranges, whereas high magnitude earthquakes i.e. >5M_w are dominant only in the peripheral part of the Shillong plateau with moderate distribution rate, leading thereby the fact that intra-crustal seismicity triggering in the Shillong plateau deciphers the activeness of faults present within the massif pertaining to high frequency of earthquake distribution.

5. Conclusion:

The seismicity analysis over the period 1966-2013 suggests that intense seismicity is predominant in Chedrang valley and its vicinity, where the dominant earthquakes are of the order of

≤4.99M_w; further the earthquake frequency distribution also infers the activeness of the prevalent faults as well as micro ruptures in and around the valley in different depth ranges. In the whole study area, within the depth range of 10 to 40km, the highest amount of 61.99% out of 1098 seismic events have been recorded with an average depth of 22.31km. Depth section plot of the seismicity reveals that beyond the depth of 40 km, the frequency of earthquake occurrence reduces drastically and becomes very few after crossing crustal depth 50km. However, it should be cited here that in the shallow regime of the uppermost crust (0 to 10km) only 24.15% of the events were recorded. The depth section view of the seismicity plot infers the bottom of the seismogenic zone in the Shillong plateau to be at 40km. The earthquakes having magnitude range in 3- 5M_w are predominant in the study area, comprising a total of 65.45% of the entire seismicity. The average magnitude of the earthquakes is calculated out to be 3.42 M_w. Thus from the above conclusion we may infer that variable seismicity pattern is observed at the sub-crust level in and around Shillong massif.

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