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GEOLOGY, TECTONIC SETTING AND LARGE EARTHQUAKES IN NORTHEAST INDIA

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Abstract:

Northeast India has five major tectonic domains having its own evolutionary history and characteristics. The region is seismically one of the six most active regions of the world the other five being Maxico, Taiwan, California, Japan and Turkey. It has experienced 19 large ($M \geq 7$) including 3 great earthquakes ($M \geq 8$). The present study aimed to correlate these earthquakes with the tectonic setting of the region and this is done by plotting the epicenters of the earthquakes to the tectonic map of the area. Indo-Burma range has experienced maximum number of large earthquakes in comparison to other domains indicating that along the plate boundary, subduction process is mostly related to the large earthquake than collision process. Intra plate activity is also responsible for some of the large earthquakes and Kopili lineament of Assam Valley was the source of such two events. The great earthquake of 1897, 1912 and 1950 are related to Po-chu –Fault in Assam-Tibet Border, Kyaukkyan fault system in Shan Plateau and Oldham Fault in Shillong Plateau respectively.

Key Words: Fault, Geology, Large earthquake, Lineament, Tectonic setting, Thrust.

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1. Introduction:

The regional sources of earthquakes are determined by analysis of both the past earthquake activity and through study and analysis of geotectonic of a region. The ground shaking in an earthquake depends on the local geological conditions, also known as 'site effect'. The primary control of site response is the rock or soil type. The harder the rock the lower the level of shaking is a good rule of thumb. Igneous rocks such as granite are considered a hard rock, soft rocks are usually sedimentary rock which include lime stone, shale and sand stone. Relative to granitic site a site underlain by sedimentary rock could experience an increase of intensity levels at the same distance from the same earthquake. Site underlain by young saturated soil or alluvium usually shake with the highest intensity. Over a period of 30 years Nandy and his co-workers have carried out extensive research in seismotectonic of the Northeast India. The Northeast India has been categorized as zone V, the highest zone of the seismic hazard zonation map of India[1] (Fig 1). The region is characterized by five distinct tectonic domains [2, 3]. (I) Eastern Himalayan mobile belt, (II) Syntaxis zone of Himalayan arc and Burmese arc (Mishmi hill block), (III) Patkoi- Naga- Chin-Arakan Yoma (Indo-Myanmar mobile belt), (IV) Plate boundary zone of the Shillong plateau and Lower Assam valley (Meghalaya and Mikir hill) and (V) Bengal Basin and plate boundary zone of Tripura- Mizoram fold belt. Each domain has its own evolutionary history, characteristic pattern and Geometry of inter and intra domain dynamics of movements producing characteristic seismicity. Northeast India being the most seismically active zone of the world carries maximum probability of a large earthquake at any time, which is due, as per version of the notable seismologists studied in the region[4 - 8]. Hence the seismotectonic correlation of large earthquakes experienced by the region is important to study the regional seismicity.

2. Geology and Tectonics of the Region:

(I) Eastern Himalayan mobile belt:

The Himalayan ranges rise abruptly from Brahmaputra plains and marge with Tibetan plateau in north covering about 350 km of eastern most part of the Himalayas and extend from Bhutan in the west to Lohit valley in the east. The entire Himalayan range is sub divided by some thrusts like Main Central Thrust (MCT), Main Boundary Thrust (MBT) and Frontal Foot Hill Thrust (FHT) systems developed as a consequence of the collision of the Asian and Indian continents. Sub Himalaya mostly comprises sedimentaries known as Siwalik and separated from the Brahmaputra plains by Foot Hill Thrust (FHT). The Sub

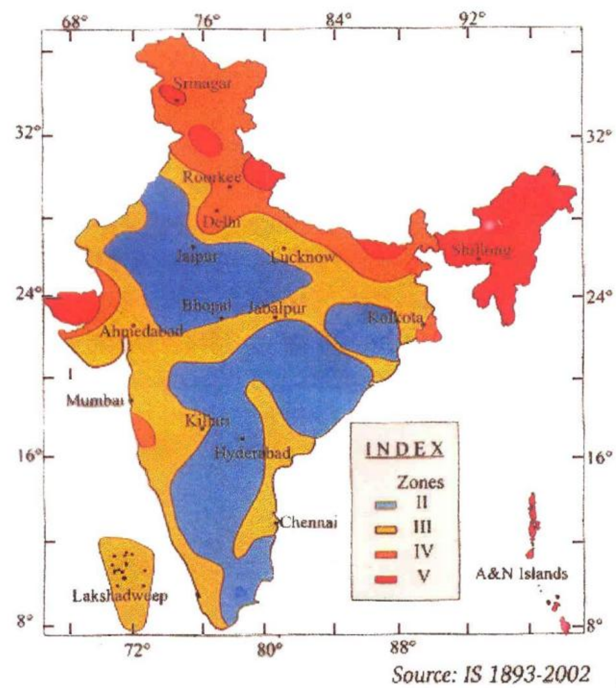

Fig.1: Seismic Zonation Map of India[1].

Himalaya is thrusted over Lesser Himalaya along Main Boundary Thrust (MBT). Lesser Himalaya is mainly formed by Upper Proterozoic to Lower Cambrian detritus sediments. Further north the Lesser Himalaya is overlain by Higher Himalaya and separated from it by MCT which dips northward at 30^0-50^0. Further north, the Higher Himalaya is overlain by Tethys or Tibetan Himalaya that is separated from overlying Trans Himalayan formation by Indus Tsangpo Suture Zone which is the zone of collision between the Indian plate and the Eurasian plate.

Seismotectonic analysis of the eastern Himalayan zone[9, 10] has clearly indicated that many of transverse strike slip faults are at present active producing most of the earthquake events in this zone. The most important of them, from west to east are East Patna, Kanchen Dzonga, Yadaon Gulu (graben), Tista, Jamuna, Dudhnoi, Kulsi, Gyau (graben), Kopili and Bomdila faults. The Dudhnoi and Kulsi faults cutting across the Meghalaya plateau and Brahaputra valley also traverse across the Frontal Himalayan Fold and Thrusts belt.

(II) Syntaxis zone of Himalayan arc and Burmese arc:

The NW-SE trending Mishmi hills are considered as northern continuation of Myanmar hills of Burma. Generally rocks of Precambrian age are exposed here. These hills abut against the Naga-Patkoi ranges of the Arakan-Yoma Mountain. The met sediments of Mishmi formation shows reverse metamorphism, representing the Lesser Himalayan has come in close juxtaposition against the Lohit meta Granodiorite and meta Diorite of a probable Trans-Himalayan province[11].

This tectonic block is traversed by four important NW-SE thrusts or reverse faults. They are from foot hills to the higher Himalayan zone, Mishmi thrust, Tidding suture, Lohit thrust and Po Chu fault. The frontal Mishmi thrust overrides the ENE-WSW trending frontal thrust belt of the Indo-Myanmar mobile belt in the Noa Dihing valley of Tirap district of Arunachal Pradesh. The earthquake events occurring in the south east extremity of the Mishmi thrust at present yielded right lateral strike slip faulting along steeply dipping NE to ENE nodal plane. Other events occurring right inside the Mishmi block yielded strike slip solutions indicating thereby that the present tectonics transport in this area is mainly through strike slip motion. The seismicity in this zone is commonly accepted as due to collision tectonics between the Indian plate and Eurasian plate[12 - 14].

(III) Patkoi-Naga-Chin Hill-Yarakan Yoma(Indo Myanmar) mobile belt :

The Indo-Myanmar arc consists of the Indo-Myanmar ranges (Arakan Yoma, Chin Hills and Naga Hills from south to North), the Myanmar basin (also called the Central Lowlands) and the eastern highlands of Shan Plateau. Indo-Myanmar range is an arcuate sedimentary belt with NS trend of folded Mountain chain, formed by Cenozoic rocks with Triassic metamorphic basement. It is considered as active accretion wedge linked to eastward subduction of Bengal Basin Oceanic crust [15 - 18]. 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 [19 - 21]. The central Basin is actually a series of Cenozoic Basin presently affected by an active tectonic inversion [22].

The Indo Myanmar Belt is a region of transition between the main Himalayan collision belt to the north and the Andaman arc to the south where the Indian plate is currently subducting under Asia. The northern extension of the belt is restricted by the southern tip of the Mishmi massif. The eastern boundary thrust [23], which is also known as the Kabaw fault separates the Myanmar Basin from Indo-Myanmar Range. A right lateral strike slip fault (the Sagaing fault, SF) separates the Eastern Highlands from the Myanmar basin. The Sagaing fault [24] is also denoted as the Shan Boundary fault system [25, 26] or Sittang fault [27]. The significant character of this belt is that it represents an inter continental convergent zone supported by the occurrence of shallow and intermediate focused earthquakes [28]. The outer belt in the Naga hill segment is characterized by the Schuppen belt, a group imbricate thrusts extending for about 350 km in a NE-SW direction [29]. The boundary between the Naga hills and the Assam fore land Basin is followed by the Naga thrust whereas Disang thrust in the South east marks the outermost outcrop limit of the Disang formation.It passes near Haflong to part of a narrow but complex fracture belt known as the Haflong fault and this fracture belt traced outwards, passes into Dauki fault. Near Haflong the fracture changes direction from NE-SW to run nearly due west. Continent- continent collision had occurred within Naga hill segment resulting in major structural configuration of high rise mountains.

(IV) Plate boundary zone of Shillong plateau and Lower Assam valley:

Shillong Plateau is separated from peninsular India of Tertiary Ganges-Brahmaputra alluvium and Createceous Rajmahal Volcanics [23] and moved to the east by 300 km along the Dauki fault [30]. The plateau covers an area of about 40000 km ^{2} within 25^0 20' N-26^0 30' N latitude and 90^0 E-93^0 50' E longitude. It is an E-W trending oblong horst block uplifted about 600 to 1800 m above the Bangladesh plains in the south which is related to collision of the Indian and Tibetan plates during the Cenozoic [31]. The plateau comprises amphibolite granulite facies basement gneisses uncomfortably overlain by the Shillong Group of green schist facies intracratonic sandy and clayey rock[3].The same geological relationship and stratigraphy is present in the Mikir Hills massif (MHM) which has been described as an eastern extention of Shillong plateau, extensive over an area about 7000 km^2 within 25.5^0-27^0 N latitude and 92.5^0-94^0 E longitude. A major N-S fracture zone Kopili rift separates the Mikir Hills massif from the Shillong plateau. The unreformed nature of the granitoids of MHM indicates that the plateau might have attained stability after the emplacements of the granitites and no further orogenic movements have taken place.

The Shillong plateau is bounded by Dauki fault in the south and Brahmaputra fault in the north [30, 23]. There are two major thrust faults in the Shillong Plateau, namely the Dapsi and the Barapani thrust. The Dapsi thrust separates the Archaean to the north and tertiary to the south, whereas the Barapani thrust separates the Archaean to the west and the Proterozoic Shillong group to the east [32, 33]. The western side is characterized by a north south trending Dhubri fault. In addition there is a south dipping hidden fault at the northern boundary of the plateau known as Oldham fault, proposed geologically the entire area has evolved during the Mesozoic to Teritiary time. The seismicity in this zone is considered as the plate boundary zone activity. The seismic activity in the Assam valley is much less as compared to the plateau region. The combined gravity aeromagnetic and seismic data indicate that the basement below the alluvial cover of upper Assam extended as a burried ridge towards northeast. To the northern part of Shillong plateau, the basement of the lower Assam valley is exposed to low lying ridges on either side of the Brahmaputra River. Satellite imagery [34] shows a number of burried lineaments (e.g. Brahmaputra fault, Kopili lineament etc.) beneath the alluvium in the lower Assam valley. The NW-SE kopili lineament and Bomdila fault are the vary active fault of the Assam valley.

(V) Bengal Basin and plate boundary zone of Tripura-Mizoram fold belt:

The Bengal fore land basin contains up to 60 km of deltaic deposits, ended from the eastern Himalayas and the Indo-Burma ranges, and carried by major river systems similar to the present day Ganges and Brahmaputra [35, 36]. Its sediments are more than 20 km thick in the Sylhet Trough and in the southern part of the Ganges Brahmaputra Delta [37]. The basement increases in depth from west to east, from 4.3 km deep on the Indian plate to depths of 10 -11 km on the extreme eastern part. The Tripura fold belt stretches from Arakan coastal area in the south through the Chittagong hill Tracts, Tripura Hills and along the eastern margin of the Surma Basin as far as the Shillong Massif in the north where it is truncated by two major structural elements of regional importance, the Dauki Fault and the Haflong Fault. To the northeast, the belt continues through the Kohima Synclinorium and merges in the Shuppon belt of upper Assam. However, based mainly on the structural configuration of the anticlines, some geologists have suggested a subdivision of this zone into two belts, the Mizo folded belt in the east and the Chittagong Tripura folded belt in the west, both separated by the NNW-SSE striking Kaladan Fault.

The main tectonic domains in these zones are EW trending Dauki fault, NE trending Sylhet fault, NE-SW Hail-Hakula lineament, NS Jamuna fault, NW Padma lineament, Tista fault, Mat and Tuipui faults. The EW trending Dauki fault demarcates the boundary between the Meghalaya plateau and Bengal Basin. In the vicinity of this fault there are two EW trending anticlines, the Sylhet and the Chhatak Structures. The seismically active steeply dipping NE Sylhet fault which passes along the NE corner of Bangladesh in Bengal Basin delimits the Surma Basin. The folding in Surma region forms a broad arc, convex towards the west following the curvature of the Indo-Myanmar Orogen. The most prominent transverse fault in between Aizawl and Luglei Mizoram is the NW-SE trending “Mat river fault”. Evidence for dextral movement along the fault has been recorded [38].

3. Database and Methodology:

The present study encompasses a rectangular area extending from 21^0 N and 29.5^0 N to 88^0 E and 97.5^0 E (Fig 2). A comprehensive data file prepared from United States

Figure 2: Location of the study area [39].

Geological Survey (USGS) and International Seismic Center (ISC) catalogs have been used to analyze the large ($M_s \geq 7$) and great ($M_s \geq 8$) earthquakes and their location of the study region to study their relation with the tectonics. Tectonic setting of the area is adopted as suggested by Evans[30] and Krishnan[40] and the epicenters of the large earthquakes of the region are superimposed on it to prepare the seismotectonic map (Fig. 3).

4. Large earthquakes of northeast India and their correlation with tectonic setting:

. The region has experienced 19 large Earthquakes ($M \geq 7$) including the 3 great earthquakes of Shillong (1897, M_s=8.7), Burma (1912, M_s=8) and Assam-Tibet border (1950, M_s=8.7). Moreover several hundreds smaller and micro earthquake have also been recorded in the region. The Major Earthquakes in Northeast India from 1869 are listed in the table 1.

The great Assam earthquake of 1897 (M=8.7) which was one of the most powerful earthquakes of India was originated in Shillong plateau. The description of this earthquake provided the principal modal for highest grade, xii, of the (Modified Marcelei Intensity scale) MMI scale[41]. A 110 km long south dipping fault naming Oldham fault, bounding the north western section of the Shillong plateau was responsible for this earthquake. During the event, the slip on this fault, amounting to 16 meters, which is amongst the greatest for any known earthquake. The event lasted for about 2.5 minutes and killed about 1542 people. The movement along the Po Chu fault zone located in the north east extremity of the Mishmi block is believed to have caused the 1950 great Assam earthquake of Mw 8.7[42, 43]. This event yielded both dextral slip along NW nodal plane and thrust movements by different workers[3]. The 23rd May 1912 earthquake (M_s=8) in Eastern Burma was related to the western part of the Shan plateau. The combination of field evidence and isoseismal reports indicate that only the northern ~140 to 160 km of the Kyaukkyan fault system ruptured during the 1912 Burma Earthquake. The shock was lasted for 1 minute and caused considerable damages[44].

Table 1. The Major Eathquakes in Northeast India from 1869.

Latitude	Longitude	Place	Date	Magnitude in M_s
25.0^0 N	93.0^0 E	Cachar	Jan. 10, 1869	7.8
26.0^0 N	91.0^0 E	Shillong Plateau	June 12, 1897	8.7
27.0^0 N	$97.0\ ^0$E	Indo-Myanmar border	Aug.31,1906	7.0
26.5^0 N	97^0 E	Myanmar	Dec. 12, 1908	7.5
21^0N	97^0E	Upper Burma	May 23, 1912	8
24.5^0 N	91.0^0 E	Srimangal	July 8, 1918	7.6
25.25^0 N	91.0^0 E	SW Assam (Meghalaya)	Sept. 9, 1923	7.1
25.5^0 N	90^0E	Dhubri	July 2, 1930	7.1
25.6^0N	96.8^0E	Assam	Jan. 27, 1931	7.6
26^0N	95.5^0E	Nagaland	Aug. 14, 1932	7.0
23.5^0N	94.25^0E	India-Myanmar	Aug.16, 1938	7.2
26.00^0 N	93.0^0E	N-E Assam, Near Hozai	Oct.23, 1943	7.2
23.5^0N	96^0E	Myanmar	Sept.12, 1946	7.8
28.5^0 N	94^0 E	Arunachal	July 29, 1947	7.7
28.50^0 N	96.50^0 E	Assam Tibet Border	Aug. 15, 1950	8.6
28.6^0N	95.7^0E	Patkai range, Arunachal	Aug.16, 1950	7.0
24.2^0 N	95.1^0E	Manipur-Burma border	Mar. 21,	7.7

			1954	
24.4^{0}N	93.8^{0}E	Indo-Myanmar	July 1st, 1957	7.2
25.15^0 N	95.13^0 E	Indo-Myanmar border	Aug.6, 1988	7.5

Kopili fault which has strike slip movent was responsible for 1869 Cacher earthquake. This fault is identified as the most active fault in the Assam valley area[33, 45]. The earthquake damaged the region heavily. Another large earthquake in 1943 (M > 7) also occurred due to the movement of this fault. The 1918 Srimangal earthquake (M = 7.6) originated beneath the Bengal basin due to rupture along the NE trending Sylhet fault that yielded high angle reverse focal mechanism solution where it is intersected by NW trending Mat fault. The 1923(M_s=7.1) earthquake is possibly linked with activity of the Dauki fault. The epicentre was at a place to the north of cherrapunji in the southern part of Meghalaya. The1930 (M_s=7.1) earthquake may be assigned to the N-S Dhubri or Jomuna fault[3]. The 1947(M=7.8) has been reported from Arunachal Pradesh in the eastern Himalayan region. This event was closely associated with the MCT. So far no great earthquake has been reported from these tectonic domains[3]. In 16 August 1950 an earthquake (M_s=7) was reported from Arunachal which was located near Dibung river. The epicenter of the 1954 termor was centered in northern Myanmar near Manipur-Myanmar borde. In 1988 the Indo-Myanmar Subduction zone experienced a large earthquake of magnitude 7.3 M_b at the location of 25.15^{0}N and 95.13^{0}E in the upper part of Central Burma basin, between Arakan Yoma in the west and the volcanic line in the east with the hypocenter at the depth of 90 km.Another two events the 1957(M_s=7.2) and the1932 (M_s=7) reported from this region may be related to the

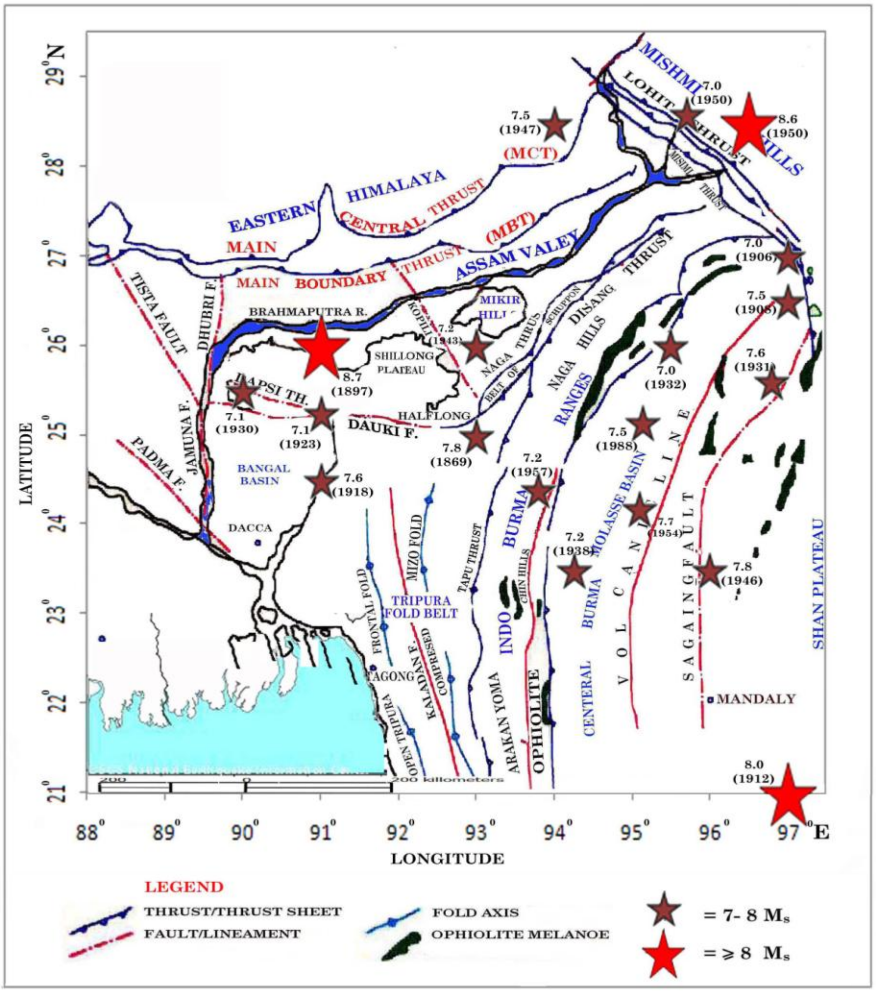

Figure 3: 19 Large earthquakes of northeast India with their Tectonic Correlation.

activity of Eastern Boundary Fault. Sagaing Fault is an active fault of indo Burma region which is closely related to the 1946 (M_s= 7.8) and 1931(M_s=7.6) events. The epicenter of the1906 (M_s=7) earthquake was centered at the meeting place of Lohit Thrust, Mishmi Thrust and Eastern Boundary Thrust. The NW-SE trending Mat river Fault is associated with the 1938(M_s=7.2) termor.

Conclusion:

A clear alignment of the epicenter of large earthquakes with different faults, lineaments and thrusts are obtained from this study which depicts their tectonic activity. The Indo Burma range , where subduction of Indian plate under Burmese is still going on has experienced maximum number of large earthquake whereas from the Eastern Himalayan region having collision tectonic only two such earthquakes are reported during the last 100 years. This may indicate that along the plate boundary, subduction process is mostly related to the large earthquake than collision process. The Kopili lineament, which was responsible for Cachar earthquakes (M > 7) of 1869 and 1943 and most active till now may be the source of another large earthquake in near future. After 1950 the region has experienced no great earthquake for long 60years which may be the return period of such earthquake for the area having highly active tectonic setting.

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