CHAPTER 3
GEOLOGY AND TECTONICS OF NORTH EAST INDIA

3.1 Introduction

The northeastern region of India represents geologically a complex framework in terms of its lithology and structure. The rocks found in this region represent each time division of the geological time scale, ranging from Archaean to Recent. The region is governed by the collisional tectonics of the Himalayan arc in its northern extremity where the Indian plate is underthrusted beneath the Eurasian plate (Nandy, 2001). The eastern margin of the region is described by the subduction tectonics of the Burmese arc where the Indian plate is subducted beneath the Burmese plate (Satyabala, 2003). These two mobile belts enormously influence the tectonic mechanism of this region. The main tectono-geological divisions of the region may be described as below:

1. the Eastern Himalaya and the Mishmi Massif,
2. the Indo-Myanmar (Burmese) Mobile Belt,
3. the Meghalaya Plateau and Mikir Hills,
4. Assam Valley and the
5. Bengal Basin and Tripura Fold Belt.

The geological and tectonic map of the northeastern region of India has been shown in Figure 3.1.

3.2 Geology and Tectonics

3.2.1 Eastern Himalaya and Mishmi Massif

In northeastern India the eastern Himalayas and the Mishmi Massif occurs in the state of Arunachal Pradesh. Here, the Eastern Himalayan mobile belt is divided into three physiographic features namely, from south to north are (i) the Sub-Himalaya comprising the Siwalik Hills, (ii) the Lesser Himalaya and the (iii) Higher Himalaya. These physiographic units are trending from east to west. They are described below as follows:
Figure 3.1: Geological and tectonic map of northeastern India (after Seismotectonic Atlas of India and its Environ, GSI, 2000 and Geological and Mineral Map of North East India of GSI, 1998)
(i) **Sub-Himalayan Belt:** These are basically Neogene molasse deposits in the foredeep which presently represented by Siwalik Hills. This comprises mainly the Siwalik sediments of Mio-Pliocene in age. Apart from this lithologic unit, there are also occurrences of marine Eocene rocks (Yinkiong) which are to be seen exposed in the windows and outliers formed by the marine Gondwana rocks in the Siang district of Arunachal Pradesh (Nandy, 2001).

(ii) **Lesser Himalaya:** As per Nandy, 2001 the main lithotectonic units within the Lesser Himalayas are as follows

   (a) Para-autochthonous Lower Gondwana sequence which comprises of coal bearing Gondwana rocks and extends as a narrow belt from eastern Nepal to the Siang area of Arunachal Pradesh.

   (b) Para-autochthonous Buxa Group of rocks which comprises of orthoquartzite-carbonate and represent stable shelf facies.

   (c) Abor volcanics covers an area of 1000 sq.km in the Siang valley of Arunachal Pradesh, with a width of about 40 km beyond Rangging to near Geku. They are seen to be closely associated with the Eocene Yinkiong Formation and the Gondwana Group and coeval with Rajmahal traps of Jurassic age (Nandy, 2001).

   (d) The Lesser Himalaya is predominantly occupied by a low to medium grade schist, which forms a litho unit known as the Daling Group.

(iii) **The Higher Himalaya:** Higher Himalaya which is mainly defined by the ‘Central Crystallines’ comprising mainly of high grade schists, gneisses and patches of granites and the Main Central Thrust (MCT) demarcates the boundary between this Himalaya and the Lesser Himalaya (Nandy, 2001).
Mishmi Massif acts as a bridge between the eastern Himalaya and the Indo-Burmese mobile belts (Nandy, 1976). The general structural trend of the lithotectonic units in Mishmi Massif is NW-SE and dipping towards NE. The rocks occurring in this Massif may be geologically and petrologically categorised into three distinct belts from southwest to northeast, each of which is segregated from one another by steeply dipping thrusts that are trending in the NW direction (Talukder and Nandy, 1976). As per Nandy (2001) these belts of rocks may be described as below:

(a) the southwestern belt: this group of rocks have also been described as the Lohit Group and is separated from the central belt of rocks by the NW dipping thrust called the Tidding suture (Nandy, 1980). This belt comprises of metamorphosed argillaceous and arenaceous rocks which have been partly migmatised, minor crystalline limestone and garnetiferous amphibolites (Nandy, 2001).

(b) the central belt: the dominant rock types comprising this belt are chlorite-epidote or amphibolites schist, serpentinites, crystalline limestones which are also known as Tidding limestones, chlorite-biotite-actinolite schist which are also defined as tiding Group (Nandy, 2001).

(c) the northeastern belt: this belt is also known as the diorite-granodiorite complex and comprises of hornblende granodiorite, coarse grained biotite leucogranodiorite with hornblende schist, amphibolite, metadolerite, metanorite and xenoliths of parametamorphic rocks and crystalline marble (Nandy, 2001).

These three belts of rocks have been reported to be mapped for about 250 km trending in the NW direction. These three belts of the Mishmi Massif are closely placed with the almost N-S oriented Himalayan lithotectonic units seen in the Siang fracture zone (Nandy, 1980) which has also been described as the Bame fault (Kumar,
et al., 1998). It is said that the rocks of the Mishmi Massif underwent four different phases of folding (Thakur and Jain, 1975).

3.2.2 Indo-Myanmar (Burmese) Mobile Belt

The geological and tectonic attributes of the Indo-Burman arc is a manifestation of north-easterly directed movement of the Indian plate which collided with the Burmese plate around early-mid Eocene time. The Burmese arc is defined by a plate boundary of nearly 1100 km long and convex westward. The Indo-Burman Ranges is a part of a complex tectonic zone with oblique subduction going on at its western boundary. The arc is bordered by a fold belt, called Indo-Burman Ranges in the west, to the east it extends upto the Burmese low lands and the Chindwin basin. The Sagaing fault extends parallel to the Indo-Burman Ranges on its eastern boundary. The Mishmi Massif forms a link between the eastern Himalayan mobile belt in the north and the Indo-Myanmar (Burmese) mobile belt on the eastern margin of northeastern India. Towards south it extends upto the Andam Spreading Ridge (ASR), Kayal, 2008. Together they form an arch-trench system (Nandy, 2001). The Indo-Burman comprises fom the north to south, the Naga Hills, Chin Hills and the Arakan Yoma (Kayal, 2008). This forms a westerly convex arcuate belt comprising of flysch and sub-flysch of Eocene to Oligocene in age along with sediments belonging to Palaeozoic-Mesozoic age with sporadic occurrences of metamorphics and patches of ophiolites. These rock types are seen occurring along the Eastern Boundary Thrust (EBT) (Nandy, 2001).

A 200 km wide and 1400 km long sedimentary basin in the central Myanmar lies to the east of EBT and is of Palaeogene to Neogene in age. This basin is bifurcated by a volcanic arc into western forearc and eastern backarc basin (Nandy, 2001).
By the close of Oligocene the molasse basins of Tipam and Surma came into being in the foreland side of Indo-Mynamar mobile belt. The thickness of the Tipam molasse basin is 4100 m and widely occurs in the northern extremity of Upper Assam, where the belt trends ENE-WSW (Nandy, 2001).

Due to the process of subduction, turbidite and ophiolite melanges got thrusted into the Indian plate. In the Naga Hills the flysh are tightly folded and are overlain by Miocene deltaic and freshwater molasses (Curray and Moore, 1974). To the eastern side of the Arakan Yoma, metamorphic schists and ultrabasic rocks are found to be overthrust into the flysh westward (Kayal, 2008).

The Naga Hills comprises of Tertiary succession of Eocene to Pliocene rocks which are laid down in form of more than eight thrust sheets and this is known as the Belt of Schuppen (Evans, 1964). A stratigraphic throw of upto 9 km and total horizontal movement of all thrusts are seen exceeding 200 km (Evans, 1964). The thrust override one another forming a complex pattern and ranging from 13 to 14 km in width (Kayal, 2008). The northwestern extension of this belt follows the alluvial deposits of Upper Assam and ends near the Haflong towards south (Kayal, 2008).

### 3.2.3 Meghalaya Plateau and Mikir Hills Plateau

The Meghalaya Plateau (Shillong Plateau) and the Mikir hills which is an extension of the Indian shield, is detached from the latter by the Bengal Basin acts as a pivot to the west of the Naga hills and to the south of the Eastern Himalyas. The average elevation of this tectonic entity is about 1000 m. The plateau is bounded by ~320 km long E-W Dauki fault system and on to west by the Jamuna and Dhubri faults (Kayal, 2008). The Precambrian basement of the Shillong plateau to the north and the thick Tertiary sediments of the Bengal basin to the south is separated by the Dauki fault. The contact between the Tertiary sediments to the southwest and the Archaean
gneiss to the northeast is demarcated by the 90~100 km long NW-SE trending Dapsi thrust, a northwest extension of the Dauki fault (Kayal and De, 1991; Nandy, 2001). Oldham (1899) mentioned about 19~20 km long NW trending fault, called Chedrang fault, and is thought to be a development during the occurrence of the great Shillong plateau earthquake of 1897 where a 10 m vertical displacement was reported. The NW-SE trending Kopili fault causes a detachment of the Mikir Hills from the Shillong plateau. It is about 300-400 km long lineament that crosses the Assam valley and reaches to MBT. It is transverse to the Himalayan trend and parallel to the Bomdila lineament. It is recognised to be a very important tectonic feature lying between the Shillong plateau and Mikir Hills known as the Kopili gap (Nandy, 2001).

The entire area of Shillong plateau evolved during the Mesozoic and Tertiary times. During the mountain building in Burma and the Himalaya, there was large scale vertical movements resulting in the uplift of the Shillong plateau in northeastern India and the Shan plateau in Burma during the Tertiary (Krishnan, 1960; Murthy, 1970). The plateau started breaking along its southern margin by the E-W trending Dauki fault during Jurassic to Cretaceous. This led to the vertical uplift of the plateau causing subsidence in both towards north as well as towards the south. Therefore, this resulted in the deposition of sediments (3-4 km) in the lower Assam Brahmaputra valley up to the MCT, while subsidence in the south led to the deposition of thicker (~15 km) sediments in the Bengal basin (Kayal, 2008). The Shillong Plateau, Mikir Hills and the Brahmaputra Valley together are known as the Foreland Spur (Evans, 1964). In 2001, Bilham and England championed the ‘pop-up tectonics’ for the Shillong plateau, which is bounded by two reverse faults, the north dipping Dauki fault to the south and WNW-ESE trending south dipping deep seated ‘Oldham fault’ at the boundary of the plateau and the Brahmaputra valley. It is learnt from geodetic
data the Shillong plateau rose violently by at least 11 m during the 1897 great earthquake which was due to the buried reverse fault called the Oldham fault which is approximately 110 km in length and dipping steeply away from the Himalaya.

The Mikir Hills Plateau is separated from the Meghalaya Plateau (Shillong Plateau) by NW-SE trending Kopili fault which passes through the alluvium plains of the Kopili River. This tectonic domain contains rock sequences representing all almost entire geological time range. The Archaean Gneissic Basement of the plateau is overlain by Proterozoic intracratonic sediments of Shillong Group along with the intrusive metadolerite Khasi greenstones, and subsequently by Upper Proterozoic-early Palaeozoic granite batholiths. The Sylhet Trap occurring in the southern extremity of the Shillong Plateau bounded between the parallel northern East-West trending Raibah Fault and southern Dauki fault. The Sylhet Traps represents Jurassic-Cretaceous volcanism in the region. The southern and the eastern extension of the Meghalaya Plateau and the southern part of the Mikir Hills show the occurrence of Cretaceous-Eocene shelf sediments. Evidences of intracontinental sedimentation upto Quarternary period have been found along the southern fringe of the plateau (Nandy, 2001). In the east-central part of the plateau and in the Mikir Hills the conspicuous occurrence of carbonatite-ultramafic complex of Upper Cretaceous age are seen to occur. The general structural trend of the active faults and the fracture zones in this plateau is observed to be N-S and NW-SE (Nandy, 2001).

Broadly the litho units can be classified as follows:

(a) **Gneissic Complex:** The gneissic complex is classified into the gneissic complex proper and the nonporphyritic granitoid rocks (migmatites). The former contains plenty of granitic gneiss of amphibolite facies. The unit is characterized by the deficiency in index minerals particularly of intermediate grade of metamorphism.
(Nandy, 2001). Highest grade amphibolite facies containing diopsidic clinopyroxene and sillimanite-garnet-K-feldsper-quartz-gneiss without muscovite forms a common assemblage and are reported from many places (Nandy, 2001). Sonaphar is well known for its deposit of sillimanite which occurs in form of sillimanite gneiss which also contains corundum and clinohumite bearing assemblage (Nandy, 2001).

There are at least three variations of Granitoid rocks. They are dioritic, granodioritic and granitic in composition. The granodioritic ones are plutonic migmatite in nature. Hypidiomorphic quartz, microcline, oligocalcse, biotite and accessories characterize the granite (Mazumdar, 1976).

(b) **Shillong Group:** The depositional condition of this group of rocks is intracratonic in a NE-SW trending basin formed over the gneissic complex with a conspicuous unconformity at the base formed by basal conglomerate (Nandy, 2001). Oligomictic conglomerate, quartz-sandstone and siltstone constitute this group of rocks. Metamorphism is less and is related to the intrusive pluton of Mylliem type (Nandy, 2001). The Tyrsat-Barapani shear zone occurs as a zone of sub-vertical dips with local reversals continues northeastwards from west of Mawphlong (Nandy, 2001). The Khasi greenstone forms an important intrusive within the Shillong Group of rocks which runs parallel to the strike of the Shillong group of rocks. The rocks may be defined compositionally as amphibolites with criss-cross occurrence of hornblende and conspicuous occurrence of neocrystallised plagioclase (Nandy, 2001).

(c) **Proterozoic-Palaeozoic Porphyritic Granite:** These are granites which occur prominently as plutons throughout the Precambrian terrain of Shillong Plateau and Mikir Hills and also shows its presence felt as inselbergs along the course of river Brahmaputra from Tezpur to Goalpara districts in Assam (Nandy, 2001). They occur mostly within the gneissic complex. The chief intrusives in form of porphyritic
granites are south Khasi batholith, Mylliem pluton, Kyrdem pluton and Nongpoh batholith which become younger in age from southwest to northeast (Kumar, 1998).

(d) **Lower Gondwana Rocks:** Lower Gondwana rocks of Permain age has been located in the Singrimari area near the western margin of the Meghalaya plateau in the Garo hills. The rock type comprising exposures of Barakar like pebble beds, sandstones and carbonaceous shales with lenticular patches of coal and plenty of impressions of *Vertibraria indica*. The sandstones are intruded by dolerite dykes and dips westwards into the Jinjiram river (Nandy, 2001).

(e) **Cretaceous Alkaline Ultramafic-Carbonatite Complex:** Small sporadic and separated occurrences of such rocks occur in a NE trending zone from Mawpyut in Jaintia Hills district in Meghalaya to Barpung in Mikir Hills of the Karbi Anglong district of Assam. These rocks are intruded by the quartzites and phyllites of Shillong Group in the Mawpyut area (Nandy, 2001). The significant occurrence of the complex is the Sung valley wherein the ultramafic-carbonatite body sharply cuts across the steeply dipping NE-SW and E-W trending quartzite and phyllite of Shillong Group with the development of narrow zone of fenite along the contact. The major rock types developed within the complex are: (i) serpentine, (ii) pyroxenite, (iii) uncomphagrite, (iv) members of the ijolite series, (v) syenite and (vi) carbonatite. Among all of this pyroxenite is the most abundant rock type and acts as a host for all the rock types developed within the complex excepting serpentine (Nandy, 2001).

(d) **Sylhet Traps:** Plateau basalts with a maximum thickness of 550-600 m, exposed in a narrow 80 Km long and 4 km wide E-W belt along the southern margin of the Meghalaya plateau are the Sylhet Traps (Nandy, 2001). They overlie the eroded Precambrian basement complex and are overlain by the Cretaceous-Tertiary shelf sediments. Basalt dykes both within the the flows and also in the adjoining basement.
rocks to the north but within the trap area along the zone of flexure, the dykes occur as swarms. The dykes occurring in the basement rocks trend between NNE and NE and among which are some alkali lamprophyre dykes in the basement complex especially towards Garo hills. In the type area individual basalt flows are 5-7 m thick on an average (Nandy, 2001).

(e) **Cretaceous-Tertiary Shelf Sediments:** Since Cretaceous times continuous sedimentation took place all along the southern, southwestern, southeastern and eastern margins of the Meghalaya plateau and along the southern and eastern margins of the Mikir Hills extending upto Upper Assam under stable shelf condition (Nandy, 2001). The Jadukata Formation in the Khasi Hills sector consisting of conglomerate and sandstone unconformably overlying the Sylhet trap and containing *Inoceramus* zone fossil forms the lowermost unit. Towards west in the Garo Hills the same formation has been termed as the Gumaghat Formation (Chakraborty, 1972). It is a polymictic boulder conglomerate having boulders of greenish or ash grey sandstone boulders; the upper part has alternations of sandstone and conglomerate with pebbles of chert, vein quartz and granites with infilling of arkosic sands derived from granites. The Mahadek Formation consisting of grained arkose and glauconitic sandstone with thickness varying from 150-400 m having stringers of pebbles made of quartz and gneiss overlies the boulder conglomerate (Nandy, 2001). In the east central Khasi Hills, in Therriaghat section a lithounit named the Langpar Formation overlies the Mahadek Formation which is of Palaeocene age and comprises calcareous shale, sandstone and sandy limestone (Nandy, 2001). Eocene Shella Subgroup consisting of three units of sandstones and three units of limestone overlies the Langpar Formation and are well developed in the south and southeastern Khasi Hills (Nandy, 2001). The units from bottom to top are as
follows: Theria sandstone (25m), Lakadong limestone (200m), Lakadong sandstone (25m), Umlatdoh limestone (55m), Nurpuh sandstone (20m) and Prang limestone (210m), Nandy (2001). The Kopili Formation (150-800m) forms a highly fossiliferous argillaceous limestone bands near their base and with sandstone bands at the top. Scattered occurrence of phosphatic nodules has been reported from the basal part (Nandy, 2001). It has been mapped as the Rewak Formation (400-600m) in the Garo hills sector with a marker bed of black shale at the base having profuse phosphatic nodules (Chakraborty, 1972). The Jaintia Group is the name given collectively to Langpar Formation, Shella Subgroup and the Kopili Formation (Nandy, 2001). The platform equivalents of Surma Group, Tipam and Dupi Tila Formations representing Mio-Pleistocene age are well developed in the Garo Hills sector, Jaintia and North Cachar Hills as well as in the southeastern part of Mikir Hills (Nandy, 2001).

3.2.4 Assam Valley

The Assam valley is an ENE-WSW trending relatively narrow wedge shaped valley tapering towards west-southwest direction and bounded by Himalayan Range to the north and the Indo-Burman Ranges to southeast, the Mishmi Massif with its bounding NW-SE trending Mishmi Thrust which delimits the Brahmaputra valley alluvium towards ENE, bounded by the Meghalaya Plateau to the south. The valley is open towards west connecting to the Ganga River valley alluvium. Assam valley has thick alluvial deposits with few jutted out Precamrian inselbergs of Basement Rocks from Tezpur westward (Nandy, 2001). The Tertiary shelf sediments overlie the Basement Rocks whose thickness decreases from south to north, i.e. towards the Himalayas. The Tertiary sediments possess oil reservoirs and form important oil fields.
in Upper Assam which are most commonly combined stratigraphic-structural traps (Nandy, 2001).

The Cenozoic sedimentation on the Assam-Shillong shelf began with the deposition of the Jaintia Group (Paleocene-Eocene) which is spread across the upper Assam sub-surface and in the Mikir hills (Kayal, 2008). The sequence of lithology from bottom to upwards is made up of basal arkoses, blanket limestone and black shale (Kayal, 2008). The Eocene sequence was deposited on the platform under shallow marine to lagoonal environments and was primarily controlled by vertical movements along the basement faults (Dasgupta, 1977). The Oligocene sequence in Assam shelf is about 600-1000 m thick sediments. The upper Assam valley, between the Himalaya and Naga Hills, is flat, around 100 km in width and 300 km in length, and extends northeast-southwest (Kayal, 2008). Beneath the alluvium, 4-6 km thick succession of Tertiary rocks overlies the Precambrian basement complex that is exposed in the Mikir Hills and in the Shillong Plateau (Kayal, 2008).

3.2.5 Bengal Basin

During the Mesozoic-Cenozoic times the Bengal geosyncline evolved which is actually the Bengal basin along with its offshore continuation, Bengal fan in the northeastern Indian ocean (Evans, 1964). Its western part is known as the Gangetic West Bengal basin, and its eastern part that forms the deeper basin in Bangladesh. Geologically, it’s intriguing that it contains ~ 15 km of sediments (Evans, 1964; Talukdar, 1982). Due to the eastward subduction of the Indian plate below the Andaman-Burmese arc the geosyncline has shrunked a lot compared to its original dimension (Curray et al., 1979). The Eocene Hinge Zone is the most important tectonic feature of the Bengal basin which separates the continental shelf in west and geosynclinal facies in the east (Evans, 1964). The Hinge zone is around 500 km long
and varies from 25 km in the north to 110 km in the central part and 35 km in the south. The Hinge line represents the boundary between the continental crust and the young oceanic crust that extends southwards into the Bay of Bengal (Curry et al., 1982).

Bengal Basin occupies part of West Bengal, entire Bangladesh and the connected depositional basin of the Bay of Bengal which encompasses the Cenozoic Assam-Arakan Basin in the geological past. The basin preserves a complete sequence of Tertiary sediments concealed by alluvial covers of ganga-Brahmaputra plains and represents an asymmetric pericratonic depositional basin in the western foreland of the Indo-Myanmar mobile belt (Nandy, 2001). Nandy (2001), subdivided the Bengal Basin into five broad subdomains: (i) North Bengal foreland, (ii) Basin margin fault zone, (iii) Stable shelf, (iv) Hinge zone and (v) Deep basin zone. The deep basin zone, with thick Tertiary sedimentary sequences which attain about 20 Km thickness in eastern part of Bangladesh extends further south towards the interior of the Bay of Bengal (Nandy, 2001). The basin opens towards south, and is bounded to the west by the Indian continental landmass, to the north by the Meghalaya Plateau and the Himalayan foredeep, and to the east by the folded outer molasse sediments of the Assam-Arakan Basin.

3.3 Seismicity and Seismotectonics

3.3.1 Eastern Himalaya and Mishmi Massif

Seismicity in this part of the Himalaya is not known to be very intense; in fact it is very sparse as evident from the microearthquake studied. Albeit the fact this part of Himalaya and the eastern syntaxial zone registered three major earthquakes viz. January 21, 1941 (M 7.0), the July 29, 1947 (M 7.8) and the M 8.7 the great 1950 Assam earthquake with its seat at the Mishmi Massif. A vertical profile along the
Himalayan trend shows the seismogenic depth upto 70 km and the seismic activity is more or less uniform along the entire section apart from the syntaxis zone which shows some clustering of events.

The seismicity of the northeastern part of India is due to continent-continent collision tectonics between the Indian and the Eurasian plates (Dewey and Bird, 1970; Tandon and Srivastava, 1975; Molnar and Tapponnier, 1977; Verma et al., 1977; Chandra, 1978; Seeber et al., 1981; Ni and Barazangi, 1984; Molnar, 1990; Holt et al., 1991, Kayal, 2008). The seismicity is broadly correlated with MBT and MCT in the Himalayan Seismic Belt. Microearthquake studies reveal the rate of seismic activity in Arunachal Pradesh is much lower compared to that of Shillong Plateau-Mikir Hills (Kayal, 1996a). The trend of seismicity was found to be N-S and is not correlatable with MBT, MCT or with the lineaments as seen in the satellite images. The depths section studies for the northeastern Himalaya reveals that the seismic activity is not confined above the plane of detachment which is at shallower depth of < 20 km but is to be seen occurring below 50 km depth at the MBT and to its south which is much below the plane of detachment (Kayal et al.,1993). This is a characteristic which is much of a departure from the one seen in the western Himalaya. The earthquake trend as well as the focal mechanism solutions suggests a NNW-SSE trending deep seated fault in the Arunachal Himalaya which is seismogenic. Microearthquake survey in the Arunachal Himalaya do reveal that the earthquakes are deeper (50-80 Km) and the concept of steady state tectonic model of the Himalaya does not hold true for Arunachal Himalaya. The well defined seismicity at depths between 50 and 100 km possibly indicate the presence of earthquakes in the upper mantle in the region of continental collision.
Mishmi Massif (Eastern Syntaxis Zone) was the seat of the great 1950 Assam earthquake. Ben-Menahem et al. (1974), based on amplitude observations, obtained a right lateral strike-slip fault plane solution. Chen and Molnar (1977) determined a north dipping thrust faulting for this event. The aftershock events show both strike-slip and shallow underthrusting (Chen and Molnar, 1977). Molnar and Pandey (1989), observed that all the relocated aftershocks lie east of the main shock in a 250 km long 100 km wide zone, referring to the fact that the 1950 Assam earthquake occurred on a gently north-northeast dipping thrust plane. Focal mechanisms for five events which showed thrust mechanisms and were located in the southeast extension of Mishmi thrust reveal a northeast dipping nodal plane for the fault; if at all the slip is assumed to be on the Mishmi thrust. Valdiya (1976), propounded that the Mishmi metamorphics thrust over the Tertiary sediments eroded from the northern Indo-Burman Ranges. Three of the events have depth of hypocentre more than 8 km and only one event which occurred on August 12, 1976 with $M_w$ 6.2 has a shallow depth of 3 km. The event of November 28, 1984 with depth of occurrence being 4 km, shows right-lateral strike-slip motion, and that may be an indication of shallow crustal deformation. Likewise another three events on the Sagaing fault, south of 26° N, is indicative of right lateral motion. The region north of 26°N latitude marks the transition from strike-slip to thrust mechanism of faulting as the predominant mode of deformation in this area of Eastern Syntaxis (Holt et al., 1991; Kayal, 1996a). Also it is evident from the depth section along the Indo-Burma ranges that the lower limit of seismic activity are much shallower beyond the 26°N latitude, indicating that the collision process has taken over the subduction tectonics (Kayal, 1996a).
3.3.2 Indo-Myanmar (Burmese) Mobile Belt

The Indo-Burman Ranges is one of the few intercontinental regions of the world famous for intermediate focus earthquakes with large concentration of the events characterized by a negative Bouguer gravity anomaly. As many as 10 large earthquakes $M > 7.0$ had occurred during the last 100 + years since 1897. A depth section of the earthquakes along NNE-SSW strike direction of the ranges, describes an intense activity, more or less uniformly down to a depth of about 200 km. But an interestingly striking feature is conspicuous beyond the latitude $26^\circ$ N, wherein a marked shallowing of the seismic activity is seen where collision process has taken over the subduction process (Mitchell and McKerrow, 1975; Kayal, 1989 and 1996a). It is evident from two vertical cross sections of the earthquakes transverse to the direction of the strike of the Indo-Burman Ranges, which falls to the south $26^\circ$ N latitude, shows a 40-45 degree dipping envelope of seismic zone called the Benioff zone. The upper boundary of the envelope demarcates normal faulting in the subducting plate, and thrust faulting as well as strike-slip faulting in the overriding plate (Kayal, 1996a and 1998). The lower boundary completes the envelope of the seismic zone or the Benioff zone. The thickness of the Benioff zone varies from 40 to 45 km. There is conformity between the structure of the Benioff zone structure and the observed Bouguer gravity anomaly (Kayal, 1989 and 1996a).

The foci distribution in the inclined seismic zone suggests that depth of penetration of the subducting lithosphere is about 200 km in the central part of the Indo-Burman Ranges, and about 150 km to the south. The volcanic arc position corresponds to the deepest part of the Benioff zone. The shallower seismicity in the Burmese platelet to the east of the Benioff zone is related to the overriding-plate
seismicity and the shallower seismicity to the west of the Benioff zone is related to the plate boundary/intraplate seismicity in the Indian plate (Kayal, 1996a).

The absence of intermediate focus events beyond about 26° N marks the northern limit of the Burmese arc. In the southern extremity of the arc (south of 20° N and north of 14° N), no well constrained hypocentres with depths greater than 50 km have been observed, and as such it is not possible to characterise the shape of the Benioff zone in this part of the arc (Ni et al., 1989; Kumar and Rao, 1995). This probably marks the transition zone between the Burma arc and the Andaman-Sunda arc (Kayal et al., 2004).

The earthquakes in the Indo-Burman Ranges and its adjoining areas can be categorized as (a) plate-boundary events, (b) Benioff-zone earthquakes and (c) overriding-plate earthquakes. Source mechanism studies depthwise reveals that within the Benioff zone (depth ≤ 90 km) show normal faulting as well as strike-slip faulting due to tension in the zone where the plate flexes or bends. The events which occur in the deeper level (> 90 km) in the Benioff zone show thrust/reverse faulting due to triggering of compressional force for increasing strength of the rocks/gravity loading of the subducted Indian plate at deeper depth. The shallower events in the overriding Burmese plate show thrust faulting as well as strike-slip faulting. The thrust faulting is caused due to interaction of the overriding plate with the subducting plate setting in the compressional force. The strike slip faulting is caused by the regional compression and internal tension within the overriding plate; the strike slip faulting mostly occurs on the Sagaing transform fault. The depth below 90 km assumes a significant role as it segregates the regime responsible for the normal fault and strike slip fault at the shallower depth (< 90 km) from that of the thrust/reverse faulting within the slab at greater depth (> 90 km) (Rao and Kalpana, 2005). This depth level has been proposed
by Kumar and Rao (1995) as the zone of contact between the Indian and Burmese lithospheres.

### 3.3.3 Shillong Plateau and Assam Valley

Shillong plateau and Mikir hills shows a high seismic activity as compared to the Assam valley. There are reports of three large earthquakes of M > 7.0 which occurred in the the Shillong-Mikir zone of which the most notable ones is 1897 magnitude 8.7 great Shillong plateau earthquake. As evident from the depth section studies it is may be inferred that the seismogenic depth of the plateau is around 50 km. The large/damaging earthquake of magnitude 7.1 of July 2, 1930 occurred on the Dhubri fault, at the western margin of the Shillong Plateau. The Dauki fault registered an earthquake of M 7.1 on September 9, 1923 and both the earthquakes were estimated to have occurred at around 50 km of depth.

The seismic activity in the Assam valley is sparse. The upper Assam area is known for its seismic quiescence, and Khattri and Wyss (1978) has designated this area as the Assam Gap for a large impending earthquake. However, Mukhopadhyay (1984) and Kayal (1996a) identified this zone as aseismic; Kayal (1996a) named it as aseismic corridor. The trend of this aseismic zone is conformable with the NE-SW trend of the upper Assam valley. This zone is about 100 km wide and 300 km in length.

The Shillong Plateau and the Mikir Hills although is an extension of the Indian shield, the seismic activity is much higher as compared to the other parts of the the shield area of the peninsular India. Initially, the earthquakes in this tectonic domain were referred to as plate-boundary earthquakes due to their location within the Himalayan Mountain Chain to the north and the Arakan Yoma (Indo-Burma Mountain Chain) to the east. Chen and Molnar (1990), concluded that earthquakes also occur
within the "diffuse zone of convergence’ extending from the foothills of the Himalaya to south of the Shillong Plateau. Kayal (2001), referred to the Shillong Plateau earthquakes as connected to intraplate seismicity extending over an area of 100 km wide and goes down to a maximum depth of 50 km in to the uppermost mantle but the seismic activity is, however, maximum in the lower crust (20-30 km) beneath Shillong Plateau. This phenomenon has been regarded to be typical of recent continental convergence where in an aseismic lower crust seems to straddle between the seismically active lower crust and the uppermost mantle (Chen and Molnar, 1983). This kind of observations has also been made for the Shillong Plateau region from studies based on microearthquake data (Kayal, 2001). Kayal (1987) and Kayal and De (1991) argued that for the plateau region microearthquake activity at a depth range of 10~35 km with maximum activity at 20~30 km, and a few as deep as 50-55 km, but almost no activity between 35-45 km. These studies suggest that two layers of seismicity exist beneath the Plateau. The lower crust is most active and some activity is found in the uppermost mantle. Bilham and England (2001), proposed the pop-up tectonics of the Shillong Plateau and stated that the the north dipping Dauki fault and south dipping Oldham fault are the two boundary faults for the pop-up tectonics. They, however, suggested that south dipping fault at the boundary of the Shillong Plateau and the Brahmaputra valley was the causative fault for the 1897 great earthquake.

Seismic tomography studies reveal low velocity zone (LVZ) at shallow depth 0-10 km and these are comparable to the surface faults in the Plateau region (Kayal and Zhao, 1998; Bhattacharya et al., 2006). High velocity zones (HVZs) are prominent in the lower crust and in the upper mantle. The high velocity structures in the lower crust are identified as the source areas for stress accumulation for
generating earthquakes beneath the plateau. High isostatic anomaly (Verma and Mukhopadhyay, 1977), high Pn velocity (Kayal and De, 1987; Rai et al., 1999b) are reported in the area, which require support of a large excess mass beneath the plateau either by dynamic process underlying the mantle or by strong lithosphere (e.g. Chen and Molnar, 1990; Rai et al., 1999b).

It is interesting to note that the microearthquake activity is delimited to the north of Dapsi thrust. Also the high intensity zone of the 1897 great Shillong earthquake was also delimited by the Dapsi thrust. At the fault end of the Dapsi thrust lies a HVZ at 20-30 km depth, which may be the stress concentrator, the source area, in the lower crust for the plateau earthquakes.

Studies carried out by Bhattacharya et al. (2002) and Bhattacharya and Kayal, 2003 revealed that an intense seismic activity beneath the 300-400 km long Kopili fault from south of the Mikir hills to Arunachal Himalaya. Tomographic images revealed that a prominent HVZ in the lower crust at the ‘fault end’. This HVZ has been related to be source area, stress concentrator, for the earthquakes along the Kopili fault. High b-value and high fractal dimensions are also identified in this zone. The seismogenic zone beneath the Kopili fault is well reflected in the b-value and fractal dimension maps, and may be identified as a high risk zone for an impending large earthquake in the area (Bhattacharya and Kayal, 2003; Kayal et al., 2006).

Kayal et al.(2006), studied the seismic activity of the Kopili fault zone and came out with the conclusion that seismic activity is more intense and base of the seismic zone extends down to depth of 45 km. The entire Kopili fault zone is, however, dominated by normal/strike-slip faulting, unlike the thrust/ strike-slip faulting earthquakes at the Dapsi/Brahmaputra fault zone in the western plateau where
‘pop-up’ tectonics is dominated. The Kopili fault zone is thought to extend transversely below the Himalaya (Kayal, 2001; Bhattacharya et al., 2002).

### 3.3.4 Bengal Basin and Tripura Fold Belt

A low level of seismic activity is witnessed for the Bengal basin whereas a moderate level of activity is observed for the Tripura fold belt. The seismic activity of Bengal basin is governed by intraplate seismicity. Among the major earthquakes, m\text{b} 7.6 event of 8 July, 1918 was sourced in the Bengal basin. The epicentre of this event is traced to the Srimangal area, Bangladesh. The activity in the Tripura fold belt may be related to the plate-boundary activity. Previous records say that an earthquake of M\text{L} 5.8 known as the 1984 Cachar earthquake occurred in the Tripura fold belt. Similarly very recently an earthquake measuring M\text{D} 5.5 occurred on 3 January, 2017 in the Ambasa area of Tripura.

The portion of the Indian plate beneath the Bengal basin is seismically less active; there are reports of a few mantle earthquakes (Chen and Molnar, 1990). Some seismic activity is observed to be associated with the Tripura fold belt which is interpreted to be the consequence of plate-boundary activity, since the area under consideration is in proximity to the Burmese arc (Kayal, 1996a). The reasons attributed to the low seismic activity in the Bengal basin are the intraplate activity (Kayal, 2001) and the thick cover of sediments. A locked portion of the Indian plate below this basin was propounded by Kayal, 1989 and 1996a. The gigantic E-W Dauki fault is probably the surface expression of the lateral segmentation of the Indian plate which is locked beneath the Bengal basin and unlocked below the Shillong plateau and the Tripura fold belt. About ~ 20 km thick sediments of the Bengal basin is well reflected as LVZ. Verma and Mukopadhyay (1977) using gravity observations estimated the sediment thickness of about 13 km. Metivier et al. (1999), on the other
hand, reported the Cenozoic sediments which may go down to 22 km and this observation is substantiated by tomographic results. Due to thicker sediments, the crustal activity is much less. A few deeper earthquakes M > 4.5 in the lower crust/mantle are, however, recorded below the Bengal basin. An earthquake recorded by digital network in northeastern India showed its location in the Bengal basin with strike slip faulting which is correlated with the Sylhet fault; the compressional stress is nearly in the NNE-SSW direction, compatible with the direction of plate motion.

Chen and Molnar (1990), using teleseismic data studied three medium magnitude (M 4.0 ~ 5.0) earthquakes in this zone show broadly an NNE-SSW compressional stress, which is also comparable with the motion of the Indian plate in the NNE direction. One of the events falls south of the Dauki fault and it could not be associated with the Dauki fault for the reasons cited above. Similarly other two events which fall in the Tripura fold belt cannot be related to the local trend of fold and faults (Chen and Molnar, 1990). The northeast dipping nodal planes are the likely fault planes, and these are oblique to local fold trends. The NNE-SSW compressional stress is the dominant stress regime in this zone.