CHAPTER I
INTRODUCTION

1.1 BACKGROUND:

Northeast India is lying at the juncture of the Himalayan arc to the south and Burmese Arc to the east, and is one of the most seismically active intracontinental regions of the world. The region was rocked by 18 large earthquakes (M7) and two great earthquakes (M>8.0) during the last 100 years. The 1897 great Shillong earthquake is the first instrumentally recorded earthquake in the country. Since 1964, with the inception of WWSSN and increase of local networks, location quality of the epicenters is much more improved. In recent years, since early 1980 several temporary micro earthquake networks are operating along with the earthquake precursor investigations in selected areas of the region.

The North-Eastern region, comprising part of the Indian plate displays an interesting seismotectonic setup in the light of Plate Tectonic Theory, where the Indian plate is subducted below the Burmese plate since Tertiary time and still the subduction is active. Manipur, in particular, in this context forms the major part of the Nagaland-Manipur- Ophiolite Belt extending SE into Myanmar and is a classic
example of the subducted zone, and is manifested in the form of a very long ophiolite belt extending for a length of 200 km from Nagaland to Myanmar through Manipur. There are many geological and structural evidences in this region indicating an active eastward subduction of the Indian Plate beneath the Myanmar Plate. The presence of the subducted Indian Plate is confirmed by the occurrence of the dismembered ophiolite suite of rocks with tectonic mélange and associated exotic rocks and is manifested in the widespread distinction of the micro-meso to macro seismicity.
It is well known that, forces acting at the source of an earthquake can be derived from seismograms, by knowing the effects of the seismic waves that have experienced by traveling from source to seismic receiver. Magnetic anomalies provide a measure of the rate of motion, while the earthquake source mechanisms supplement it with the direction of the relative motion of the plate. The source mechanism studies are being widely used in comprehending the active tectonic processes, which are far more complex in a small-scale rather than on the global tectonics. Monitoring of earthquakes and their characterization in the regard to the tectonic setup has thus become essential. In order to corroborate this, an attempt has been made to study, analysis and correlate the seismicity of the region with the general tectonics of the region.

The characterization of space-time evolution of ruptures produced by large earthquake, their fundamental implication, cycles, seismic hazards and damage pattern is a critical requirement for understanding the earthquake mechanism. Seismotectonics, the relationship between earthquake occurrence and tectonic processes, has played a major role in developing and understanding the geology of the region. Shallow – depth earthquakes are manifestations of local tectonic movements of the crust, and are basically mechanical phenomenon. The seismogenic preparation of strong earthquakes seems to be associated with large-scale diastrophism, and even with material motion within mantle, while the concrete conditions for strong earthquake generation depend principally upon the physical properties, structures and state of stress of the crust.

Therefore, it is required to study the relationship between various layers within the crust and focal depth distributions. In order to understand the seismotectonic setup of Manipur, the seismic data (acquired from seismic network of Manipur) are analyzed for the determination of seismic attenuation, source
parameters, fault plane solutions and crustal structure and to relate with lithotectonic setup of the region. It helps to decipher the present subduction trends.

1.2 LOCATION AND ACCESSIBILITY:

Manipur is located in the northeastern region of India and falls under parallels 23.5°N to 25.75°N and meridian 93°E to 94.75°E. It encompasses an area of 23,000 sq. km approximately and its capital Imphal is linked by air and surface with rest of the country. As the geographical extent of the subduction Belt encompasses large area, the present study extends beyond Manipur, covering a major part of NE India and the western part of Myanmar.

![Physiographic map of the study area.](image)

Fig. 1.2. Physiographic map of the study area.

1.3 PHYSIOGRAPHY:

Major part of the area is made up of hills constituting the southern extension of Naga hills. The southern hill ranges in the physiographic divisions include Patkai, the Naga, the Barail hills, the high land of Manipur and Lushai hills. The entire region is highly undulating except with a central valley nearly 45 km long.
trending N-S and is 20 Km wide, with an average elevation of 780 m (msl) approximately, surrounded by high hills. The Patkai and the Naga ranges form water-divide between India and Burma (Fig. 1.2).

Fig. 1.3. Generalized tectonic map of the study area.

1.4 PREVIOUS WORK:

1.4.1 Geology and Tectonic Setup:

The tectonic setting of the study area, i.e, Manipur and its adjoining areas is shown in Fig. 1.3. The prominent features are the Indo-Myanmar Ranges, comprising Naga Hills, Chin Hills and the Arakan-Yoma, which is believed to be
formed during Oligocene as a result of eastward subduction of the Indian plate beneath the Burmese Plate (Brunnschweiller, 1966).

In order to understand the subsurface geology, a number of workers (Evans and Crompton, 1964; Gulattee, 1956; Verma, 1976; Nandy, 1986) interpreted the gravity data. The gravity pattern follows the tectonic trend in this region. The E-W trend of anomaly is the characteristic trend of Himalayas. Meghalaya plateau and Mikir hills follow the E-W closures. The westerly convex N-S trend eastward over the Surma Basin, Indo-Myanmar Orogen and Central Myanmar Basin. The gravity patterns indicate gradual increase in thickness attaining along the Chindwin Syncline. The Sagang Fault is also discernable through gravity data. The subduction zone is characterized by NNE-SSW to N-S anomaly of gravity data (Fig. 1.4).

Fig. 1.4. Bouguer anomaly map of the study area. The contours values are in mgal (after Nandy, 1986)

The northeastern part of India including Bengal, Northeastern Himalaya, Shillong Plateau (Chouhan et al., 1965) and adjoining Myanmar and Chinese region,
is seismically most active. Several major earthquakes manifest the high level of seismic activity, during past two hundred years and the present level of micro earthquake activity is related to the tectonic framework of the region. The Indo Myanmar Ranges (IMR) is considered to be the northern prolongation of Indonesian island, which in turn is linked up northward with the eastern end of the Himalayas. The IMR is divided into three parts from north to south viz. the Naga-Patkai Hills, the Chin Hills and Arakan-Yoma Hills. The northeastern region of the Indian Plate consists of the Indo Myanmar Ranges of Late Mesozoic Ophiolite rocks along tectonised belts, e.g., Indus Tsangpo zone and Naga-Arakan-Yoma-Andaman belt. The N-S trending 2000 km long, sigmoid Naga-Andaman belt of ophiolites, representing the basic volcanics and ultramafic rocks and closely associated with late Mesozoic oceanic sediments.

The narrow tectonised ophiolite belt is believed to represent the remnants of the Tethyan (Neo-Tethyan) oceanic crust which was largely subducted, resulting in the collision of Indo-Australian plate with Eurasian (Tibetan) and the Sunda (Cathy Asian) plates. The Naga hills representing the northern end of the IMR and the Himalayas are generally regarded to have been formed by continent-continent collision. In the southern section of IMR, the frontal collision zone forming a belt of Schuppean thrust gives place to broadly N-S trending folds belts. The weak frontal folds are still growing offshore and onshore in the eastern part of the Bay of Bengal adjacent to the Andaman Nicobar (Moore et al., 1980).

The broad geological framework of NE India including IMR and Eastern Himalayas along with their linkage with the adjoining region of southern Tibet and Myanmar are discussed on the basis of seismicity and gravity features within the frame of parallel N20° to N31° and meridian E88° to E98°. The major and significant tectonic elements recognized from the study of lineaments are as follows:
In the Bengal basin, the important faults are NW-SE and NE-SW trending with fractures running parallel to it. There is a N-S trending fault passing through the western margin of the Shillong Plateau. The continuation of this lineament is envisaged further north. The E-W trending Dauki fault separates the Bengal basin from the Shillong massif with a thin cover. The NW-SE trending Kopili fault passing in between Shillong and Mikir Massif can be traced from the Naga-Arakan-Yoma thrusts belt to Tibet across Brahmaputra alluvium. The Naga-Arakan-Yoma arcuate fold belt is traversed by NW-SE and NE-SW faults and fractures. The eastern margin is affected by a series of thrusts and further east lies at the central Burma Tertiary Molasse basin and Shan plateau. The inner Myitkyina and Mandalay Ophiolite belt is truncated by Shan fault to the north, Mishmi Hills occupying the north eastern corner of the India has NW-SE trending high angle frontal thrusts viz, the Mishmi thrust and Lohit thrust besides other lineaments having the same trend (Nandy, 1973, 1981).

The Bouguer anomaly map prepared by Nandy (1986) for the region shows the following features:

a. The anomaly varies from +40 mgal in the southern margin of Shillong Plateau to −550 mgal in the Trans Himalayan region.

b. The contour in general, run E-W with a minor kink along the belt of Schuppean and a major deflection along the Tsangpo suture. The gradient is flat to gentle in the Lesser Himalayan zone north of MBT.

c. The steep gravity gradient across the southern margin of Shillong Plateau significantly marks the contact of thick sedimentary pile in northern Bengal Basin and Sylhet Trap along the Dauki fault.

d. The northeastern corner of the Bengal Basin is characterized by E-W elongated contour with a minima of −70 mgals of northeast of Dhacca, whereas in the main Bengal Basin, the contour trend NE-SW with values varying from −20 to 30 mgals.

e. In south, Burma Basin, Naga-Arakan belt and Central Burma Molasse Basin, the arcuate gravity contours parallels the tectonic trend.

f. The zone between the eastern margin of Indo-Myanmar Orogen and Central Volcanic line is characterized by a gravity minima with the lowest value of −175 mgal.
1.4.2 Seismicity:

Northeast India is considered to be one of the six most potential sites of strong earthquakes in the world. Earthquakes in this belt (Fig. 1.5) are shallow to intermediate depth (up to 200 kms). The focal depths increase towards Myanmar where the continental land mass is subducting eastwards. Earthquakes of this region are mainly due to Main Boundary Thrust (MBT), Naga Thrust, Haalong Thrust, Dauki

![Seismicity Map](image)

**Fig. 1.5.** Seismicity map of the study area (ISC data from 1964 to 2000)
fault and other numerous lineaments. Focal mechanism of the earthquakes has shown Thrust-faulting, Strike-Slip and Normal faulting. Earthquakes of normal faulting are seen with focal depth less than 90 km.

Many prominent historical earthquakes like, 1897 Shillong Earthquake, 1957 Assam earthquake with magnitude more than 8 M and many earthquakes with magnitudes greater than 7m rocks the entire NE indicating the area to be seismically active.

1.4.3 Seismology:

Various attempts are made in determination of source parameters such as Brune, 1970, 1971; Savage, 1972; Tumarkin and Archukta, 1994; Beresnev and Atkinson, 1977; Archambea, 1964, 1968; Aki, 1967; Hanks and Wyss, 1972; Beresnev, 2001. There are number of models, which are useful to determine the seismic source parameters, Brune, 1970, Keilis and Brook, 1959; Gupta, 1979 and Boatwrate, 1980. A simple seismic shear wave with linear rupture propagation according to Aki (1967) shows in far-field smooth displacement and velocity spectra. The magnitude value corresponding to $M_S - \log M_0$ is linearly correlated (Kanamori, 1977). In the past decade studies of earthquakes have become increasingly focused on the details of source, path, and site processes. Detailed modeling of the nature and distribution of step during major events has become almost routine (Hartzell and Heaton, 1986; Hartzell and Iida, 1990; Wald et al., 1991; Steidl et al., 1991; Wald and Heaton, 1994). One of the most widely applied methods for characterizing the significant and stable feature of ground motion has been the stochastic model (Hanks and McGuire, 1981; Boore, 1983; Boore et al., 1992; Silva, 1992; Schneider et al., 1993; EPRI, 1993; Atkinson and Boore 1995).

There are several workers that proposed mechanisms for intrinsic absorption (Knopoff, 1964, Jackson and Anderson 1970; Marko et al., 1979;
Dziewonski, 1979). Walsh (1966) proposed functional sliding on dry surface of the cracks as attenuation mechanism. Nur (1971) proposed viscous dissipation in a zone of partially melted rock to explain the low velocity/high attenuation zone beneath the lithosphere. Marko and Nur (1979) examined the effect of partial saturation of cracks on absorption. Sato (1982) suggested that strong increase in attenuation for high frequencies is due to the travel-time (phase) fluctuations caused by velocity fluctuation. There have been many studies of scattering by distributed cracks and cavities (Vardan et al., 1978; Benites et al., 1992; Benites et al., 1997; Kibuchi 1981; Matsunami, 1990; Kawahara and Yamashita, 1992). The coda waves from small local earthquakes have been interpreted as superposition of backscattered body waves generated from numerous heterogeneities distributed randomly but uniformly in the Earth’s crust (Aki, 1969; Aki and Chouet, 1975). Attenuation of seismic waves is described by the dimensionless quantity called quality factor $Q$ (Knopoff, 1964), expressing the decay of wave amplitude during propagation in the medium. The attenuation properties of various seismic regions have been studied by a number of investigators (Aki, 1969; Aki and Chouet, 1975; Sato, 1977; Jin and Aki, 1986).

Herrman (1980), Roecker et al., (1982), Singh and Hermann (1983) shows that, in general, the high seismically active region displays low coda $Q_C$ and stable shield type structure shows high values. Gupta and Kumar (2002) made several attempts to compare the $Q_C$ for various lithotectonic regions.

1.4.4 Seismotectonics:

Several workers, with contrasting views concerning the seismotectonic of the regions, tectonic evolution and current stage are being done till today. Mitchel and Mckerraw (1975) considered the evolution of arc due to the process of eastward subducting plate of India beneath the Burmese Plate continuing form Late Cretaceous to the present. Curray et al., (1979) proposed a lenticular plate, forming the structural province in the area between the Arakan Yoma in the west and Indo China high lands.
to the east. Le Dain et al. (1984) suggested, subduction of Indian plate below Burmese arc has stamped recently or become aseismic and the hanging lithospheric slab is dragged towards north by India. Tapponnier et al. (1982) proposed that active spreading in Andaman Sea and lateral motion along the Shan-Sagaing transform fault in Myanmar. Analyzing the Seismic data, various workers have suggested that Indian plate has been actively subducting below the Burmese arc as indicated by the presence of well defined Benioff zone (Santo, 1969; Das and Fiban, 1975; Verma et al., 1976; Mukhopadhyay, 1984; Nandy 1986a; Mukhopadhyay and Das Gupta 1988; Ravikumar et al., 1995; Rai et al., 1996; Satyabala 1998.)

The 1100 km stretch of the Burmese arc have been examined by Mukhopadhyay and Das Gupta (1988) adding the gravity data to delineate the geometry, stress distribution of pattern of faulting within the Subduction zone. They further examined 45 focal mechanism solutions using P-wave first motion and based on the study, low angle thrust events at the upper edge of the Benioff zone and pure thrusting along shallow dipping nodal planes towards east and southeast was reported.

Das Gupta, Bhattacharya and Jana (1999) have further carried out detailed analysis of earthquakes data for the entire Myanmar - Andaman subduction zone. Rai et al., (1996) worked out the geometry of the Benioff zone in the Indo-Myanmar region from the analysis of travel time residual and focal mechanism solution and revealed the presence of non uniform Benioff zone farmed by NNE-SSW trending high velocity slab penetrating into upper mantle beneath the Indo-Myanmar orogen, Ravikumar et al., 1996 examined the stress distribute in pattern of the subducting slab in Indo-Myanmar region using the Harvard CMT data and observed that three has been a segregation of strike slip events security mostly in the upper half, separated by 90km level. The same depth also confirms the normal events to a shallow range. The P-axis azimuth corresponding to the events along the slab trend predomination NNE, while those occurring further east in the overriding slab mostly E-W to NNE. Satyabala (1998) examined 37 CMT solution earthquakes and analyzed the relationship between
the geometry of the subducting slab in predominantly tensional for shallow and intermediate depth earthquake suggesting active in the area.

1.5 Objectives:

Objectives of the present study are

i. Tectonic and structural setup of the area
ii. Determination of source parameters
iii. Coda $Q_C$ attenuation
iv. Site response $H/V$
v. Seismotectonic evaluation of the region