CHAPTER-II
GEOTECTONIC SETTINGS OF SURMA VALLEY

2.1. INTRODUCTION

Northeastern Region (NER) of India and its adjoining area is one of the most complex tectonic provinces in the world. The geographical boundary with latitude 22°-30°N and longitude 89°-98°E covers a considerable portion of NER, India. Plate boundary zone and the intraplate area are the main components of NER, India (Nandy, 2001). Among plate boundary zones, the broad tectonic domains are; (a) the Eastern Himalayan collision belt to the north, which includes the Trans-Himalayan Tethyan zone, the Andean type grano-diorite margin comprising the Main Boundary Thrust (MBT) and Main Central Thrust (MCT), (b) the Assam syntaxis zone where the Himalayan and Burmese arc meet the Mishmi Block. This zone is folded and trusted by the Lohit and Mishmi Thrust and, (c) the Indo-Burma subduction zone to the east where Indian lithosphere is believed to be subducting below Indo-Burman Ranges. The intraplate part of the region comprises the Shillong Plateau, the Mikir Hills and the Assam valley jawed between the Himalayan and Burmese arc, Tripura folded belt, Brahmaputra Valley and the intermontain depression of upper Assam (Curray et al., 1982). Besides these, Surma valley is also a complex tectonic feature comprising two active faults namely Mat and Sylhet faults. All these features with its complicated geotectonic setup as shown in Figure 2.1 (a and b) influence the NER, India to be seismically very active which can be revealed from smaller magnitude earthquakes that release sizable energy daily. During the last 100+ years the region experienced 20 large (M≥7.0) and two great earthquakes of June 12, 1897 (M≥8.5; Oldham, 1899) and August 15, 1950 (M=8.7; Poddar, 1950; Tillottson, 1953). These two great earthquakes have caused extensive destruction in the region.

Geological, tectonic, geophysical, seismotectonic and G.I.S. studies of the region are briefly reviewed in order to provide a context for the subsequent analysis and bring out the complexities of the nature of subduction which are also reflected by the seismicity and kinematics of plate motion of the Surma valley and its surrounding.
2.2 TECTONIC SETTINGS

2.2.1 Surma Basin

The Surma Basin on the western boundary of the Burma plate has undergone a complex history of tectonics. The Sylhet trough, a sub-basin of the Surma Basin, records transition from a passive rifted continental margin to a foreland basin on the margins of two mobile belts, the Indo-Burman ranges and the Himalayas (Johnson and Alam, 1991). Subsidence rate of the Sylhet trough accelerated in the Miocene epoch and increased 3-8 times from Miocene to Pliocene-Pleistocene time, mainly in response to continued encroachment of the Indo-Burman Ranges and south-directed overthrusting of the Shillong Plateau on the Dauki Fault. The time of uplift of the Shillong Plateau has been inferred from a coarsening of sediment lithology that starts in the Pliocene (Johnson and Alam, 1991) and the rate of vertical uplift has been estimated to be 2.5 ± 1 mm/yr by Bilham and England (2001). To the south of the Indo-Burma region is the Andaman spreading ridge where spreading is understood to have been initiated about 13 Ma during Mid-Miocene (Curray et al., 1979).

The Basin is bounded on the north by the Shillong-Plateau, east and southeast by the Chittagong-Tripura folded belt of the Indo-Burman ranges and to the west by the Indian Shield platform. To the South and Southwest it is open to the main part of the Bengal Basin. The topography is predominantly flat with some north-south trending ridges of twenty to several hundred meters elevation present in the northeastern border. The published bouguer anomaly map show gradual higher values (negative) towards the center of the basin. Mizoram lies in the Neogene Surma basin which is bounded by the post-Barail unconformity, subsequently faulted to the east; the E-W Dauki fault and NE-SW Disang thrust to the north and northeast; the NE-SW Sylhet fault and Barisal-Chandrapur high concealed below the alluvium of Bangladesh to the west and north-west (Nandy, 2001). To the south, the basin is extended up to the Arakan coastal area of Myanmar. Within this vast terrain of Surma valley lies Mizoram along with the states of Tripura, Cachar and Karimganj districts of Assam and western part of Manipur, Sylhet and Chittagong districts of Bangladesh and Arakan coastal zone of Myanmar. There are many NE lineaments/faults in Surma basin which show strike-slip displacement of the fold axes along them. Mizoram is
flanked by many oblique faults like Mat, Tuipui, Saitual and Sateek faults which run across the breadth of the state in NW directions and which are in turn traversed by smaller lineaments/faults at many places. Extensive work have been carried out on the seismicity of the Northeast but studies on the seismic status of Mizoram in particular is lacking.

2.2.2 Indo-Burman (Arakan-Yoma) Ranges

Indo-Burman orogen is an important geotectonic element in Assam-Arakan region. The presence of the subducted slab of the Indian plate, dipping east along the Burmese arc is well established (Das and Filson, 1975; Ravikumar, 1996, Satyabala, 1998). According to Mitchell and Mckerrow (1975), the evolution of the arc to a process of eastward subduction of Indian plate lies to the west of Myanmar folded belt.

Indo-Burmese ranges are believed to have been formed during Oligocene as a result of eastward subduction (Brunnschweiler, 1966). The bulk of these ranges are composed of thick turbiditic sequences of Cretaceous to Upper Eocene shales and sandstones, deposited on the oceanic crust to the west. The structural trends in these ranges change from NE-SW direction in the Naga hills to NW-SE direction along the Arakan Yoma and Chin hills. To the east of Eastern Boundary Thrust (EBT), there is a 200 km wide and 1400 km long Palaeogene and Neogene Central Myanmar sedimentary basin. This basin is bounded by north-south San-Sagaing fault to the east and the Sino-Myanmar highland. The study by various workers based on seismicity data suggests that the Indian plate is actively subducting below the Burmese plate as indicated by well defined Benioff zone (Das and Filson, 1975; Mukhopadhyay and Das Gupta, 1988; Rai et al., 1996 and Satyabala, 1998 etc.).

2.3 SEISMOTECTONICS IN AND AROUND SURMA VALLEY

Based on the distribution of epicenters, fault plane solutions and geotectonic features, northeastern region can be divided into five seismotectonic zones. There are Eastern Himalayan collision zone, Indo-Myanmar subduction zone, Syntaxis zone of Himalayan arc and Burmese arc (Mishmi Hills), Plate boundary zone of the Shillong Plateau and Assam Valley and Bengal Basin and Plate Boundary Zone of Tripura
Mizoram fold belt (Kayal, 1996; Nandy, 2001). Tectonic setting of Surma valley is shown in Figure 2.2. Following is the brief description of these zones.

2.3.1 Bengal Basin and Tripura-Mizoram Fold Belt

Situated in the western foreland part of the Indo-Burman orogenic belt is the Tertiary Surma Basin. The Shillong Plateau and the Sylhet Trough bound the Surma Basin in the north and, at its eastern limits, are the nearly north-south fold belts of Tripura and Chittagong Hills. The Shillong Plateau has a maximum elevation of about 2 km and is bounded to the south by the Dauki Fault. The Dauki Fault forms the contact between the Shillong Plateau and the Sylhet trough. The eastern and northern parts of the Bengal Basin have been subjected to more structural modification than the western and southern parts and a similar distribution applies to recorded seismicity (Morgan and McIntire, 1959). A number of high angle thrust faults have been recognized across the Chittagong-Tripura hills (Khan, 1991). Folds and thrusts in the Bengal Basin are also seen on the Landsat imagery (Le Dain et al., 1984; Nandy, 1980) and field investigations reveal that not only Early Tertiary rock but Pliocene and Pleistocene sediments have also been involved in the folding and underthrusting. North-South trending folds that are uplifted in the Chittagong-Tripura fold belt plunge northward into the Sylhet trough subsurface (Johnson et al., 1991) and the folds decrease in amplitude westward and are not present west of about 910, where the Sylhet fault trough merges with the main part of the Bengal Basin. Within about 40 km south of the Dauki fault, the north-trending folds in the subsurface of the Sylhet trough are deflected to a northeast trend. Marine seismic surveys show that the beds close to the seafloor are deformed over anticlinal structures without any thinning or wedging of beds over the structures (Khan, 1991). The maximum thickness of the sedimentary section in the basin is more than 10 km and it thickens further to the east to 20 km or more (Ganguly, 1997).

The main tectonic domains in this zone are E-W trending Dauki fault (which demarcates the boundary between the Meghalaya plateau and Bengal basin), NE-SW trending Sylhet fault, Gumti fault, NE-SW Hail-Hakula lineament, N-S Jamuna fault, NW-SE Padma lineament, NNW Tista fault and NW-SE Mat and Tuipui faults.

2.3.2 Indo-Myanmar Subduction Zone
The Indo-Burma subduction boundary is highly oblique to the direction of relative velocity of the Indian tectonic plate with respect to the Eurasian plate. Burma (Myanmar) is situated in a complex tectonic zone with a hyper-oblique subduction at its western boundary, a dextral transform fault on the eastern boundary, the Mishmi thrust in the north acting as a buttress and the spreading Andaman ridge in the south. The area has features of active subduction zones such as a Wadati-Benioff zone (WBZ) of earthquakes, a magmatic arc, thrust and fold belts. Although this region is seismically active, fault plane solutions of this region do not show underthrusting at the subduction interface and the P axes are oriented nearly parallel and not perpendicular to the trend of the thrust and fold belts of the region (Le Dain et al., 1984; Chen and Molnar, 1990). On this basis, even though there is no other independent evidence of a recent change in the stress regime of the Indo-Burma region, there is almost a consensus that the subduction in this region is no longer active (e.g., Guzman-Speziale and Ni, 1996). However, the region has seismicity features comparable to other active subduction zones. For example, an examination of the relationship between the Wadati-Benioff zone geometry and the principal axes of the CMT solutions showed that the degree of clustering of the T axes in the down-dip direction is comparable to that in active subduction zones around the world (Satyabala, 1998).

Seismotectonics of the region has been the focus of several studies. Early work (e.g., Fitch, 1970; Rastogi et al., 1973; Molnar et al., 1973; Chandra, 1975; Saikia, 1986) recognized an eastward dipping zone of seismicity consistent with subduction along the Burma Arc. Le Dain et al., (1984) studied active faulting and tectonics of the region by integrating information derived from Landsat imagery, historical seismicity and fault plane solutions of earthquakes from 1964 to 1977, and information available on Cenozoic and Quaternary tectonics of the region. Landsat images reveal roughly parallel, north-south trending folds often vergent to the west and with a wavelength of a few kilometers between 20-22°N near 94°E implying east-west shortening (Le Dain et al., 1984). Chen and Molnar (1990) found that the earthquakes beneath the northern Indo-Burman ranges define a gently dipping ESE zone with a depth of 30-45 km beneath the Bengal basin and of 40-90 km beneath the ranges. They inferred that these earthquakes may have occurred within the subducting Indian lithosphere and not at the interface between the subducting and overriding plates because the P axes of these earthquakes are parallel to the north-south trending.
seismic zone and the north-south trending folds of the Indo-Burman ranges. On this basis Chen and Molnar (1990) concluded that either recently or in geologic time (since 1 Ma) the orientation of maximum compression may have changed dramatically, or, more likely, the deformation in the Indo-Burman ranges is decoupled from that in the underlying Indian plate while the northward movement of the ranges must be accommodated along the Sagaing and other faults farther east. The great Assam earthquake of 1950, which occurred in the eastern Syntaxis bounding the Burma plate in the north, is understood to have occurred on a gently NNE dipping thrust fault (Molnar and Pandey, 1989).

This is a highly seismic zone in which about 10 large earthquakes (M ≥ 7.0) have occurred during the last 100 years. The depth of focus of this zone goes upto 200 km south of 26°N latitude, and north of this, the depth becomes lesser. This may be due to the subduction process, south of this latitude and collision process north of it (Mitchell and Mc Kerrow, 1975; Kayal, 1987, 1996). The structural trend in this zone swings from NE-SW in the Naga Hills to N-S along the Arakan-Yoma and Chin Hills and the main discontinuities in this zone are Naga thrust and Disang thrust.

2.4 GIS BASED TECTONIC MAP OF MIZORAM AND ITS VICINITY, SURMA VALLEY

In order to have a comprehensive idea of geologic and tectonic settings, it is essential to prepare a tectonic map based on geological field observations. Some parts of Surma valley, NER, India are inaccessible and it is difficult to conduct geological field surveys in these places. Geological Survey of India (GSI) made an attempt for the first time to produce the regional geology of the entire Northeast India and the adjoining regions with the help of remotely sensed data available as satellite imagery studied in conjunction with available geologic maps of the area (Nandy, 2001). The satellite imageries were generated by NASA, USA and are obtainable through EROS data center, USGS. All morphotectonic lineaments were drawn and their significance was evaluated later by comparing the available information on ground truth.

With the advancement of technology and information available in the internet, high quality imageries are available under certain terms and conditions for personal use and research purposes. Many of the data available online are developed by reputed private and government organizations like NASA, Google Inc., etc. The high resolution satellite imageries are generated using sophisticated instruments and
advanced techniques which make them very reliable and precise and can endure extreme close-up. The GIS maps used in this chapter are constructed using imageries taken from NASA World Wind and Google maps available free of cost for research purposes.

The GIS maps and satellite imageries depicted in this chapter are obtained from Google map (Figs. 2.1b, 2.3, 2.4) and World Wind (Fig. 2.5). Google Maps (formerly Google Local) is a web mapping service application and technology provided by Google, free (for non-commercial use), that powers many map-based services, including the Google Maps website, Google Ride Finder, Google Transit, and maps embedded on third-party websites via the Google Maps API. It offers street maps, a route planner for traveling by foot, car, or public transport and an urban business locator for numerous countries around the world. Google Maps satellite images are not in real time due to security reasons.

Google Maps uses a close variant of the Mercator projection, so it cannot show areas around the poles. Google Maps provides high-resolution satellite images for most urban areas in the United States (including Hawaii, Alaska, Puerto Rico, and the U.S. Virgin Islands), Canada, and the United Kingdom, as well as parts of Australia and many other countries. The high-resolution imagery has been used by Google Maps to cover all of Egypt's Nile Valley, Sahara desert and Sinai. Google Maps also covers many cities in the English speaking areas. Not all areas on satellite images are covered in the same resolution; less populated areas usually get less detail. Some areas may be obscured by patches of clouds.

With the introduction of an easily pannable and searchable mapping and satellite imagery tool, Google's mapping engine prompted a surge of interest in satellite imagery. Sites were established which feature satellite images of interesting natural and man-made landmarks, including such novelties as "large type" writing visible in the imagery, as well as famous stadia and unique geological formations. With the addition of contour lines to the terrain view on April 2, 2008, the application of Google map has increased manifold, especially to the community of researchers. The coordinates are reliable enough and the quality of the map is of high resolution. The GIS maps used in this chapter (Figs. 2.1b, 2.3 and 2.4) are developed using Google terrain map after careful merging.
World Wind is an open source (released under the NOSA license) virtual globe developed by NASA and the open source community for use on personal purposes. Old versions need Microsoft Windows but the more recent Java version, World Wind Java, is a cross platform and provides a suite of demo applications. The World Wind Java version was awarded NASA Software of the Year in November 2009 for 2010. The program overlays NASA and USGS satellite imagery, aerial photography, topographic maps and publicly available GIS data on 3D models of the Earth and other planets.

World Wind was released for the first time in 2004 by NASA. The latest version (1.4), developed mainly by open source community members from World Wind Central/Free Earth Foundation, had its premiere on February 14, 2007.

Apart from the Earth there are several worlds in World Wind: Moon, Mars, Venus, Jupiter (with the four Galilean moons of Io, Ganymede, Europa and Callisto) and SDSS (imagery of stars and galactics). All these worlds are available in the File menu.

Users can interact with the selected planet by rotating it, tilting the view, and zooming in and out. Five million place names, political boundaries, latitude/longitude lines, and other data can be displayed. World Wind provides the ability to browse maps and geospatial data on the internet using the OGC’s WMS servers (version 1.4 also uses WFS for downloading place names), import ESRI shapefiles and kml/kmz files. This is an example of how World Wind allows anyone to deliver their data. The resolution inside the US is high enough to clearly discern individual buildings, houses, cars (USGS Digital Ortho layer) and even the shadows of people (metropolitan areas in USGS Urban Ortho layer). The resolution outside the US is at least 15 meters per pixel.

Microsoft has allowed World Wind to incorporate Virtual Earth high resolution data for non-commercial use. World Wind uses digital elevation model (DEM) data collected by NASA's Shuttle Radar Topography Mission. This means one can view topographic features such as the Grand Canyon or Mount Everest in three dimensions. In addition, World Wind has bathymetry data which allows users to see ocean features, such as trenches and ridges, in 3D. Many people using the applications
are adding their own data and making them available through various sources, such as the World Wind Central or blogs mentioned in the link section below. All images and movies created with World Wind using Blue Marble, Landsat, or USGS public domain data can be freely modified, re-distributed, and used on web sites, even for commercial purposes.

**Figure 2.5** is prepared using NASA World Wind version 1.3, the program overlays NASA and USGS satellite imagery, aerial photography, topographic maps and GIS data on 3D models of the Earth. In this digital elevation model (DEM) map, both Sylhet fault in Bengal Basin and Mat fault in the Tripura Mizo fold belt are visible which are demarcated by red lines.

The faults and lineaments present in **Figure 2.3** are digitized separately using a software package, MAPINFO version 5.5. For digitization it is essential to define the position of geographical objects relative to a standard reference grid, which is called Geo-coding. Since the tectonic map is well demarcated by geographical coordinates (Latitudes and Longitudes), it is easier to Geo-code the map. After Geo-coding minimum 4 reference points, accurate information regarding geographical coordinates of all the ungeocoded parts of the maps can be obtained. After the process of Geo-coding any desired fault and lineaments can be extracted into a file having ASCII format. All the digitized faults and lineaments are combined into a single layer in MAPINFO and superimposed onto the base map as shown in **Figure 2.3a**, thereby obtaining the modified tectonic map (**Fig. 2.3b**) of the region. The faults and lineaments in **Figure 2.3b**, present in the Tripura-Mizo fold belt, which are observed from the high resolution GIS map are marked as A, B, C, D, E, F, G, H, I and J. It appears that these labeled faults and lineaments are not identified nor describe earlier.

The folded structure of the Arakan Yoma and the Tripura ranges are found at the junction of two moving continental plates (i.e. Indian and Burmese Plates). It is an actively deforming transgressional plate margin and associated with fold-thrust belt and is generally referred to as the Indo-Burmese fold-thrust belt or the Arakan-Yoma Orogen. This structure comprises of early Miocene and late Paleocene clastic sediment of Surma Group. The northern and eastern parts of the basin are far more complicated than the southern and western portions. The relief and complexity increases towards the east. The anticlines are commonly faulted. The folds decrease in
amplitude westward, and are not present west of about 91°, where the Sylhet trough merges with the main part of the Bengal Basin. The folded belt of Mizoram is a part of Tripura-Mizo folded belt which can be divided into a frontal sub-belt consisting of narrow box like anticlines separated by wide flat synclines of Tripura and South Assam and inner mobile belt consisting of tight linear folds of Mizoram and West Manipur. It comprises a series of sub parallel arcuate elongated doubly plunging folds arranged en-echelon with asymmetric and tight anticline and broad syncline and trending in an average North–South direction with a slight convexity towards the west. An accretionary prism best characterizes the tectonic setting of the region. The major outcrop of stratigraphic succession in Mizoram comprises of Upper and Middle Bhuban Formations.

The area is dominated by north-south trending structural systems, the prominent features is the NW- SE trending Mat fault, which cut across the entire area and divides into two distinct sections (Figs. 2.3 and 2.5). It can be easily identified when observed in satellite imageries from GIS maps obtained from NASA World Wind and Google Terrain maps. A conspicuous valley exists where the fault cuts through (Figs. 2.6 and 2.7). It is rather easy to identify this feature in the field as the fault strike in NW-SE direction, which is against the regular trend of the ridges i.e., in N-S direction. A river called ‘Mat’ flows along the fault scarp in the valley between the towns of Serchhip and Thenzawl (Fig. 2.8) from which the name, Mat fault is adopted. Almost all of the anticline in the northern part of the section has slightly west-vergent structural geometries with steeper western limbs than eastern limbs indicating an overall top-to-the-west direction of shear and tectonic transport during development of the structures. From Mat fault to the southern side, the west-vergent asymmetry of folds is less pronounced. Most of the folds within the southern part of the section appear to be symmetric, upright, sub-vertical folds. A number of the anticlines are doubly-plunging structural uplifts. Mizoram, as being a part of Bhuban formation of Surma Group and Tipam Group belonging to Miocene - Pliocene age of Tertiary Period, comprises of about 99% of sedimentary rocks. The structures are very complex and are traversed by repetitions of anticlines and synclines.