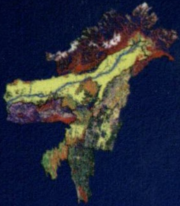

NORTH-EAST INDIA
Geo-environmental issues

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SUJIT DEKA

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Tectonic Evolution, Sedimentation and Geodynamics of North-East India

B P Duarah

Abstract

North-eastern India is a tectonically complex area possessing great scope in understanding the evolutionary processes of the earth's crust. With the advancement in the field of earth science, new concepts on the evolution processes of the region have been developing, giving a large scope for further study. Some of these issues have been addressed in the article.

Introduction

The north-eastern part of India has a unique geographical and geological disposition which invites many researchers to explore the region from different angles. The Brahmaputra valley is a wedge-shaped landlocked area, bounded to the north by the Himalayas, to the east by the Mishmi Hills and to the south by the Indo-Burma (Myanmar) Orogenic belt. It has wide openings towards the west connecting the mainland of India and Bangladesh. There is large-scale variation in the altitudes of the topography in the region from about 28 metre above m.s.l. in Dhubri to several thousand metre in the mountains of the Himalayas and Mishmi Hills (more than 7000 metre in many places), about 2500 metre in the Naga-Patkai Hill range of the Indo-Burma Orogenic Belt, about 1500 metre high Shillong Plateau to the southwestern part, and the Karbi-Anglong and North Cachar Plateau

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(Mikir Massif, Mathur and Evans, 1964) in the south central part of the Brahmaputra valley. The Brahmaputra valley has an almost flat alluvial cover with gentle slope towards the west. Its eastern part is approximately about 250 metre above m.s.l. and the valley is about 80 km wide. South of the Mikir Massif is a valley of another important river of the region, the Barak (Surma) which is also flowing from east towards west, exactly similar to the Brahmaputra, but with tortuous meanders due to shallow alluvium and peculiar dome and basin type tectonic landform which result from the position of doubly plunging anticlines and synclines respectively. There are myriads of low, round-topped hillocks scattered throughout the synclinal valleys, locally known as "*tila*" giving a typical landform in the Barak valley. In the Brahmaputra valley alluvium high level terraces are very distinct being occupied mostly by the tea gardens, and are known as Older Alluvium and chronologically older than the lower level ground occupied by the Recent Alluvium.

Lithologically the Shillong Plateau and Mikir Massif expose the Basement Complex of metamorphic and igneous rocks of Precambrian age, south and southeastern part of which possess platformal shelf facies sedimentary sequence of Upper Cretaceous (Maestrichtian) and Tertiary periods. Towards the western extremity of the plateau, near Singrimari in Garo Hills, there is an occurrence of Lower Gondwana rocks of Permian age. The Naga-Patkai range of hills are composed entirely of Tertiary sedimentary sequence of the Assam-Arakan sedimentation basin which was transgressed by sea from the late Cretaceous time and gradually occupying the entire Barak and Assam Valley, the northern boundary of that sea was defined by the Shillong Plateau, the Mikir Massif and its foreland spur extending towards northeast up to the Mishmi Hills in Arunachal Pradesh. The paleo-sea receded gradually from Miocene time towards south and southwest and fluvial sedimentation gradually overlain the marine sequences. In the Himalayas, metamorphic and igneous rocks occupy a major part, only a narrow belt of Lower Gondwanas of 4-5 km wide is located in the southern part, followed by about 10-15 km wide belt of Siwalik sedimentary rocks and their equivalents of Cenozoic (Tertiary and Pleistocene periods together) era. Though the Siwaliks are fluvial sedimentary sequence, marine Eocene sequences are also discovered in the Arunachal Himalayas (Tripathi *et al*, 1981; GSI, 1989a). The igneous activities which were very common during the long period of Precambrian time, during the Phenerozoic there was quiescence excepting the Abor volcanics (Mathur and Evans, 1964) of Arunachal Pradesh, Sylhet Traps of southern part of Meghalaya and its equivalent in Karbi Anglong, and Carbonatite Complex of the Sung valley (Krishnamurthy, 1985) and a few other places in the Shillong Plateau (Pascoe, 1968). Recent borehole data in the Bengal basin detected the continuity of the Sylhet Trap volcanism with the Rajmahal Traps due to Kerguelen plume outbursts during 107 Ma and 133 Ma, the aerial extent of this plume activity in the south has now been traced up to Bhubaneshwar (Roy, 2006). Ophiolitic mélange are found in the trans-Himalayan region and in Nagaland-Manipur plate subduction margin. The Himalayan belt is trending east-west and the other northeast-southwest trending along an arcuate belt with its convexity towards northwest. Yet another belt, the Tidding Ophiolite Belt, trending NW-SE is located along the western part of the Mishmi hills (Lohit Granitoid Complex) in Arunachal Pradesh separated by the Lohit Thrust (GSI, 1989b). Though, the earlier two are contemporaneous and genetically related, the Tiding Ophiolite belt reserves some controversy and might be equivalent to the other two or somewhat older.

Plate Tectonics and Sedimentation

The Indian Plate got separated from the main Gondwanaland towards the end of Jurassic (Fig.1.1) and gradually migrates towards the north-east and migrated a great distance by the end of Cretaceous (about 66 Ma ago, Fig.1.2). This northern migration of the Indian Plate was initiated by the development of the Tethyan Trench along the northern margin of the Tethys Ocean. Gradually, due to continued northward migration, the Tethys was shrinking and by the Eocene time north-western part of India almost came to a state of continental-continental collision with the Eurasian Plate, and the eastern part of India still remained open (Fig.1.3, Uddin and Lundberg,1998). This continent-continent collision resulted gradual uplift of the Himalayas through thrust-related crustal shortening. Towards the end of consuming the oceanic plate, the front of the Indian continental plate broke down along low-angle thrust to accommodate convergence and thrusted sheets piled up in the marginal part of the Indian continental plate, initiating the origin of the Himalayas. As a result the Indian plate flexed down and sliding beneath slivers of crust that once was part of India's northern margin. The thrust plane dips at a gentle angle of only a few degrees beneath the Lesser Himalayas, whose rocks apparently slide over a surface that once was the top of India, where plants grew and animals walked (Molnar, 1986).

The uplifted terrain initiated the development of drainage system in the rising mountains which drained towards the east. This drainage system got large sediment input from the young rising Himalayas. The Balakot Formation, located in the Hazara–Kashmir Syntaxis of Northern Pakistan, is a continental foreland basin sedimentary sequence that contains detritus eroded from the India–Eurasia suture zone and the metamorphic rocks of the Himalayas (Critelli and Garzanti, 1994) and overlies the Palaeocene shallow marine Patala Formation. The Balakot Formation has been interpreted as being by far the oldest continental sedimentary succession in the foreland basin that contains detritus from the Himalayan metamorphic belt; the start of similar sedimentation did not occur elsewhere in the basin until more than 20Ma later. As the northwestern part become land-locked with the Tibetan landmass, its northern journey was drastically retarded in this section. However, the eastern part of the Indian Plate continued migration at much faster rate due to great oceanic front before the Tibetan landmass, resulting rotation of the Indian Plate in the counter-clockwise direction. As a result the Tethys Sea was collapsing gradually from the west towards east and by the mid-Miocene time the entire Himalayas completely came out of the Tethys and the west flowing Brahmaputra river system came into existence. The continental collision was diachronous overall, and that orogenic uplift, and consequently foreland-basin evolution, initiated earlier in the western Himalayas and propagated eastward over several tens of millions of years. The ^{40}Ar-^{39}Ar dating of the detrital micas from the Balakot formation gives an age of 36–40Ma (Najman et al, 2001) which was dated before as latest Palaeocene to Mid Eocene (55–50Ma) on the basis of palaeontological evidences (Bossart and Ottiger, 1989). This raises doubt on the diachronous evolution of the foreland basin, but might not be hold as case of disapproval of diachronous status, since the already deposited oldest fluvial/continental deposits plausibly moved down the Himalayas. The early originated east flowing river is the Ganges of the present time. Both the rivers together supply sediments to the Bengal basin at present. The sediment profile of Eocene sequence from the Indus basin shows composition of quartzose detritus from the Indian block and lithofeldspathic detritus from the developing suture on the Asian margin whereas in the Bengal basin the Eocene sediments are overwhelmingly quartzose indicating no contribution from the Himalayas (Uddin and Lundberg, 1998). The initial input of Himalayan detritus to the Bengal basin was in early Miocene time. Miocene sandstones of the Surma Group yield a clear record of unroofing of the eastern Himalaya and/or the Indo-Burma ranges. There existed a Miocene fluvial system as evidenced by the lithofacies and sediment characteristics of the Tipam Group in Upper Assam with its time equivalent marine upper Surma Group in the Barak valley indicating a southwest flowing river system. This river gradually progressed towards southwest due to gradual recession of sea by that time and the fluvial sediments have been deposited in the Barak/Surma valley. Probably this river system ha been indicated by Uddin and Lundberg (1999) as paleo-Brahmaputra. The rising Himalayan front in the south forms the foreland basin, called the Siwalik basin. The part of the foreland basin contains marine Subathu formation which is gradually overlain by estuarine and later fresh water fluvial sediments. The general coarsening up Siwaliks sediments are 6 to 8 km in thickness. During the Mid-Miocene to Mid-Pliestocene (Lower to Upper Siwaliks) the orogenward part of the Ganga plain was uplifted and thrusted basinwards in several discrete steps.

As the Indian plate is flexed down, the Ganga-Brahmaputra foreland basin deepens, the initial river system of which was set in that basin was the Siwalik or the Indo-Brahm river. Its deepest part, just south of the range, is continually overthrust by the advancing Himalayas. As the basin deepens, erosion of the Himalaya provides a steady supply of new debris to keep it filled. As a result the foreland basin is shifted towards the south along with the Ganga and Brahmaputra river system. Continued thrusting episodes at the northern edge of the basin, the Siwalik sediments are plowed into folds and thrust on top of one another and are overthrust by the older rocks of the Lesser Himalaya, making the southern front of the Himalaya rise abruptly above the Indus-Ganga-Brahmaputra plains. The gentle angle at which the Lesser Himalaya got thrusted is probably responsible for the relative slow uplift of the Lesser Himalaya having gentle topography such as in the broad Kathmandu Basin. The Main Boundary Fault (MBT) seems to steepen beneath the Greater Himalaya, and consequently this portion of the Himalaya rises rapidly as India is pushed or pulled under it. The extraordinary wall of mountains of the Greater Himalaya, cut only by rare steep canyons, is probably a result of this rapid uplift, perhaps as much as 1 cm per year, outpacing erosion (Molnar, 1986). The rate of India's penetration into the rest of Asia – about 5 cm per year – has persisted for 40 million years, i.e. about 2000 km of Indian plate by now is below the Tibetan Plateau. The isostatic readjustment of this thick crust of the Eurasian plate and the underthrusting Indian plate together is the cause of the rise of the Tibetan Plateau. Probably another slice eventually will be taken from India and added to the front of the Himalaya. In fact, were India to continue its penetration for several more tens of millions of years, the entire subcontinent might be reduced to a stack of crustal slices, which like all old mountain ranges of the shield area would slowly erode away. Regardless, even at the rate that the Brahmaputra, Ganga and Indus rivers carry the Himalaya away, the mechanisms for regenerating its relief seem to be functioning reliably.

The high-relief and tectonically active Himalayan range, characterized by markedly varying climate but relatively homogeneous geology along strike, is a unique natural laboratory possessing several factors controlling the composition of orogenic sediments. Coupling of surface and tectonic processes is most evident in the eastern Namche Barwa syntaxis, where the Tsangpo-Siang-Brahmaputra river, draining a large elevated area in south Tibet, plunges down the deepest gorge on Earth. Here composition of river sands changes drastically from lithic to quartzofeldspathic. After confluence with the Lohit river, draining the Trans-Himalayan equivalent Mishmi arc batholiths, sediment composition remains remarkably constant across Assam, indicating subordinate contributions from Himalayan tributaries. Independent calculations based on petrographical, mineralogical, and geochemical data indicate that the syntaxis, representing only ~4% of total basin area, contributes 35.6% to the total Brahmaputra sediment flux, and ~20% of total detritus reaching the Bay of Bengal (Garzanti *et al*, 2004). Such huge anomalies in erosion patterns have major effects on composition of orogenic sediments, which are recorded as far as the Bengal Fan.

Rainfall, which directly controls erosion potential and sediment flux (Galy and France-Lanord, 2001) varies considerably across the belt, both from north (as low as 0.1 m/yr in arid Tibet) to south (several m/yr in north Indian rain forests), and from west (basin-wide average 0.4 m/yr for the Indus) to east (basin-wide average 1.75 m/yr for the Brahmaputra). As a consequence, average annual sediment yields increase sharply eastward, from 6500 tons/km^2 for the Indus to ~1800 tons/km^2 for the Brahmaputra, which is the big-river basin with the highest denudation rates on Earth (0.69 mm/yr). In spite of a much smaller catchment area than the Indus and the Ganga, the Brahmaputra

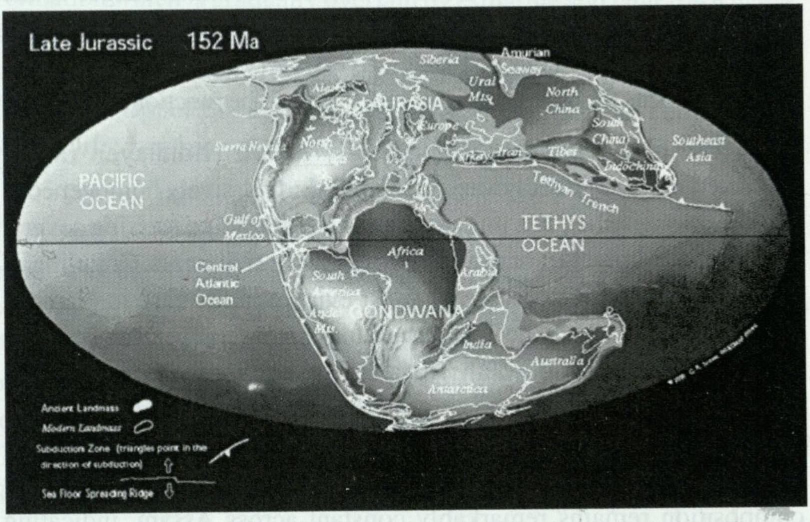
Late Jurassic 152 Ma
Amurian Seaway
Siberia
Ural Mts
North China
LAURASIA
Europe
South China
Southeast Asia
Sierra Nevada
North America
Turkey
Iran
Tibet
Indochina
Tethyan Trench
PACIFIC OCEAN
Gulf of Mexico
TETHYS OCEAN
Africa
Central Atlantic Ocean
Arabia
South America
Andes Mts
GONDWANA
India
Australia
Antarctica
Ancient Landmass
Modern Landmass
Subduction Zone (triangles point in the direction of subduction)
Sea Floor Spreading Ridge

Fig. 1.1

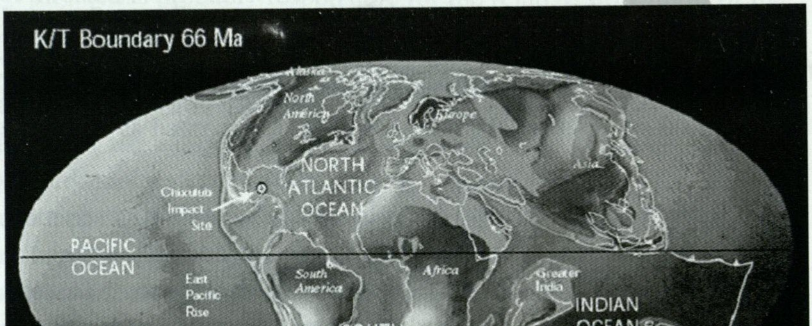
K/T Boundary 66 Ma
Alaska
North America
Europe
Asia
Chicxulub Impact Site
NORTH ATLANTIC OCEAN
PACIFIC OCEAN
East Pacific Rise
South America
Africa
Greater India
INDIAN OCEAN
SOUTH ATLANTIC OCEAN
Australia
Antarctica
Ancient Landmass
Modern Landmass
Subduction Zone (triangles point in the direction of subduction)
Sea Floor Spreading Ridge

Fig. 1.2

has a significantly larger sediment discharge (suspended load 540-1157 million tons/yr), surpassed only by the Huanghe and the Amazon.

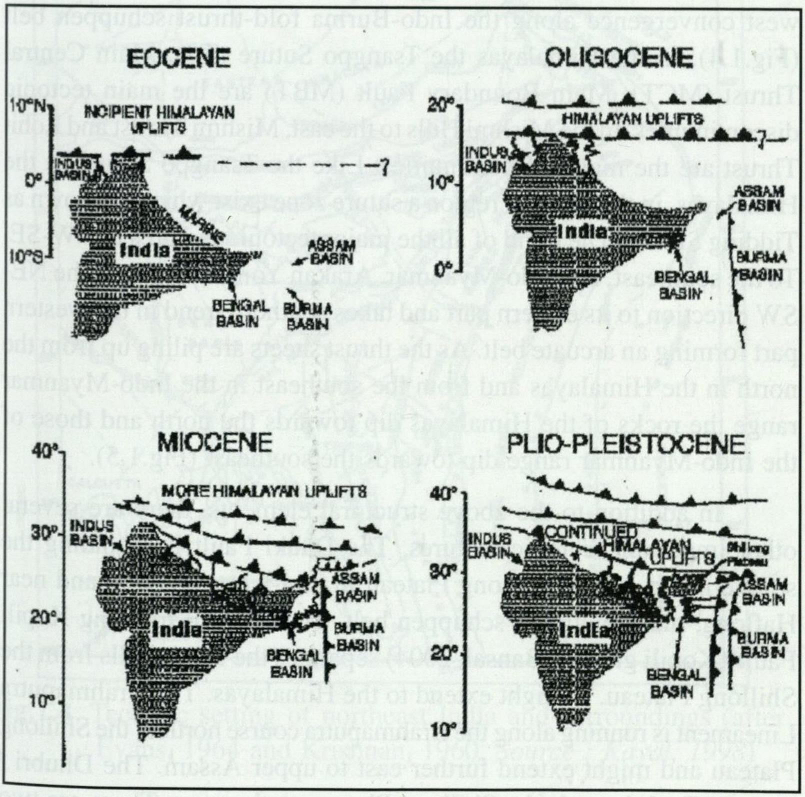

Fig.1.3 Schematic paleogeographic reconstructions of the Himalayan foreland and surrounding areas from Eocene to Pleistocene time, suggesting provenance evolution and eastward propagation of Himalayan collision. *Source : Ashraf Uddin and Neil Lundberg (1998)*

Tectonic Setting

The complex tectonic setting of the northeastern region due to north-eastward movement of India along the Himalayan arc and east-west convergence along the Indo-Burma fold-thrust schuppen belt (Fig.1.4). In the Himalayas the Tsangpo Suture (TS), Main Central Thrust (MCT), Main Boundary Fault (MBT) are the main tectonic discontinuities. In the Mishmi Hills to the east, Mishmi Thrust and Lohit Thrust are the major discontinuities. Like the Tsangpo Suture in the Himalayas, in the Mishmi region a suture zone exist which is known as Tidding Suture. The trend of all the major tectonic features is NW-SE. To the southeast, the Indo-Myanmar, Arakan Yoma extends in the NE-SW direction to its eastern part and takes southern trend in the western part forming an arcuate belt. As the thrust sheets are piling up from the north in the Himalayas and from the southeast in the Indo-Myanmar range the rocks of the Himalayas dip towards the north and those of the Indo-Myanmar range dip towards the southeast (Fig.1.5).

In addition to the above structural elements, there are several other important tectonic features. The Dauki Fault is bounding the southern part of the Shillong Plateau in east-west direction and near Haflong, meets with the schuppen belt. The NW-SE trending Kopili Fault / Kopili graben (Bansal, 2004) separates the Mikir Hills from the Shillong Plateau. It might extend to the Himalayas. The Brahmaputra Lineament is running along the Brahmaputra course north of the Shillong Plateau and might extend further east to upper Assam. The Dhubri / Jamuna Fault bounds the Shillong Plateau to the west. There are two more important faults, the Dudhnai and the Kulsi in the central part of the plateau trending NS do exist and they bear indication of recent tectonic activities (Rajendran, 2004; Sukhija *et al*, 1999) along with Chidrang Fault and Dapsi Thrust in the Garo Hills.

In the Barak valley the folded structures dominate over the thrusts due to adjustment of the Tertiary sediments due to lesser amount of plate convergence. The folds become low and wide towards the Bengal basin and dies down in the west; the entire area possesses anticlines

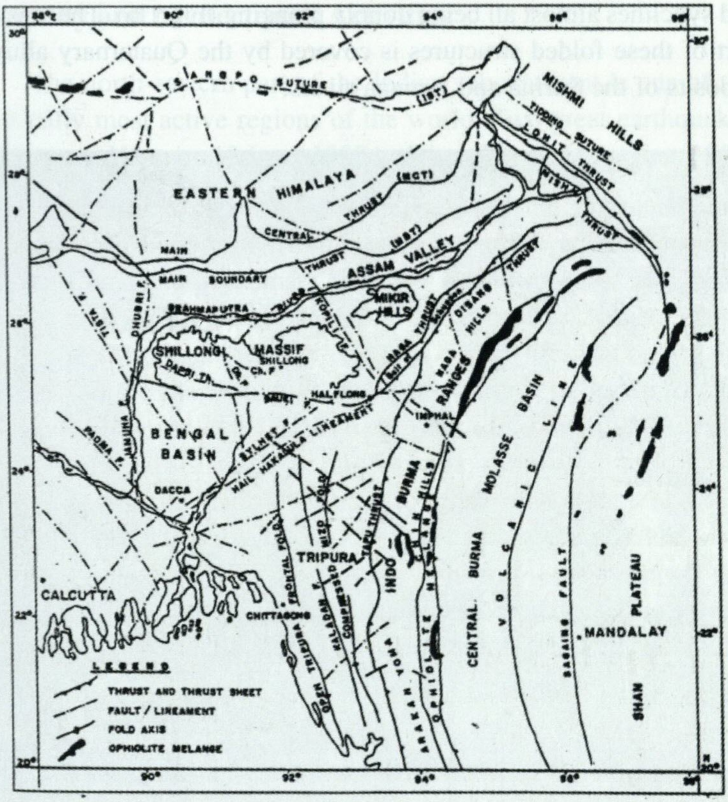

Fig.1.4 Tectonic setting of northeast India and surroundings (after Evans, 1964 and Krishnan, 1960. *Source : Kayal, 1998*)

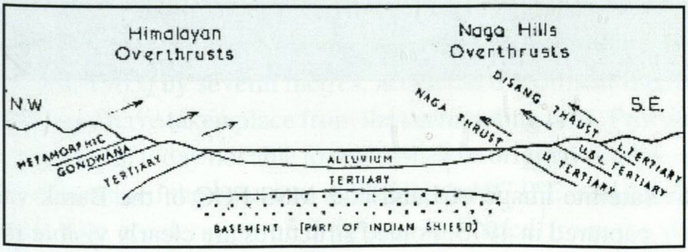

Fig.1.5 Sketch section across Upper Assam (*Source : Mathur and Evans, 1964*)

and synclines almost all being doubly plunging (Fig.1.6). The western part of these folded structures is covered by the Quaternary alluvial deposits of the Surma and Jamuna rivers.

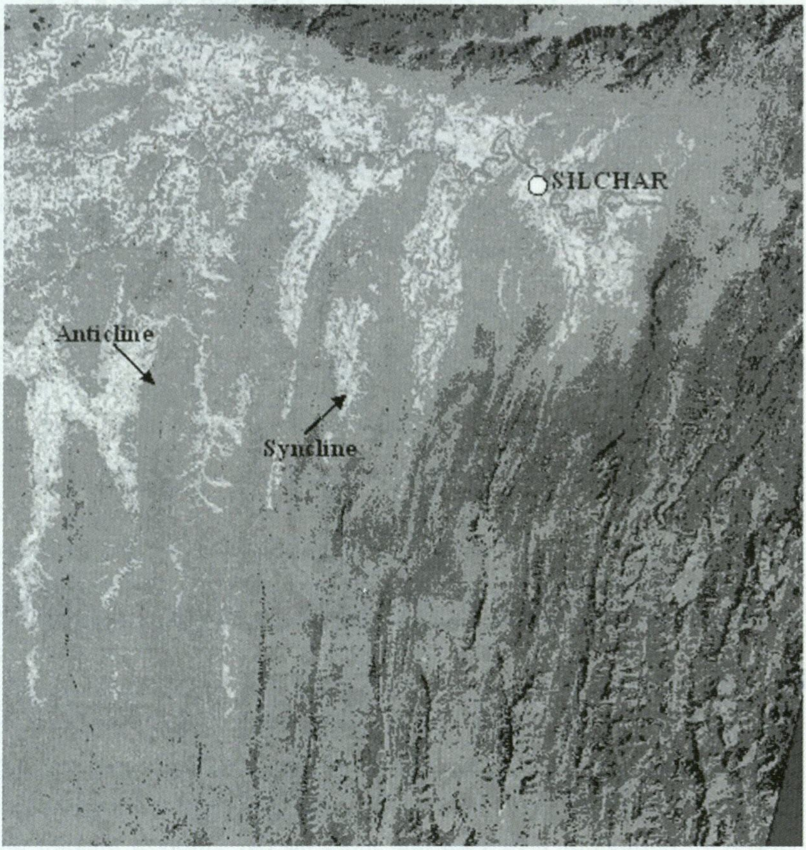

Fig.1.6 Satellite image of Landsat-2 MSS FCC of the Barak valley captured in 1975. Folded structures are clearly visible in the Tertiary folded sequence of the Assam-Arakan sedimentation basin

Seismicity and Neotectonics Activities

The north-eastern part of the Indian subcontinent is one of the seismically most active regions of the world. Two great earthquakes have occurred here on 12 June, 1897 and the other on 15 August, 1950.

The epicentre of the first earthquake was in the Shillong Plateau and the other in the eastern Mishmi region at Rima, near the tri-junction of India, China and Myanmar. The 1897 earthquake was assigned a magnitude of ~8.7 by Gutenberg (1956), an estimate based on records of Milne's instrument (Richter, 1958). Loss of life was only 1,542 compared to the magnitude. It was fortunately less because of the earthquake occurred at 5.15p.m. local time and most of the persons were outdoor, and also might be due to bamboo and wood made house-type practiced in the region. Damage to property, however, had been very great. Within an area of 30,000 square miles, all brick and stone buildings were practically destroyed. Oldham (1899) reported that acceleration resulting from the earthquake exceeded that of the gravity. There was evidence of two surface faults, Chidrang and Dudhnoi faults. These faults extended over 18-20 km with throws up to 35 feet in the crystalline rocks (Fig.1.4).

The 1950 Assam earthquake magnitude was also determined instrumentally as 8.7. The loss of life was 1,520 and was more damaging than the 1897 earthquake. Fissures and sand vents occurred (Photo-1) in many localities in the alluvial plains (Poddar, 1952; Kayal, 1998). Railway lines (Photo-2) and road suffered considerable damages. Its damaging intensity was such that the Brahmaputra river beds got uplifted (Goswami, 1985) by several metres, accelerated sediment input to the river channel have taken place from the surrounding hills. Probably the entire terrain till today not able to reestablish its original condition. The USGS determined the epicentre at 28.5ºN and 97.0ºE, and focal depth at 20km. An acceleration of 0.5g was estimated from the damage survey in the epicentral region, which is quite less than that of the 1897 great earthquake. The fault has variously been stated as normal fault

(Tandon, 1955), thrust fault (Wickens and Hodgson, 1967) and strike-slip fault (Ben-Menahem *et al*, 1974).

In addition to the above, several large / damaging earthquakes have occurred in the region, viz., Dhubri earthquake (M7.1) of July 2, 1930; Cachar earthquake (M5.8) of December 31, 1984; the Indo-Burma earthquake (M7.5) of August 6, 1988 earthquakes.

The plot of epicentres of the earthquake from 1918 to June, 2007 (fig. 1.7) shows there clustering and aligned in certain areas. These sites are located along the Indo-Burma mountain belt, syntaxial bend of the Mishmi hills, central part of the Shillong Plateau and Brahmaputra alluvium just north of it, and in the Bomdila region in the eastern Himalayas. A few points also cluster along the Kopili Fault. Based on the data distribution in the Shillong Plateau some workers believe Dauki Fault as a thrust (Bilham and England, 2001; Rajendran, 2004). Mathur and Evans (1964) consider it as a right-lateral strike slip fault and still another group belief it to be normal fault (Kayal, 1998). Bilham and England (2001) say that the Shillong Plateau had been uplifted by compressional force acting in the N-S direction along the north dipping Dauki Fault in the south and the hidden Oldham Fault trending WNW-ESE in the northern part of the Shillong Plateau. Rajendran et al (2004) supports the pop-up concept, however, raises doubts on the existence of the Oldham Fault and suggested that the Brahmaputra lineament which is located further north, north of the Brahmaputra river, a south dipping thrust fault helped the pop-up mechanism.

Photo 1 Choked well in Jorhat town in Purana Masjid (Poddar, 1952)

Photo 2 Signal point dragged about 6 feet and railway lines snapped, Saikhowaghat during the 1950 Assam Earthquake (Poddar, 1952)

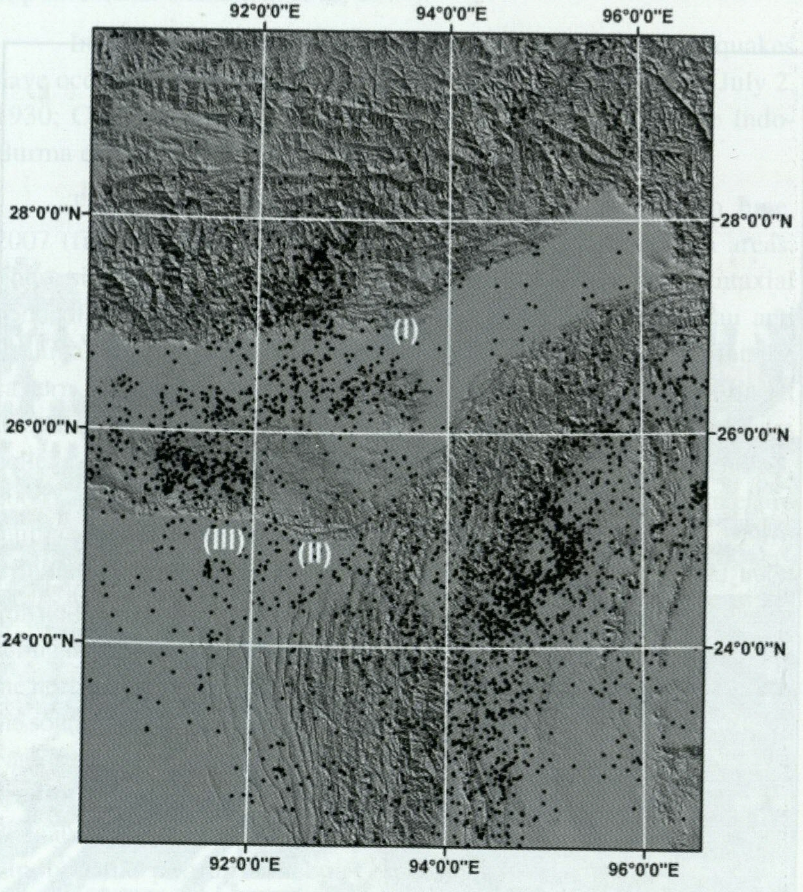

Fig.1.7 The earthquake epicentre plot for the period 1918 to June, 2007 in the northeastern part of India on SRTM mosaic image. The place marked (I), (II) and (III) are indicative of neotectonics activities, discussed elsewhere in the text. *The STRM data have been downloaded from GLCF website and epicentre data from USGS and ISC websites.*

Neotectonic activities in the area are evidenced by the present seismic activities. There are many other evidences throughout the region of neotectonics activities. The river terraces in the Lohit, Burhi Dihing, ia Bhareli river are some of the neo-tectonic activities in the region. The high-level alluvial terraces of Older Alluvium are well developed in upper Assam and in the Sonitpur district indicates the neotectonics activities during the Quaternary. A study in the Chandubi Lake in the western part of the Kamrup district gives interesting results of neotectonics activities (Duarah *et.al.*, 2007) and discussed below.

Tectonic Activities and Geomorphic Transformation of the Chandubi Lake – A Case Study

Chandubi (Sandubi) lake (*beel*) is located in the northern foothills of the Shillong Plateau and is at a distance of about 47 km south-west of Guwahati. The lake is situated in a tectonic environment in the domain of the NNE-SSW trending Kulsi Fault and where the fault cuts across the ENE-WSW linear fabric. The early Survey of India toposheet of the area shows that the lake environment prevailed along both sides of the Kulsi river (representing the "active" Kulsi Fault) during 1911-13 (Fig.1.8). The western dominant lake is called Ukiam lake and the eastern prominent lake is known as the Chandubi lake. Subsequently, the western lakes transformed into alluvial plains and the size of the Chandubi lake has been reduced as documented in the toposheet of 1967-68 survey (Fig.1.9). The Landsat-7 ETM+ image of the year 2002 shows further reduction in size of the Chandubi Lake.

The water body located in the westernmost part is the Ukiam *beel* which had an area of about 311 Ha which have been completely transformed into alluvial plains as has been recorded in the Survey of India toposheet of 1967-68 survey (Fig.1.9). The Chandubi *beel* had an area of about 1023 Ha in the year 1911 which reduced to 225 ha by the year 1967. During the period about 194 ha of water body has been transformed into marshy land. Thus, the Chandubi had diminished its effective size by 604 ha (i.e. more than 59% of the original size in 1911) within a time span of 56 years in a relatively stable plateau, where geomorphological processes are generally less active than the close-by Himalayan belt in the north of the Brahmaputra valley. At present, the lake further got its size reduced by siltation process as well as through active eutrophication. But certainly, eutrophication process cannot be held responsible for such anomalous reduction of size of the Chandubi lake as evidenced by sediment profiles along the lake margins. The Chandubi lake has been further reduced in its size in course of time and its area, as depicted in 2002 ETM+ image, is only 119 ha of water body remains (Fig.1.10) which is less than 12% size of 1911 and almost in the verse of vanishing out.

A north flowing palaeo river system located north-northeast end of the Chandubi *beel* may indicate a possible outlet of the lake through that river system (Fig.1.8), which is the general slope direction of the topography. The sand layer dated in the NE end of the lake, from three meter below the ground, close to the paleochannels, using thermolumenescence dating techniques in quartz grains, gives an age of 6780±680 years which have been corrected as 4074±570 years after measuring average dose rate as 4.27±0.60 mGy/yr (table 1.1). This, though does not give the age of the lake, it is clear that the lake is older than 4074±570 years. Perhaps the lake area has suffered from tectonic disturbances subsequently as the upper sequences of the sediments are fine clayey lacustrine deposits. Though from the present work we have not able to identify any major paleo-earthquake signature in the area, we, perhaps, may consider penultimate earthquake of 1897 Great Assam Earthquake which happen 1200 year before (Rajendran et al., 2004) which causes the development of the paleochannels blocking the upper reach of the earlier river channel, transforming it to Chandubi lake.

Table 1.1 Data on thermoluminescence dating and estimated age of the lake sediments at Chandubi lake*

Material	Average Dose Rate (mGy/yr)	Equivalent Dose (Gy)	Estimated Age (Year)
Sand	4.27 ± 0.60	17.053 ± 0.005	4074±570

**Procedures used in this analysis were similar to those described by Aitken (1985). Thermoluminescence was measured with Riso TL/OSL (model TL DA-15) reader (located at Manipur University, Imphal). The dose rate was determined on the basis of assaying Th and U by alpha counting techniques and the K content using inductively coupled plasma-atomic emission spectrometer (ICP-AES).*

There are numerous upright tree trunks located in the north-eastern part of the lake. The plausible explanation for this phenomenon is the rise of water level in the area, thus submerging the existed thick forests surrounding the lake. This is more so in the northeastern part as the topography in the area is quite low as compared to the bounded forest area to the south. This might happen in three ways – (i) due to subsidence of the area during some tectonic activities, or (ii) due to blocking of the old outlet towards the northeast; or (iii) due to combination of both. The upright tree trunks in the lake, however, support non-subsidence of the forested land. The rise of water level in the lake has been resulted from the blocking effect of the northern outlets of the lake by huge sediments transported from the hills subsequent to the 1897 earthquake; and not due to direct subsidence during the Great 1897 earthquake, which is commonly held responsible for. The evidences in support of our inference are the thick sediment profiles of coarse to medium sand in the southern part, which are lacking in the northern part. In the north, the sediment profiles, in most of the subsided areas, are thin and mainly composed of clay-sized sediments. Load structures in the sediments are very common in the southern part of the lake. However, no convincing seismites have been recorded from the southern part of the lake.

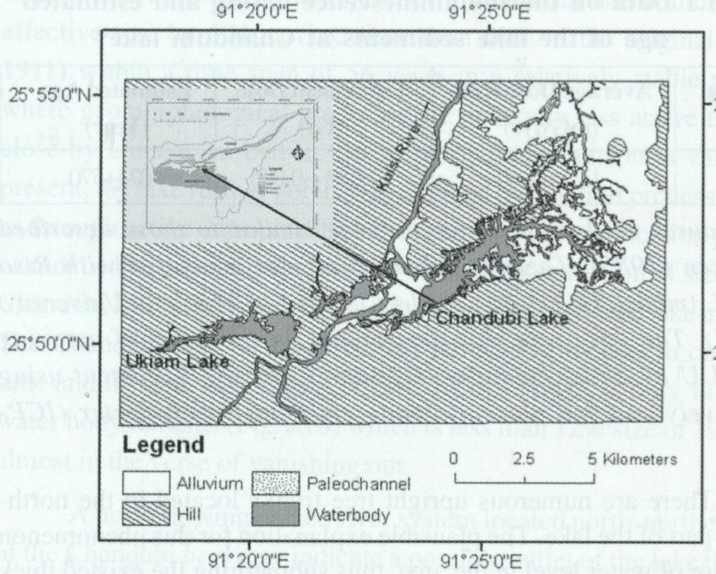

Fig.1.8 The map of the Chandubi area prepared from the Survey of India toposheet of 1911-13 (one inch to a mile). Inset is the location map of the area

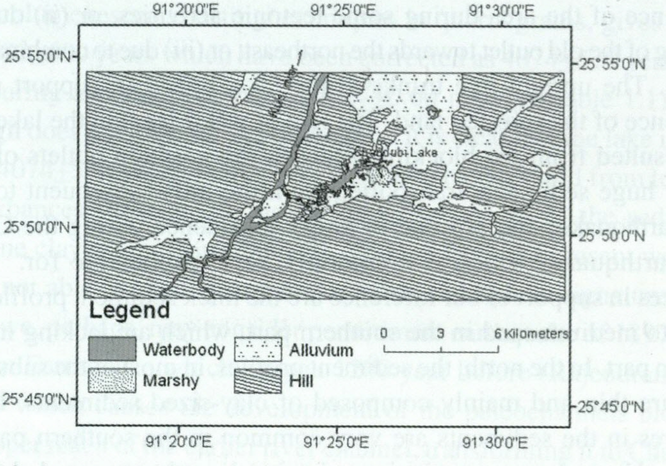

Fig.1.9 Status of the Chandubi lake during 1967-68 as depicted in the Survey of India toposheet on 1 : 50,000 scale

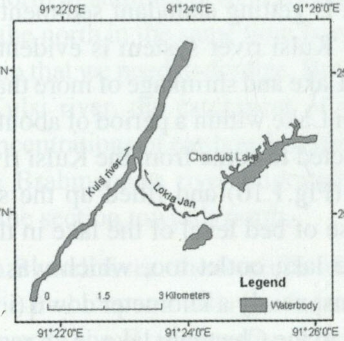

Fig.1.10 Status of the Chandubi lake in the year 2002 as interpreted from the Landsat-7 ETM+ image. *Image source : GLCF website*

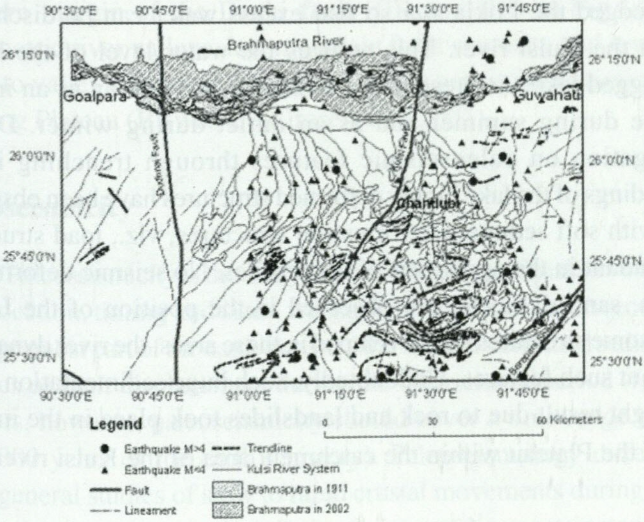

Fig.1.11 The map shows the northern migration of the Brahmaputra in the Kulsi river confluence. The hatched course is of November 2002, as interpreted from Landsat-7 ETM+ image. The dotted is a mosaic of Survey of India toposheets of the year 1911-13 and part around Goalpara of the year 1924 prepared on one inch to a mile scale. South of Brahmaputra is the catchment of the Kulsi river. Earthquakes of magnitude > 4 represent the period 1897-2001 and earthquakes of magnitude < 4 represents 1944-2000. *Seismic data source : ISC*. Data west of 91°E longitudes have not been plotted in the figure (After Duarah *et al*, 2007)

That the area is getting abundant sediment discharge from the plateau through the Kulsi river system is evident from the complete burial of the Ukiam Lake and shrinkage of more than 88% water spread area of the Chandubi Lake within a period of about 90 years. That high sediment load, expected to come from the Kulsi river, entered the lake through Lokia *Jan* (Fig.1.10) and filled up the southern part of the lake. This results rise of bed level of the lake in the area, thus raising the bed level of the lake outlet too, which was a separate channel meeting the Kulsi, just nearly a kilometer down (i.e. north of) the inlet channel of the Kulsi to the Chandubi lake. As a result water in the *beel* rises to a much higher level submerging a large area of the forest and few forest village of the area. Subsequently, as reported by the villagers, they dredged the Lokia *Jan* so that excess water can be discharged through the Kulsi river. This reduces the water level of the highly waterlogged lake. At present, the Lokia *Jan* is working as an inlet to the lake during summer and as an outlet during winter. During investigation on paleoseismic features through trenching in the surroundings of the lake highly deformed structures have been observed, along with soft sediment deformation structures, viz., load structures are abundant in the upper part of the profiles. No seismic deformation features, sand dyke etc. are observed in the position of the Ukiam lake. If some structures had developed in those areas, the river dynamism wiped out such features. Undoubtedly, such huge sedimentation in the lake might result due to rock and landslides took place in the interior parts of the Plateau within the catchment area of the Kulsi river.

Brahmaputra Migration in the Plateau Front

It has been observed that the Brahmaputra river is shifting its course to the north direction in front of the Kulsi river confluence, a tributary of the Brahmaputra, which otherwise mostly a south migrating river (Fig.1.11). Though details have not been discussed in the present work, the burial of the Chandubi lake mostly in its north - compelling it to migrate towards north in addition to its shrinkage, and migration of the Brahmaputra to the north in the same time frame seems to have an important relationship that we need to divulge. Both of them have been connected by the Kulsi river, the catchment of which envelops the area of very high concentrations of earthquake epicentres in the central plateau region. The Brahmaputra river migrated more than 5km in certain localities in the section towards north.

East of the Jia Bhareli river, the foothills of the Himalayas have protruded towards the Brahmaputra valley with smooth mountain front with its convex towards the Brahmaputra (Fig.1.7), and is due to neotectonics activity going on in the area and resulted out of stress accumulation (Das, 2004). The similar features are found along the southern margin of the Dauki fault [(II) and (III) in Fig.1.7]. The asymmetric river valleys, low mountain front sinuosity and low valley width to valley depth ratio are all indicating active neotectonics in the Shillong Plateau (Biswas and Grasemann, 2005).

Paleoseismicity

Paleoseismicity is the study of prehistorical earthquakes - especially their location, timing and size - whose signatures have been recorded in the uppermost part of the earth's crust in the form of deformed sedimentary features of fault displacement during the Quarternary period (for some workers, however, paleoseismicity should cover a time range of about last 1000 years of the earth's history). Paleoseismology differs from more general studies of slow to rapid crustal movements during the late Cenozoic (i.e. neotectonics) in its focus on the most instantaneous deformation of landforms and sediments during earthquakes. This focus permits study of the distribution of individual paleoearthquakes in space and over time periods of thousands or tens of thousands of years (McCalpin, 1996). In the northeastern part of India, the paleoseismological study is of immense potential since, the instrumental database of the region is reasonably week due to earlier poor instrumental coverage, and short time range (hardly more than 100 year). The paleoseismological study may extend time-frame for several thousand years past. Recently the palaeoseismological study has been carried out in the Shillong Plateau (Sukhija *et.al.*, 1999; Rajendran *et al.*, 2004), though the other parts almost remain untouched. The most commonly available paleoseismic signatures are developed by liquefaction process (Photos-3 and 4). The recurrence period of earthquake in the Shillong Plateau of the magnitude similar to 1897 Great Earthquake of Assam has been variously estimated as 500 years (Sukhija *et.al.*, 1999), 3000 years (Bilham and England, 2001), 1200 years (Rajendran *et al.*, 2004). Paleoseismic study in the region has been carried out by the author, and a section from the Kukurmara village, Kamrup District is discussed below.

Paleoseismic section at Kukurmara Village

Moving towards north, nearer the Brahmaputra plains near an abandoned channel section of the Kulsi river, which the local people informed as much older alluvial plains, we attempted a few trenching which gives clear evidences of seismogenic deformational as well as dyke structures. We have prepared detailed log of one of the sections along with its OSL and AMS carbon dating (Fig.1.12; Latitude $26^0 0' 32''$N : Longitude $91^0 25' 2''$ E). The Optically Stimulated Luminescence (OSL) age has been determined in quartz, grain size of 90-150 um with filtered green light from halogen bulb using Single Aliquot Regeneration method.

The calendar dates for the sections, S_0, S_1, S_2, S_3 and S_4 sand beds are 128 (73±7 yrs BP), 133 (78±8 yrs BP), 110 (55±4 yrs BP), 117 (62±8 yrs BP), 145 (90±14 yrs BP) years respectively as determined from the OSL method. The AMS carbon date for in situ tree trunks from S_1 bed yields 175 years (Fig.1.12). The dates indicate that the sediments are older then the 1897 Great Earthquake, and the dykes might results from that earthquake. From the section, it seems the sediments do not contain records of much older events, which, if present, might have been erased by the dynamic fluvial processes in the region. The sediments in the area are highly deformed and various structures have been noticed. However, the dykes are of smaller size in medium grained sediment layers. Further north, nearer to the Brahmaputra except few minor features largely the sediments are undisturbed. Similar is the case towards south of the area in and around Kulsi village. These areas have shallow bedrocks and covered by clayey red soils of the hills and are not suitable for generating seismically induced liquefaction features.

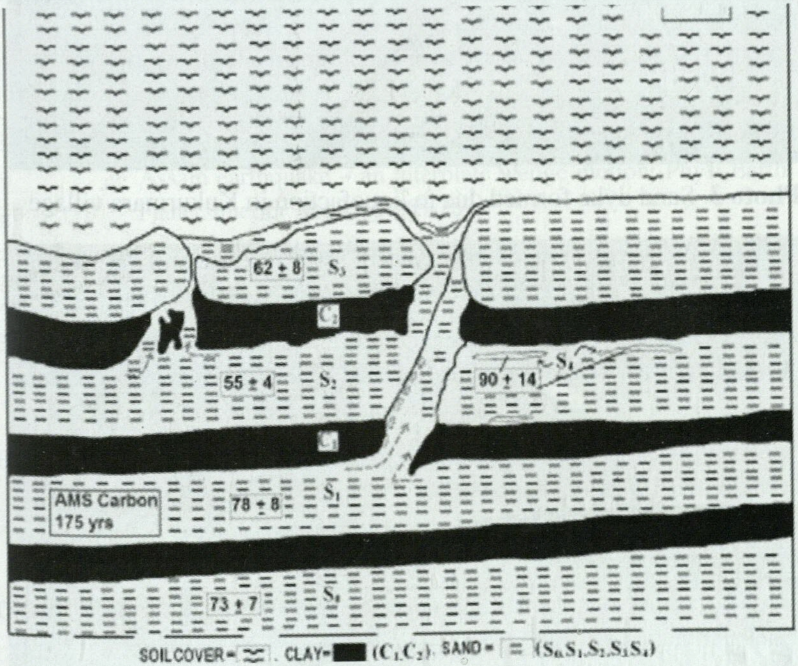

Fig.1.12 The Kukurmara trench section discussed above

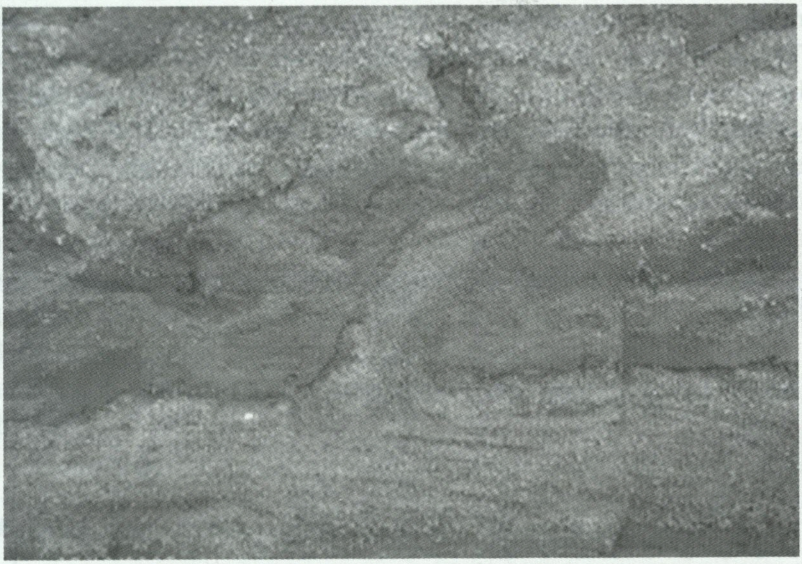

Photo 3 Sand dyke formed due to liquefaction in Kukurmara village

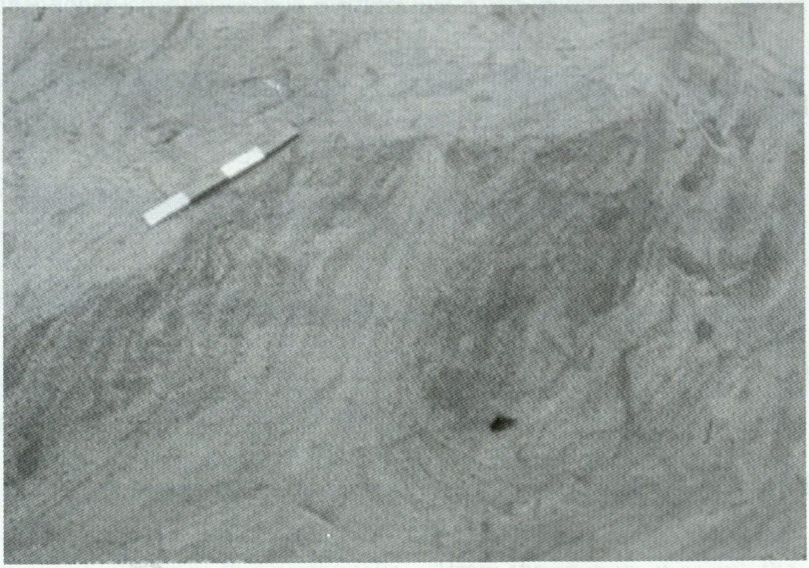

Photo 4 Sandblow structure from Rangapani, Garo Hills. (Scale 20cm)

Conclusion

The northeastern part of India has developed its complex tectonic fabric due to the northward journey of the Indian plate which collided with the Eurasian plate 40 million years ago, and the process is still continuing. A comprehensive study of tectonics in the region requires a multidimensional approach.

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