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Morphological and Microstructural Evidences of Paleo-Seisminc Occurrences in an Earthquake Prone Zone of Tripura, India

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ABSTRACT: Morphology and structure of a faulted zone not only express the present status but also preserve the evidences of early seismo-tectonic occurrences. The present paper aims to assess the morphological as well as subsurface evidences of early seismo-tectonic occurrences in an earthquake prone zone of Baromura Hill, Tripura. Tectonically this is a part of Tripura-Mizoram fold belt and fall within Zone V of BIS seismic map. In the present research the tectonic lineaments of Baromura Hill was identified by using satellite data. For that purpose, Landsat TM shortwave infrared, midwave infrared and near infrared was selected for preparing suitable band combination. A classified thermal infrared was used for final operation. From the remote sensing operation five clear tectonic lineaments were found. During the field work rock samples were collected for laboratory testing. Thin sections of the rocks show that complex stress pattern was developed during the geological past which caused strong seismo-tectonic occurrences. From the study it can be assessed that though the nature of the paleo-seismic occurrences were almost same but the level of impact varied through spatial and temporal scales due different physical properties and arrangements. It is also clear from the study that the geological evolution of this place is more complex as it seems to be. Tectonic and geomorphic processes worked together through the Tertiary and Quaternary periods and played equally important role for landform evolution.
KEY WORDS: morphology, tectonic lineament, microstructure, grain scale deformation, Baromura Hill, geomorphic process.

1 INTRODUCTION

Baromura Hill of Tripura is considered as one of the most complicated geological as well as tectonic zone of the southern extension of Purvachal range of north-eastern India. According to Alam et al. (2003) this area is a part of Chittagong-Tripura fold belt or adjoining eastern geo-tectonic province of Bengal Basin. The geological succession of this part shows that in Miocene epoch the area under review was dominated by marine-coastal environment (Dey, 2005). Evidences of marine coastal depositions like Bhuban sandstone (Early Miocene deposition), Bokabil shale (Miocene deposition), Tipam (Late Miocene to Early Pliocene deposition) and Dupitila (Late Pliocene deposition) sandstones strongly support its dynamic character during last 25 million years. Structural evidences also express silently that strong influence of tectonic activities in this are might cause the changes in landform in Tertiary–Quaternary period. Dutta (1974) also stated that Pliocene and Quaternary periods are marked by tectonic changes in wide area of northeastern India. Sea level condition of Bay of Bengal remained very dynamic through out Tertiary period (Dey, 1999) which has a prominent impact upon landform evolution in the present study area. Dey et al. (2012), Hazra et al. (2001), Dey and De (2002) and Dey (2002) remarked in their works that probably sediment deposition during the Miocene in the Bengal Basin plays a vital role for the southward shifting of shoreline which extended the land area in all the geo-tectonic provinces of Bengal Basin. With the shifting of shoreline, a different type of geomorphic and biological environment started to be developed during that time. Apart from that climatic changes might play additional roles of the relative fall of sea level. An early research by Nandi (1985) proves that depositions occurred under more hot climatic condition than the recent times. So, it is clear that the history of landform evolution in this area started during Miocene epoch. Considering the dynamic nature of the physical environment of North-East India, the present authors decided to perform a study on early seismo-tectonic characters of Baromura Hill range of Tripura (Fig. 1). The main objective of this study is to identify the sedimentary evidences of the hidden environmental dynamism of the selected study area during the geological past which is not much exposed in the contemporary scientific literatures.

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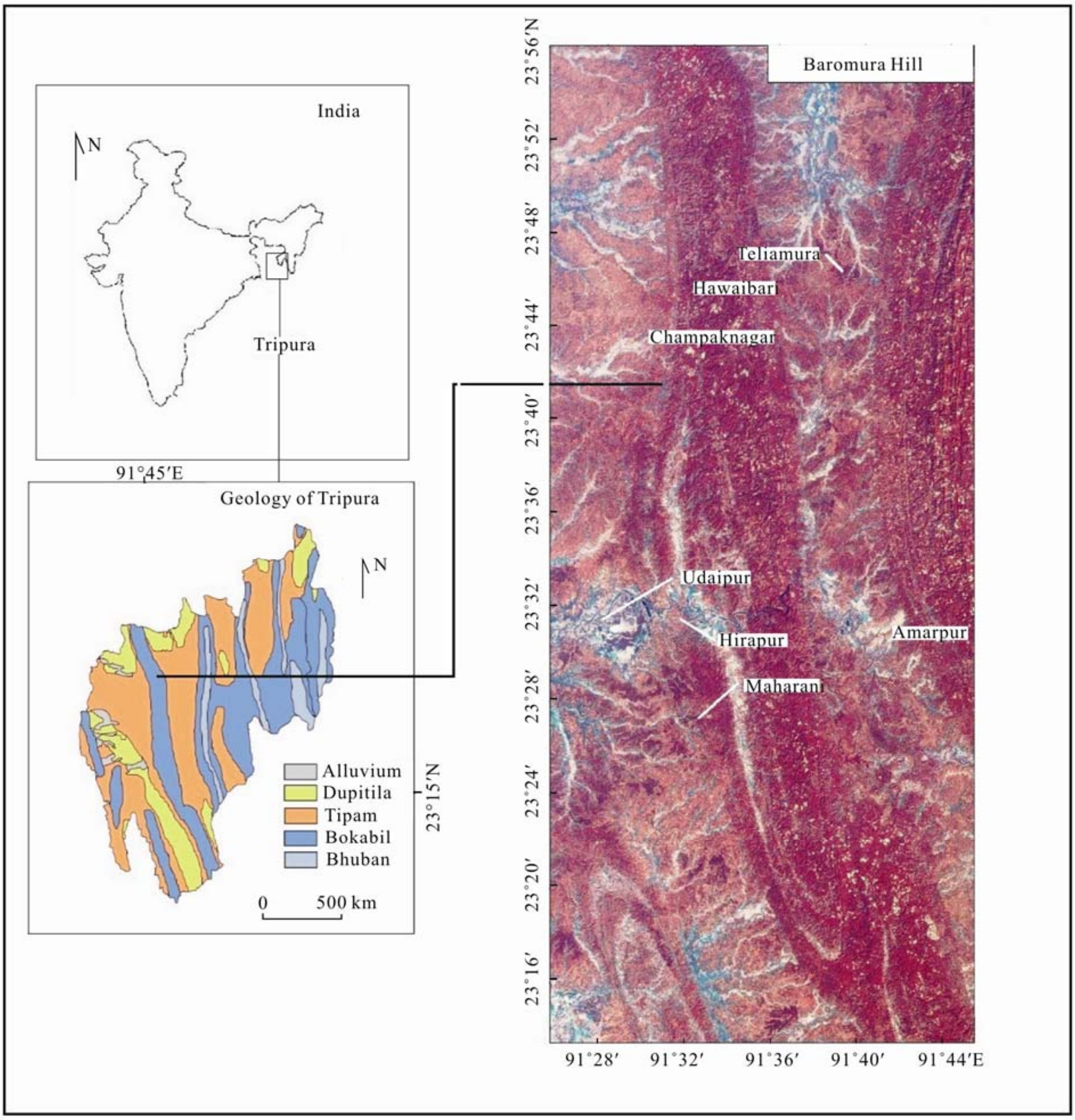

Figure 1. Location, regional geology (based on GSI map 1 : 50 000) and environs of Baromura Hill.

Table 1 Geological successions of Baromura Hill

Geological period	Epoch	Group	Formation	Lithology
Tertiary	Early Pliocene (5.3 Ma)	Tipam	-	Marine-coastal and estuarine sand rocks with shale and fossil wood.
		Line of unconformity		
	Miocene (23.3 Ma)	Surma	Bokabil	Marine-coastal Shale with minor sandstone
		Base not seen		

Source: Extracted from an unpublished report of Geological Survey of India, 2002.

2 REGIONAL GEOLOGY

Geologically Baromura Hill consists of unmetamorphosed upper tertiary sediments belonging to Surma and Tipam groups. Recent depositions are common in the study area where the anticline gradually decreases. Surma Group is represented by Bokabil Formation. In this formation alteration of grey shale and brown ferruginous calcareous sandstone is common. It is overlain by Tipam rocks in which sandstone is dominating mineral. Table 1 is showing the geology of the Baromura anticline.

3 PRESENT SEISMIC STATUS

Early studies show that most of the catastrophic earthquakes in north-east India are detected as tectonic in origin (Bhattacharjee, 1998, Kayal, 1998, 1987; Gupta, 1993; Gupta and Singh, 1989, 1986, 1982; Agarwal, 1986; Guha and Bhattacharya, 1984). Northeast India falls within the Zone V in the seismic hazard map of India updated in the year of 2000 by the Bureau of Indian Standards (BIS) and considered as seismically one of the six most active regions of the world along with Mexico, Taiwan, California, Japan and Turkey. According to the seismic zonation map prepared by Thingbaijam et al. (2008) Northeast India is divided into four broad seismic zones (Fig. 2) namely eastern Himalayas zone (EHZ), Mishmi block zone (MBZ), Eastern boundary zone (EBZ) and Shillong zone (SHZ). Tripura, a small peripheral state of northeastern India, experiences frequent seismo-tectonic occurrences over the last hundred years.

4 METHODOLOGY

4.1 Fieldwork and Sampling

Both manual observation and technical applications have been adopted for identification of a fault line in northern part of Baromura Hill. Multi sources data like Survey of India (SOI) topographical sheets (Scale: 1 : 50 000) No. 79M/9 and Geological map of Tripura (prepared by Geological Survey of India scale: 1 : 500 000 during 1970s) and Google Earth view were consulted at initial stage of the study. Various field maps were prepared during the fieldwork. Ground control points were fixed by GPS tool. The GPS was calibrated in WGS-84 (modified) that the ground control points can be used in geo-referenced satellite images with the same ellipsoid/map datum. Sediment characters and bedding patterns were also studied from the exposed structures during the fieldwork. As in the present research microstructure study is one of the main objectives, total 30 samples were collected from different places of Baromura hills. Finally 18 samples were selected for laboratory testing (9 from northern part of Baromura and 9 from the southern parts).

4.2 Identification of Morphological Signatures through Various Spectral Resolutions

In the late 20th century remote sensing has been used as a very helpful tool for assessing seismo-tectonic characters. Henderson et al. (1996) attempted to extract lineaments (faults and fractures) from aerial photographs and satellite images. Masoud and Koike (2006) used Landsat-7 ETM+/SRTM DEM for assessing lineaments and their relationship with hydro-geological

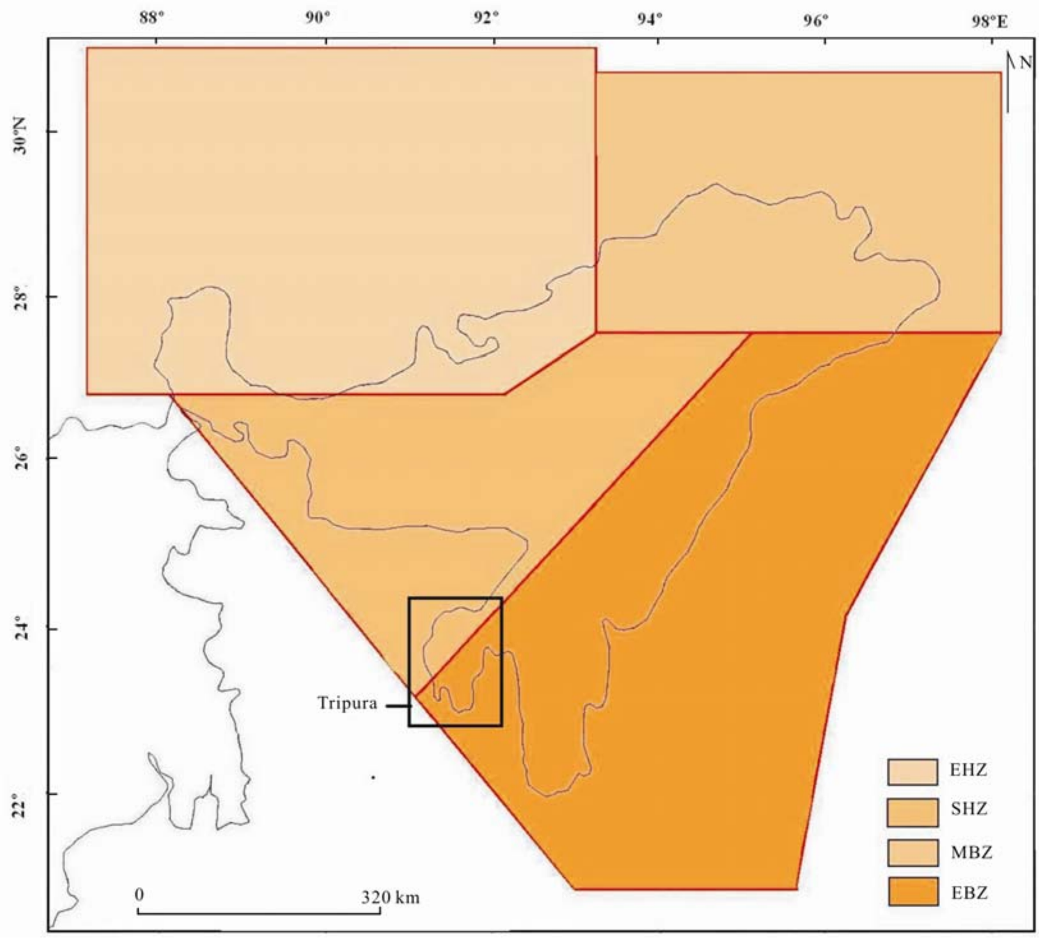

Figure 2. Seismic map of northeastern India (after Thingbaijam et al., 2008).

setting in Siwa region of Northwest Egypt. Abdullah et al. (2009) worked with Landsat-5 TM and, SPOT-5 satellite sensors and compared them for lineament mapping in Hulu Lepar area. In a very recent work Dey et al. (2009) attempted to identify the tectonic lineaments from radiometric spectral resolution. Keeping the success of the above discussed researches remote sensing technique was adopted in the present study to visualise the surface signatures of tectonic lineaments in the selected study area through different suitable spectral bands. Landsat TM data was used for digital operation (Fig. 3). In this study a specific range of electromagnetic waves from 0.76 to 2.35 μm was selected for preparing band combination which is very suitable for visualise the drainage as well as lineaments. Thus the combination of Band 7 (short-wave infrared as R), Band 5 (mid-wave infrared as G) and Band 4 (near infrared as B) was used as the base image for digital operation. As thermal radiance of the earth's surface is sensitive to the interrelated factors like vegetation cover, slope, soil moisture etc (Bernstone et al., 1997; Doran and Parkin, 1994), general thermal emission pattern of the surface was considered as an affective tool for measuring morphological signatures. In a very recent work Dey et al. (2011a, b) used superimposed thermal band and short-wave infrared band of Landsat for detecting a fault line of southern Baromura Hill which was consulted during the processing of thermal infrared band. An automated classification was done on thermal infrared band (10.40–12.50 μm) to assess the normal spatial thermal distribution pattern. Finally the band combination 7-5-4 was overlaid by classified thermal band.

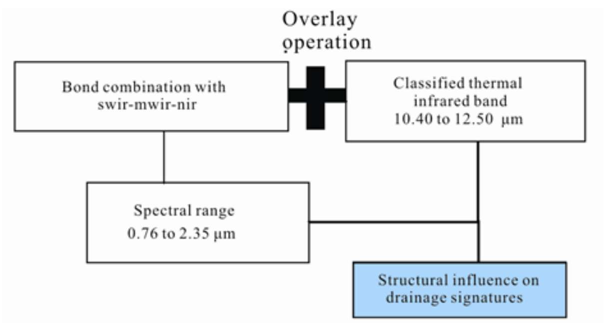

Figure 3. Flow chart showing the digital data analysis from satellite data.

4.3 Thin Section Making and Microstructure Study

Rock microstructures provide clues for the interpretation of rock history and good understanding of the physical, chemical and structural relationships of minerals (Vernon, 2004). During preparatory planning some early studies like Brewer (1976), Bale and Schmidt (1984), Katz and Thompson (1985), Wong et al. (1986), Jacquin and Adler (1987), Hansen and Skjeltrop (1988), van der Meer (1996, 1993, 1987), van der Meer and Laban (1990), Menzies and Maltman (1992), Vernon (2004), Mamtani et al (2007), Cashman et al. (2007), and Dey et al. (2011a, b), etc. were consulted. In the laboratory the present authors used different instruments like core cutting and grinding unit, lapping and polishing unit, glass stick, petrographic glass slides etc for preparing thin sections. Core cutting and grinding machine was used for initial cutting and shaping the samples. The prepared samples were dried by electric warmer under fixed 25 ℃ temperature. Resin and hardener (araldite) were used in 1 : 1 ratio for fixing the shaped and polished samples on the glass slides. Finally polishing/lapping machine was used for making thin sections.

4.4 Assessment of Grain-Scale Deformation Character

High resolution inverted microscope was used to analyzing the micro-fabric and grain scale deformation characters of the fault rocks (Table 2). Samples C7, C8, C9. C10, C11, C12 (North Baromura) and samples TP1, TP2, TP3, TP4, TP5, and TP6 (South Baromura) were used for studying the general microfabric patterns and grain order deformations. Samples C13, C14, C15 (north) and HT7, HT8, HT9 (south) are used for assessing the pattern of deformation. All the images of the samples were taken by high resolution CCD camera with 10X magnification. Brightness-contrast slicing operation was done for measuring the grain shape and grain level deformation characters.

5 RESULTS

5.1 Surface Signatures of Early Tectonic Occurrences

Geomorphologically Baromura Hill is an elongated fold area with undulating/rugged landform which can be classified into three units namely, (a) rugged landform with more than 100 m elevation and, (b) undulating area of the hill and fold fringe with less than 100 m elevation, (c) basins of the streamlets. The crest of the anticlines forms the crest of the range and the gentle deep of the flanks form the slopes of the range. The elevation and steepness of eastern slope is comparatively higher than western part. It is also very remarkable that the eastern slope of Baromura Hill is marked by very dense vegetation cover with various indigenous plant species.

A wide range of variations in structural features have been observed in Baromura Hill from north to south. The northern sector of Baromura is characterised by medium elevations. The width of the fold belt is also less than its southern part. Some prominent natural lakes (at 118 to 125 m elevation) are found in this area which are the sources of small streamlets. Elevation and width of the fold belt gradually increase towards south. The middle part is characterised by highest elevation (197 m at 23.970 416ºN latitude and 91.520 739ºE longitude) and maximum width. In this part, the extensions of the eastern and western fold limbs result wide fringes of the fold belt. Towards south the elevation again decreases.

On the basis of satellite data (spatial scale thermal variation), field observations and literature survey five clear north-south tectonic lineaments were detected (Fig. 4 and Table 3). Among those four were presented very roughly in a 1 : 50 000 geological map prepared by the Geological Survey of India during the 1970s. Udaipur fault line has been detected by Dey et al. (2009). The prominent lineaments of the northern Baromura were mentioned in this paper as West Baromura Marginal fault (WBMF), West Baromura fault (WBF) and Hawaibari fault (HF). In this area some trellis drainage pattern has been developed which supports strong tectonic influence on the

Table 2 Microstructure analysis of the selected samples

Place of sampling	Location	Name of the samples in this work	Figure numbers	Analysis done
Champaknagar, Sadhu-para, Hawaibari along NH 44	North Ba-romura Hill	C7, C8, C9, C10, C11, C12	5 and 6	Microfabric and grain scale deformation
		C13, C14, C15	7	Deformation patterns
Pitra and Hirapur area	South Ba-romura Hill	TP 1, TP2, TP3, TP4, TP5, TP6	5 and 6	Microfabric and grain scale deformation
		HT7, HT8, HT9	7	Deformation patterns

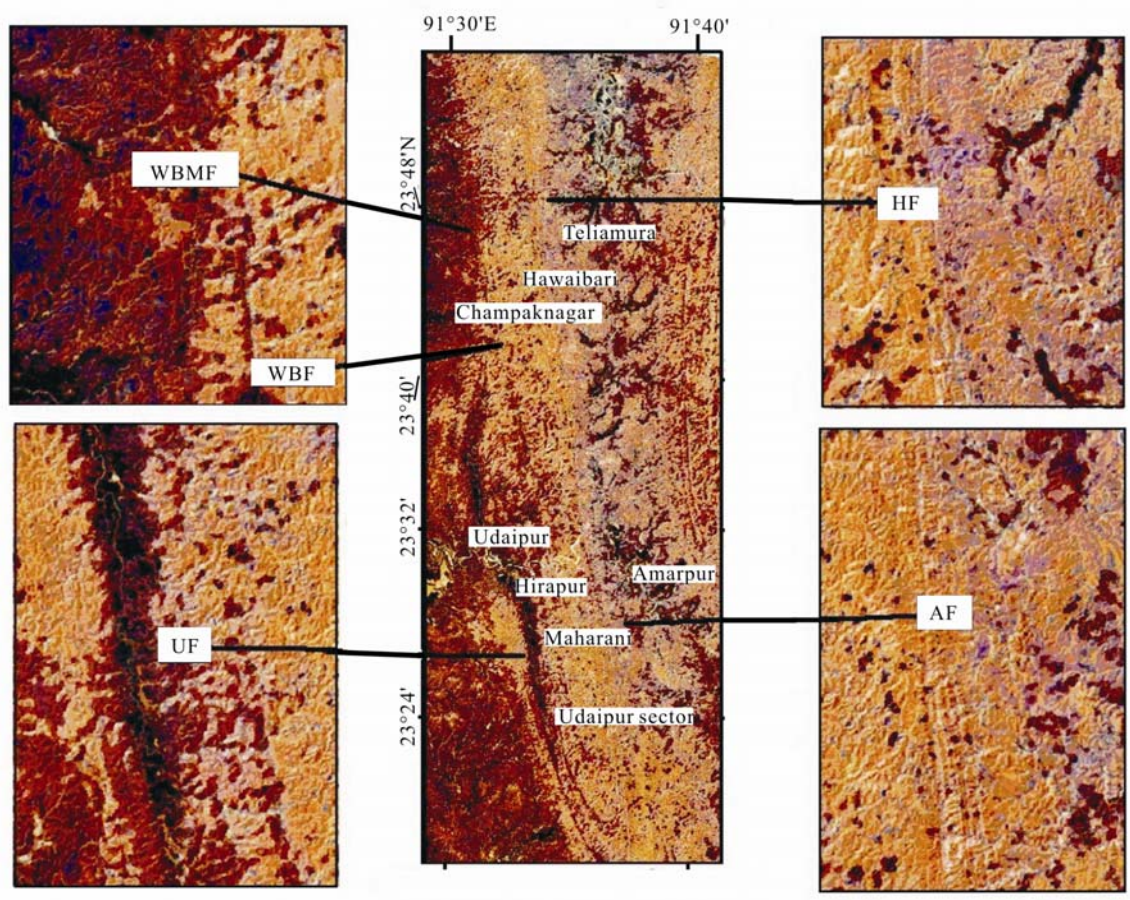

Figure 4. Identification of prominent tectonic lineaments in Baromura Hill from processed satellite data.

structural and surface conditions. In some places streamlets are flowing along those lineaments. In the southern part two sharp lineaments namely Udaipur fault (UF) and Amarpur fault are observed (AF). Udaipur fault, located in the western fringe of Baromura fold, is 33 km long and extended from north to south. In this place another very prominent trellis drainage patterns have been observed. Tectonic lineament of the south-eastern part was mentioned as Amarpur fault in Fig. 4 and Table 3 as it is very close to Amarpur Town.

5.2 Microfabric Patterns and Grain Geometry of Fault Rocks

A wide range of variations in microfabric patterns and geometric character has been found from the different samples collected from Baromura Hill (Fig. 5). From the tested samples it has been observed that most of the samples are strongly or moderately foliated in this region. In the northern part of the study area some nucleated microfabric patterns are found. Samples C7, C8 and C9 are the good examples of nucleated pattern. Though the general shape of the grains of those sample sub-round to round some very prominent angular shaped larger particles have been observed in the nucleus. Sample C10 shows plastic behavior as a very prominent micro-fold has been found in this sample. Grain scale brittle-ductile deformation on the micro-fold is the evidence of strong stress development during the geological past. Another brittle-ductile deformation is observed in sample C12.

In southern part sub-angular to round particles are found which are characterised by elastic behavior under very high level stress. In the samples TP1, TP2 and TP3 very clear

Table 3 Observed tectonic lineaments of Baromura hill

Location	Tectonic features	Early reference sources
West of northern Baromura Hill	West Baromura Marginal fault (WBMF)	Geological Survey of India Map 1 : 500 000
	West Baromura fault (WBF)	Geological Survey of India Map 1 : 500 000
Eastern part of Baromura Hill	Hawaibari fault and other small faults (HF)	Geological Survey of India Map 1 : 500 000
South-west Baromura Hill, south of R. Gumti	Udaipur fault (UF)	Dey et al. (2011a; 2009)
South-east Baromura Hill	Amarpur fault (AF)	Geological Survey of India Map 1 : 500 000

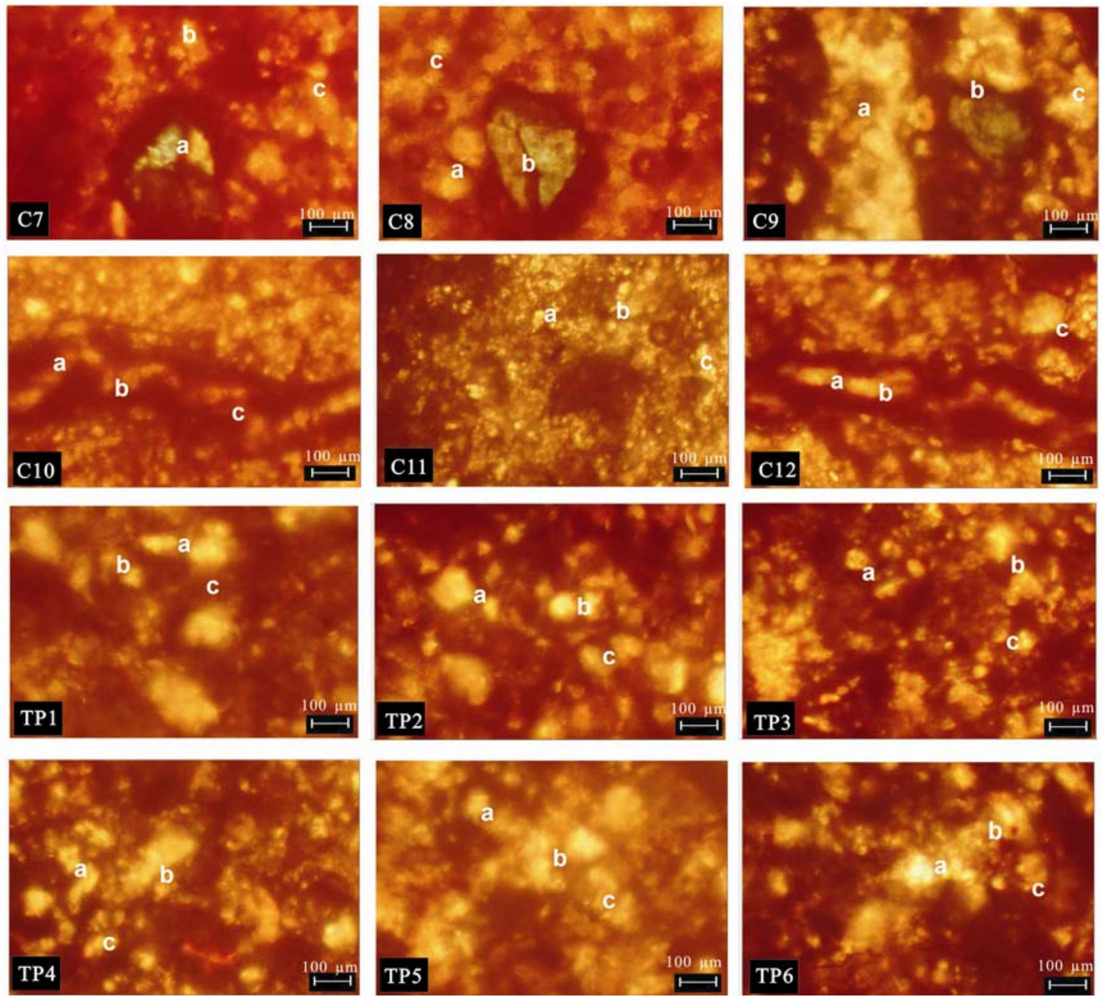

Figure 5. Geometric shape and grain arrangements (micro-fabric) of the tested samples of fault rocks (grain scale deformations of the marked a, b, c are presented in Fig. 6).

sub-round to round shape particles are observed. In samples TP2 and TP3 some very small sub-angular particles are arranged between the larger round or sub-round grains. Samples TP4 and TP6 are characterised by various size and shape of grains. Medium sized sub-angular to sub-round grains are found widely in sample TP5. In the samples of southern Baromura evidences of strong cataclasis has been observed. Fluid veins developed under high level hydro-thermal alterations along the foliations.

5.3 Grain Scale Brittle Deformation Characters

Tested samples of Baromura hill are characterized by very high level grain scale deformation under various levels of stresses. From Fig. 6 it has been observed that complex tress pattern was developed by early seismo-tectonic occurrences which caused grain order brittle and brittle-ductile deformations in this region. Sample C7 (a, b, c) and C8 (a, b, c) shows that grain scale deformation caused by both normal stress and shear stress. Interestingly shear stress has been observed clearly only on the larger particles. For example, in sample C8 (b) the larger crystalline particles (hard quartz) are marked by prominent shear stress. Samples C9, C12 and C10 (a, b, c) and samples TP1 and TP2 (a, b, c) show the deformations of medium size grains by very clear development of bi-directional normal stress. In samples C11 (a, b, c), TP6 and TP6 (a, b, c) multi direction stress developed which resulted fault breccias.

Sometimes high level friction by parallel slip decreases the stress resistively and normal stress reacted on those small grains blocks which created breccias (for example sample C11 b and C). The level of stress can be assumed as the smaller grains are also found broken here. Samples C11 (a, b, c), C12 (b), TP3 (c) and TP4 (b) represent the deformation of smaller grains by very high level tectonic stress.

6 DISCUSSIONS

In most of the parts of Baromura Hill general bedding patterns are represented by uni-models which clearly indicate that the initial deposition of this area occurred under a stable environmental conditions. Clay and sand alteration also support that climatic fluctuation influenced the geomorphic process intensity during the early depositional periods. As the early sediment deposition in this part of the remnant Bay of Bengal started from the north and the shoreline started shifting southward (Dey, 2005), the northern Baromura hill is characterised by comparatively older depositions than the southern Baromura depositions. The structural evidences show that tectonic activities started later which created the fold belts of this region in various phases. It can be assessed that during Late Tertiary and Early Quaternary periods, several tectonic activities disturbed the normal depositional environment (Table 4).

Microstructures of the rocks also support some physico-chemical differences among the northern and southern Baromura. Very prominent plastic character in the north and elastic character of the south Baromura Hill argued in favor of spatial scale physical variations. Stronger foliations are detected in the southern part than in the northern part which indicates the spatial variations of hydrothermal alteration in Baromura Hill. In samples C13, C14 and C15 (Fig. 7) explains low to moderate foliations and strong grain scale brittle deformations. Breccia structures are very common in those samples. Samples collected from southern parts have different microstructure patterns. Samples HT7, HT8 and HT9 clearly show typical fault rock microstructure which is strongly foliated rocks with high level brittle deformation. In these samples the pattern of deformation indicates that unidirectional or bidirectional stress modified the microstructure geometry during seismo-tectonic occurrences. Detailed optical testing strongly support that all the tested samples are characterised by three main physical processes of tectonic activities like (a) stress (tension or compression) created primary fracture, (b) friction due to grain boundary slip along the fracture line and finally, (c) fluid flow provided weakening mechanism to initiate seismic slip.

The existing geomorphology of this area shows high level tectonic influence in surface condition of Baromura Hill area. Maximum elevation of this area observed on the fold axis. Small streams are directed according to the dips of the limbs. A remarkable structural control on geomorphology has observed along the tectonic lineaments. Development of trellis drainage patterns along the fault lines support the influence for high level stress during the geological past. As this place is very close to the boundary zone of Indian plate, the anti-clock wise movement of the plate and subduction under Burma platelet may have been playing very important role for stress development. Many early researchers like McKenzie and Sclater (1971), Curray and Moore (1974), Sclater and Fisher (1974) etc. advocated for the dynamic pattern of plate-to-plate interaction between the Indian, Tibetan (Eurasian) and Burma Plates in Tertiary and Quaternary periods and its impact on geophysical changes of the north-eastern part of Indian subcontinent. The north-south extension of the tectonic lineaments along the fold axis of Baromura also proves that initially huge normal stress developed from eastern and western parts and caused north-south fractures. The present surface characters of

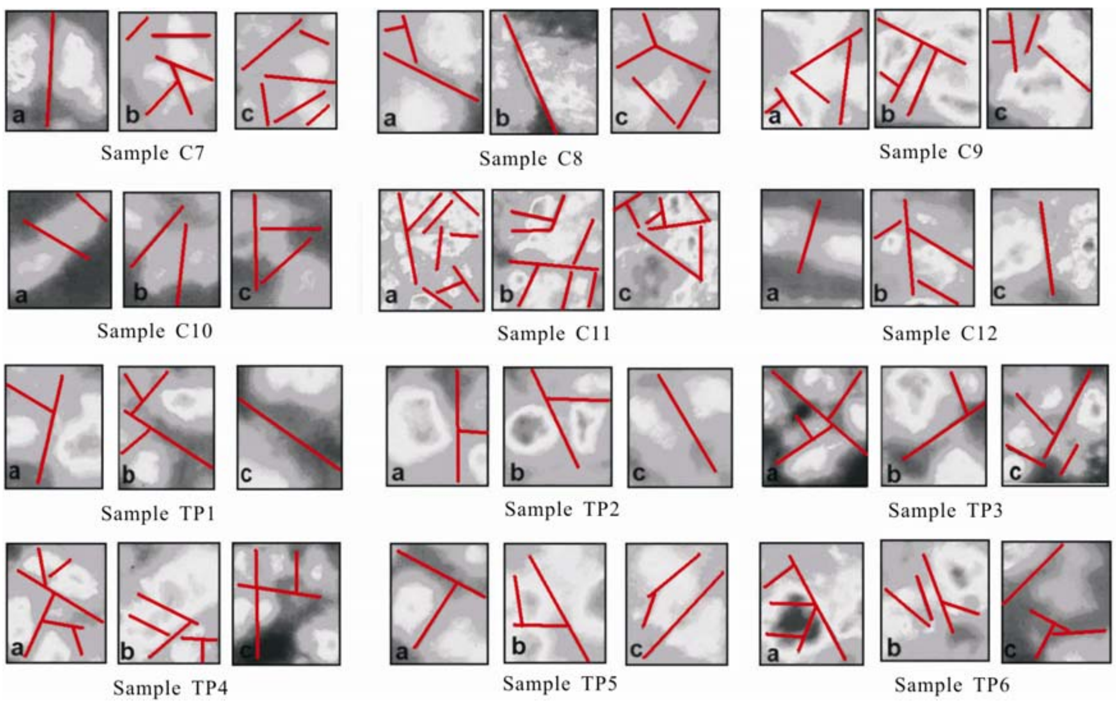

Figure 6. Pattern of grain scale deformations of the tested samples.

Table 4 Structural evidences of landform evolution history in Baromura Hill during Late Tertiary–Early Quaternary periods

<table>
<tr><th colspan="2">Geological time of deposition</th><th>Rock type</th><th>Strata</th><th>Geomorphic process</th><th>Tectonic evidences</th><th>Remarks on assumed environmental conditions</th></tr>
<tr><td colspan="2">Early Quaternary period</td><td rowspan="3">Tipam</td><td rowspan="2">Plane bedding and cross bedding</td><td rowspan="2">Generally unidirectional flow but to wards the Late Pliocene some oscillation occurred</td><td rowspan="3">Third phase tectonic evidence mostly influences the present geomorphic condition of this area. Folding found in both Tipam and Bokabil depositions. Morphological signatures of faulting prove that they occurred during recent geological past.</td><td rowspan="3">After the change of environment the deposition continues under stable environmental. Some environmental variations influenced the change of source zone and types of minerals. Towards the end of the Pliocene 3rd phase tectonic upliftment started and marine-coastal environment started to be shifted towards south and a new setup of geomorphic system gradually developed in the fold belt.</td></tr>
<tr><td rowspan="6">Late Tertiary period</td><td>Late Pliocene</td></tr>
<tr><td>Early Pliocene</td><td>Ripples/sand waves</td><td>Marine-coastal process dominated. The sandy character of deposition indicates the macrotidal environment.</td></tr>
<tr><td rowspan="4">Late Miocene to Middle Miocene</td><td colspan="4">Line of unconformity</td><td>Environmental shifting: Mesotidal to macrotidal environmental change</td></tr>
<tr><td rowspan="3">Bokabil</td><td>Some tidal ripples/plane bedding</td><td>Marine-coastal process dominated. The deposition of muddy clay is evident of domination of tide wave (mesotidal environment).</td><td>Second phase folding is a recumbent fold. High degree metamorphism and deformation of rocks found in the study area</td><td rowspan="3">Landform evolution of this area started with the sediment deposition under continuous process in Middle Miocene. A moderate tectonic unliftment occurred in Early Miocene. After this 1st phase tectonic event the sediment deposition occurred under stable environment. A recumbent fold structure was found in the upper layers of 1st phase folding. Evidences show that these layers has been metamorphosed by huge pressure and temperature during the tectonic event. Another stationary environmental condition occurred thereafter which causes the development of plane bedding.</td></tr>
<tr><td>Plane bedding</td><td>A layer of concrete sandstone (misfit deposition) indicates the change of process and the source zone of deposition.</td><td rowspan="2">Frist phase; very moderate tectonic evidence. The folding was observed only in lower Bokabil deposition</td></tr>
<tr><td>Plane bedding</td><td>Tidal wave domination under marine-coastal environment.</td></tr>
</table>

Based on exposed structures, chronological arrangement was done on the basis of Table 1.

this area is highly evident that many seismo-tectonic events occurred during the recent geological past as the tectonic lineaments are still not much modified by the surface geomorphic process (river) except the Udaipur fault in South Baromura. Recently Dey et al. (2012) examined the structural condition of Udaipur fault which shows that Maharani River (a small streamlet) deposited thick layer of sediment in the fault zone. This thick alluvial layer also support that this fault is comparatively older and geomorphic process for longtime upon it to modify the upper part of the faulted zone. Very prominent faulted topography in the northern part of Baromura hill proves that these are the results of seismo-tectonic occurrences during recent geological period.

7 CONCLUSION

The present study opens the fact that geological evolution this area is more complex, than it is understood from the existing surface condition. The change of geomorphic processes intensity during the Tertiary and Quaternary periods results the variations of sand and clay alternation, beddin g thicknesses and arrangements within uni-models. Climatic change might have play very important role for the variations of geomorphic processes at temporal scale and that resulted several landform modifications. Moreover it is observed that the depositional characters of north and south have some differences in physical characters. In the northern part rocks of very prominent plastic character was found while in the south most of the cases elastic characters are found at grain scale. This variation of

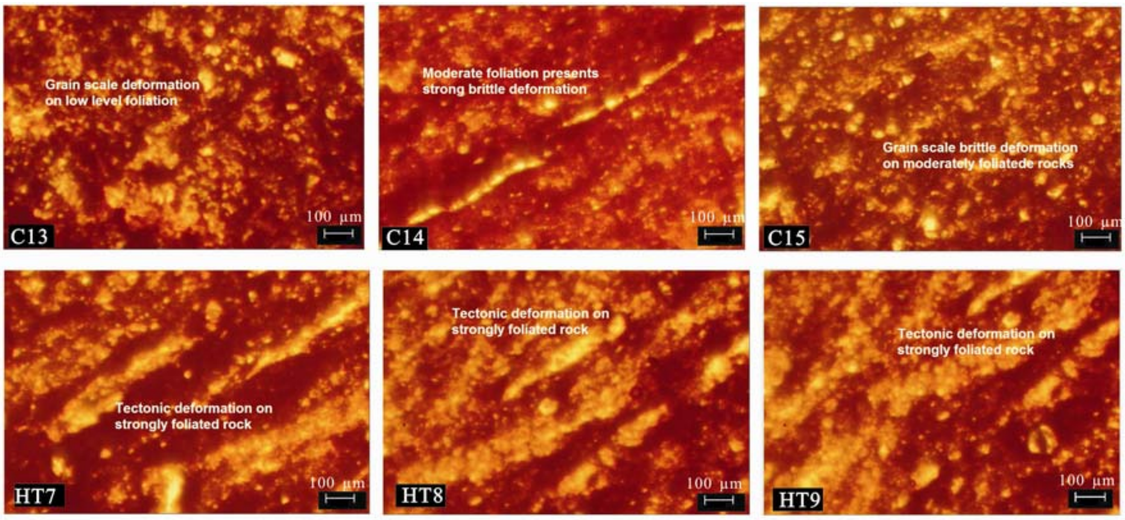

Figure 7. Level of foliations and general deformation patterns of the faulted zones by strong stress development during the geological past.

depositional character indicates that either the process intensity was changed or the source zone was changed during the later part of depositional period. Besides that there are ample structural evidences which strongly support the role tectonic movements in landform evolution in the whole Northeast India. Baromura Hill, one of the major earthquake prone zones in Northeast India, has experienced several seismo-tectonic occurrences in the geological time and even during the recent times. The north-south extended lineaments prove that high level structural modification occurred by strong tectonic displacements during the geological past. Grain scale brittle and brittle-ductile deformation characters and marks of high-level hydro-thermal alterations are the evidences of complex stress development inthe past. Some differences between the northern and southern part microstructures are also remarkable as it represents the spatial and temporal various stresses in this place. Finally it can be said that continuous process of tectonic movement which is related with Indian plate boundary influenced the structural and landform evolution during Tertiary and Quaternary periods.

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REFERENCES CITED

Abdullah, A., Akhir, J. M., Abdullah, I., 2009. A Comparison of Landsat TM and SPOT Data for Lineament Mapping in Hulu Lepar Area, Pahang, Malaysia. *European Journal of Scientific Research*, 34(3): 406–415

Agarwal, P. N., 1986. A Recent Earthquake in Northeast India. In: Friedr, V. S., ed., Proceedings of 2nd International Seminar on Earthquake Prognostic, Berlin. 24–27

Alam, M., Alam, M. M., Curray, J. R., et al., 2003. An Overview of the Sedimentary Geology of the Bengal Basin in Relation to the Regional Tectonic Framework and Basin-Fill History. *Sedimentary Geology*, 155: 179–208

Bale, H. D., Schmidt, P. W., 1984. Small-Angle X-Ray Scattering Investigation of Submicroscopic Porosity with Fractal Properties. *Physical Review Letters*, 53: 596–599

Bernstone, C., Dahlin, T., Bjulemar, L., et al., 1997. Identification of Poor Ground with the Aid of DC Resistivity: Results From Work on the Öresund Bridge Connections. In: Proc. 3rd Meeting Environmental and Engineering Geophysics. Environmental and Engineering Geophysical Society, European Section. Aarhus, Denmark. 431–434

Bhattacharjee, S., 1998. Earthquakes in Northeast India Mitigation—A Possible Approach. In: Sharma, G. D., ed., Status of Landslides in Northeast India and Natural Disaster Management. Assam University Press. 77–84

Brewer, R., 1976. Fabric and Mineral Analysis of Soils. Huntingdon, New York

Cashman, S. M., Baldwin, J. N., Cashman, K. V., et al., 2007. Microstructures Developed by Coseismic and Aseismic Faulting in Near-Surface Sediments, San Andreas Fault. *Geology*, 35: 611–614

Curray, J. R., Moore, D. G., 1974. Sedimentary and Tectonic Processes in Bengal Deep-Sea Fan and Geosyncline. In: Burk, C. A., Drake, C. L., eds., The Geology of Continental Margins. Springer, New York. 617–628

Dey, S., 1999. Natural Environmental Control through Seasons on Morphology of Digha-Shankarpur Coastal Tract of Medinipur, West Bengal. *Indian Journal of Geography and Environment*. l–4: 16–23

Dey, S., 2002. Impact of Sea Level Change upon Landform Development along Digha Coastal Tract and Risk Assessment by Process Efficiency Process. *Indian Journal of Geomorphology*, 7: 111–117

Dey, S., 2005. Conceptual Models for the Assessment of Tertiary-Quaternary Geomorphic Evolution of Paleo-Coastal Tripura. *Annals of the National Association of Geographers, INDIA*, XXV-1: 73–80

Dey, S., De, R., 2002. Evidences of Environmental Changes at

Ancient Coastal Civilisation of Tamralipta. *Indian Journal of Geography and Environment,* l–7: 80–85

Dey, S., Sarkar, P., Debbarma, C., 2009. Morphological Signatures of Fault Lines in an Earthquake Prone Zone of Southern Baromura Hill, North-East India: A Multi Sources Approach for Spatial Data Analysis. *Environmental Earth Sciences*, 59(2): 353–361

Dey, S., Sarkar, P., Debbarma, C., et al., 2011a. Geophysical Signatures of Tectonic Environment in an Earthquake Prone Zone of Southern Baromura Hill, Northeast India. *Environmental Earth Sciences,* 63: 437–441

Dey, S., Debbarma, C., Sarkar, P., et al., 2011b. Experiment on Visualizing Micro-Level Surface Characters of Sediment Sections: A Methodological Approach to Reflectance-Based Alternative Petrographic Image Analysis. *Arabian Geoscience,* 4(5–6): 899–906

Dey, S., Sarkar, P., Debbarma, C., et al., 2012. Seismic Assessment in Southern Baromura Hill, Northeast India, Considering Geophysical Aspects. *Environmental Earth Sciences,* 66(2): 421–431

Doran, J. W., Parkin, T. B., 1994. Defining and Assessing Soil Quality. In: Doran, J. W., ed., Defining Soil Quality for a Sustainable Environment. *SSSA Spec. SSSA, Madison, WI, Publ.*. 35: 3–21

Dutta, G. N., 1974. Some Geomorphological Aspects of Tripura State. Abstracts of Proceedings of Indian Science Congress, Tripura. 130

Guha, S. K., Bhattacharya, U., 1984. Studies on Prediction of Seismicity in Northeast India. Proceedings of World Conference on Earthquake Engineering, San Francisco, USA. 21–27

Gupta, H. K., 1993. Patterns Preceding Major Earthquakes in Northeast India. *Current Science*, 64(11–12): 889–893

Gupta, H. K., Singh, H. N., 1986. Seismicity of Northeast India Region: Part II: Earthquake Swarm Precursory to Moderate Magnitude to Great Earthquakes. *J. Geol. Soc. India*, 28: 36–406

Gupta, H. K., Singh, H. N., 1989. Earthquake Swarm Precursory to Moderate Magnitude to Great Earthquakes in Northeast India Region. *Tectonophysics*, 167: 255–298

Gupta, H. K., Singh, V. P., 1982. Is Shillong Region, Northeast India, Undergoing Dilatancy Stage Precursory to a Large Earthquake? *Tectonophysics*, 85: 31–33

Hansen, J. P., Skjeltrop, A. P., 1988. Fractal Pore Space and Rock Permeability Implications. *Physical Review B,* 38: 2635–2638

Hazra, S., Ghosh, T., Baksi, A., et al., 2001. Sea Level Change: It's Impact on West Bengal Coast. *Indian Journal of Geography and Environment*, 6: 25–37

Henderson, D. B., Ferrill, D. A., Clarke, K. C., 1996. Mapping Geological Faults Using Image Processing Techniques Applied to Hill-Shaded Digital Elevation Models. *IEEE Transactions*, 8: 240–245

Jacquin, C. G., Adler, P. M., 1987. Geometry of Porous Geological Structures. *Transport in Porous Media*, 2: 571–596

Katz, A. J., Thompson, A. H., 1985. Fractal Sandstone Pores: Implications for Conductivity and Pore Formation. *Physical Review Letters*, 54: 1325–1328

Kayal, J. R., 1987. Microseismicity and Source Mechanism Study: Shillong Plateau, Northeast India. *Bull. Seismol. Soc. of Am*., 77(1): 184–194

Kayal, J. R., 1998. Seismicity of Northeast India and Surroundings-Development over the Past 100 Years. *J. Geophysics*, 19(1): 9–34

Mamtani, M., Mukharji, A., Chaudhuri, A. K., 2007. Microstructure in Banded Iron Formation (Gua Mine, India). *Geological Magazine*, 144(2): 271–287

Masoud, A., Koike, K., 2006. Tectonic Architecture through Landsat-7 ETM+/ SRTM DEM-Derived Lineaments and Relationship to the Hydrogeologic Setting in Siwa Region, NW Egypt. *Journal of African Earth Sciences*, 45: 467–477

McKenzie, D., Sclater, J. G., 1971. The Evolution of the Indian Ocean Since the Late Cretaceous. *R. Astron. Soc. Geophys*., 24: 437–528

Menzies, J., Maltman, A. J., 1992. Microstructures in Diamictons—Evidence of Subglacial Bed Conditions. *Geomorphology*, 6: 27–40

Nandi, M., 1985. Geographical Account of Tripura. In: Gan-Chowdhui, J., ed., An Anthology of Tripura. Inter-Indian Publication, New Delhi. 1–9

Sclater, J. G., Fisher, R. L., 1974. Evolution of the East Central Indian Ocean with Emphasis on the Tectonic Setting of the Ninetyeast Ridge. *Geol. Soc. Am. Bull*., 85: 683–702

Thingbaijam, K. K. S., Nath, S. K., Yadav, A., et al., 2008. Recent Seismicity in Northeast India and Its Adjoining Region. *J. Seismol*., 12: 107–123

van der Meer, J. J. M. 1996. Micromorphology. In: Menzies, J., ed., Glacial environments. Butterworth-Heinmann, Oxford. 335–355

van der Meer, J. J. M., 1987. Micromorphology of Glacial Sediments as a Tool in Distinguishing Genetic Varieties of Till. *Geological Survey of Finland*, 3: 77–89

van der Meer, J. J. M., 1993. Microscopic Evidence of Subglacial Deformation. *Quaternary Science Reviews*, 12: 553–587van der Meer, J. J. M., Laban, C., 1990. Micromorphology of Some North Sea Till Samples, a Pilot Study. *Journal of Quaternary Science*, 5: 95–101

Vernon, R. H., 2004. A Practical Guide to Rock Microstructure. Cambridge University Press, UK

Wong, P. Z., Howard, J., Lin J. S., 1986. Surface Roughening and the Fractal Nature of Rocks. *Physical Review Letters*, 57: 637–640