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Geomorphological signatures of Neotectonic deformations and Paleo-earthquake study in Jorhat and Mokokchung districts of Assam and Nagaland, India

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*Abstract:***Tectonics plays an important role in landscape evolution, the records of which are preserved in geomorphic features. Evidence of past earthquakes is preserved in sediments in the formof liquefaction structures. The study of active tectonics and paleo-earthquakes is carried out in the Jorhat and Mokokchung districts of Assam and Nagaland respectively. The evidence of ongoing tectonic activity in the study area isthe presence of irregular water bodies along Naga Thrust, the presence of different levels of terraces, river channel shifting, avulsion of meander belt, presence of pressure ridge, and variation in sinuosity of rivers. In the study area, the primary ground ruptures are not identified as the last Great Assam Earthquake was experienced in 1950. It is already 72 years since then so the records of primary ruptures if any in the past are obliterated by erosion and deposition of sediments. Secondary ground failure in the form of liquefaction structures with sand dykes, seismites, and hydroplastic deformation of sediments are encountered in the deposits along the bank of Bhogdoi River at Koleapani Tea Garden, Pukhuria, Gongapur, and Hatigarh.**

*Index Terms:***Liquefaction, Naga Thrust, wetlands, Pressure Ridge, Great Assam Earthquake, seismites, hydroplastic, Bhogdoi River**

I. INTRODUCTION

Active tectonics in recent times has led to the crustal deformation and modification of the topography through exogenic processes (Whipple et al. 2009; Strecker et al. 2007; Raj, R. 2007; C. K. Singh 2014; 2015). The fluvial system plays an important role owing to its ability to incise, which ultimately led to the lowering of landscape and denuding actively rising mountain front. In seismically active regions of the world, active faults are considered to be the source oflarge-magnitude earthquakes and the paleoseismic investigations along such faults have proved their capability in producing large earthquakes periodically (Nakata, 1989; McCalpin, 1996; Lavé et al.,2005; Kumar et al.,2006; Yeats and Hussain, 2006).

In this paper, the key aim is to identify theevidenceof ongoing tectonism in the study area which enhances our understanding of the active forces and their role in molding the surface. The dynamics of dual subduction of the Indian plate beneath the Eurasian plate and Burmese plate has led to the deformation of the northeastern part of the Indian Plate(Evans 1964;Tapponnier et al 1977;Kayal 1991;Bilham& England 2001).The study is conducted near the Naga Hills mountain front, so the deformation is reflected as the manifestation in topography, geology, and geomorphology. The complex seismotectonic setup of the collisional boundary experienced several major earthquakes in the past; namely the 1897-Shillong and the 1950-Great Assam Earthquake. The compressional regime has generated a complicated geotectonic framework (Nandy 2001). Two major perennial rivers namelyBhogdoi and Kakodonga transect the study area. Bhogdoi, a major tributary of the Brahmaputra River lost its direct link after the 1897 earthquake (Das, 2014). Extensive liquefaction features are confined near the flood plains of the river Brahmaputra and its tributaries (Poddar, 1952). Isopach map aroundMajuli Island shows a prominent 'Jorhat Fault' (Prasad and Mani, 1983), representing most probably the local tectonic boundary. To evaluate seismic hazards in the Naga Schuppen belt it is crucial to identify the dynamics of active faults. There is a very prominent E-W bound

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fault called the ‘JorhatFault’, passing through the tail end of Majuli Island (Lahiri& Sinha 2014). Delineation of paleoseismic features is of great importance to studying the movements along active faults in the tectonically active region. A paleoseismic investigation is one of the most commonly adopted techniques foridentifying historic and pre-historic earthquakes in tectonically active regions of the world (McCalpin, 1996). The detailed study has been carried out by extensive field mappingand the use of satellite data which includes SRTM, Google Earth Imagery, and topographic maps.

undulatory topography continues towards the south till the Assam-Nagaland border where slight undulatorytopography changes to low hills. To the north Older Alluvium is present while to the south Tipam Group of rocks is exposed. This juxtaposition of the Older Alluvium of Pleistocene age with the Tipam Group of rocks of Miocene age and abrupt change in topography indicates the presence of range bounding thrust. This range bounding thrust is Naga Thrust.

Terraces of Older alluvium of the Pleistocene age occur in the foothills of Naga Hills in the south while Younger Alluvium to the north. Jorhat fault is the tectonic boundary between Older and Younger Alluvium.

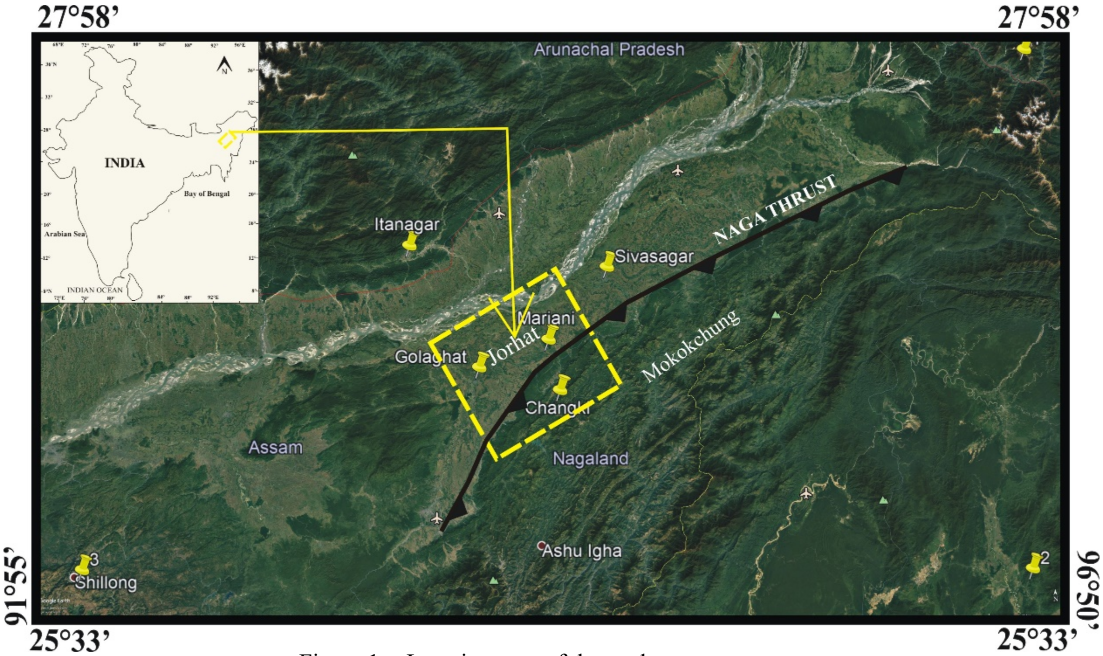

Figure 1: - Location map of the study area

II. Geological setting of the area

The present study area (Fig. 1) lies in the foothills of the Naga Schuppen Belt. The Naga Thrust forms a major tectonic boundary juxtapositioningthe Older Alluvium of Assam Valley and the Tipam Group of rocks (Fig. 6) in the Naga PatkaiRanges. It is in the border areas of Assam and Nagaland. The study was conducted in different parts of the Golaghat, and Jorhat districts of Assam, and the Mokokchung district of Nagaland. The area is intercepted by the Jorhat Fault(Fig. 6) forming a major tectonic boundary controllingthe landscape evolution. Regionally the Jorhat fault culminates as the Basement structural nose of Mikir Hills and it divides Upper Assam Basement high with a saddle in between(Kumar et al 2012). The Quaternary deposits in the Assam valley are under compressive stress (Nandy 2001; Raoof et al. 2017; Alam et al. 2019;Gogoi et al. 2022) acting in opposite direction from the Himalayan Frontal Thrust Belt in the north and Naga Thrust Belt in the south. Distinct variation in topography is noticed in various areas of Golaghat and Jorhat (near Mohbondha). Dissected topography on both sides of NH-37 is observed. The

The lithology of the area comprises soft sediment mainly sand, silt, and clay deposits. These sediments are classified into Older Alluvium and Younger Alluvium. Older Alluvium is consolidated, oxidized, and uplifted from the present floodplains of the Bhogdoi and Kakodonga rivers. Younger Alluvium on the other hand is less consolidated,oxidized, and forms the present flood plains. The Younger Alluvium forms extensive deposits towards the north of the Jorhat Fault while the Older Alluvium occupies the southern part (Fig. 6).

III. Evidence of active tectonics

A. Presence of irregular water bodies along the Naga thrust

Innumerable irregular water bodies (Fig 2) are aligned close to Naga Thrust. These are formed due to stockpiling of water in the valley carved by streams that probably once drained through the area in the past. Due to the northward propagation of the Naga Schuppen Belt, there was an obstruction to the flow. Streams with less discharge could not erode the uplifted frontal part of these basins and formed lakes(Fig. 3) while others with highdischarge and erosive power drained through the area. The formation of these water bodies is due to the upliftment of the area that created a barrier to the flow of streams indicating active tectonic deformation in the area.

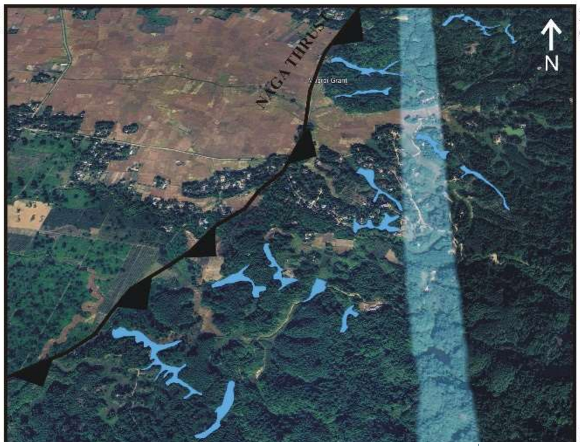

Figure 2: - Irregular lakes along the mountain front in close proximity to Naga Thrust.

Figure 3: - Bird's eye view of Irregular lakes to the south of the Naga Thrust.

B. *Presence of unpaired terraces*

Unpaired terraces are encountered on both banks of the Bhogdoi River. In the Koleapani Tea Estate, four different levels (Fig. 4) of terraces are present on the east bank while on the west bank three levels of terraces are encountered which indicates upliftment.

Terraces are found either due to continuous incision of the river with high erosive power or if the area is undergoing upliftment or else it might be a combined process of incision and upliftment.

The bank height is measured at different places from Naga Thrust to Jorhat Fault. The bank height near Gongapur is found to be a maximum of about 13 m while in Koleapani Tea Estate is 8m. In the Older Alluvium (hanging wall block of Jorhat Fault) bank height is comparatively more and as the river enters Younger Alluvium (footwall wall block of Jorhat Fault) bank height decreases. This indicates that the area is undergoing tectonic modification.

C. *Channel Shifting*

In the past Bhogdoi River drained through the Naga Hills and entered the plains of Assam to meet the Brahmaputra at NimatiGhat. In the present time, the river has taken a right-angle turn north of the bypass of Jorhat town leaving behind its former course (Fig. 5). Presently it moves parallel to the river Brahmaputra and joinsthe river Dhansiriwhich finally drains into the Brahmaputra. This shifting of the river channel towards the south is due to sagging in the footwall block of the Jorhat fault.

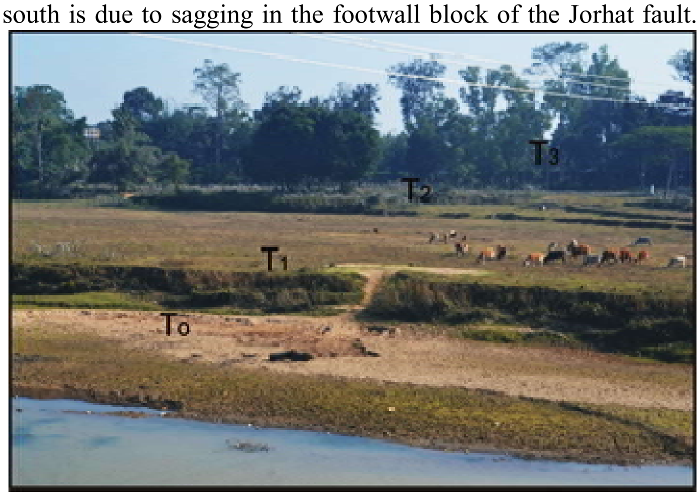

Figure 4: - Presence of different level of terraces

The sagging resulted in a southward tilt in the area which results in the southward migration of the river channel.

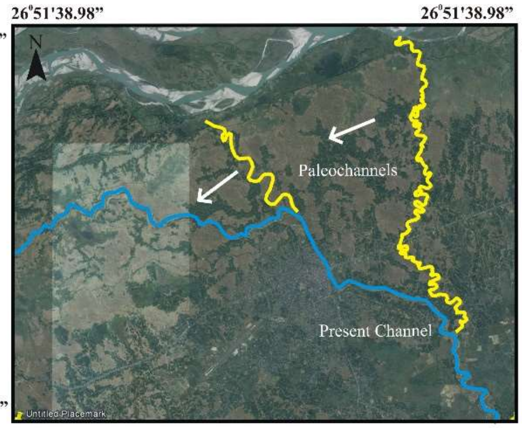

Figure 5: - Gradual channel shifting of Bhogdoi river

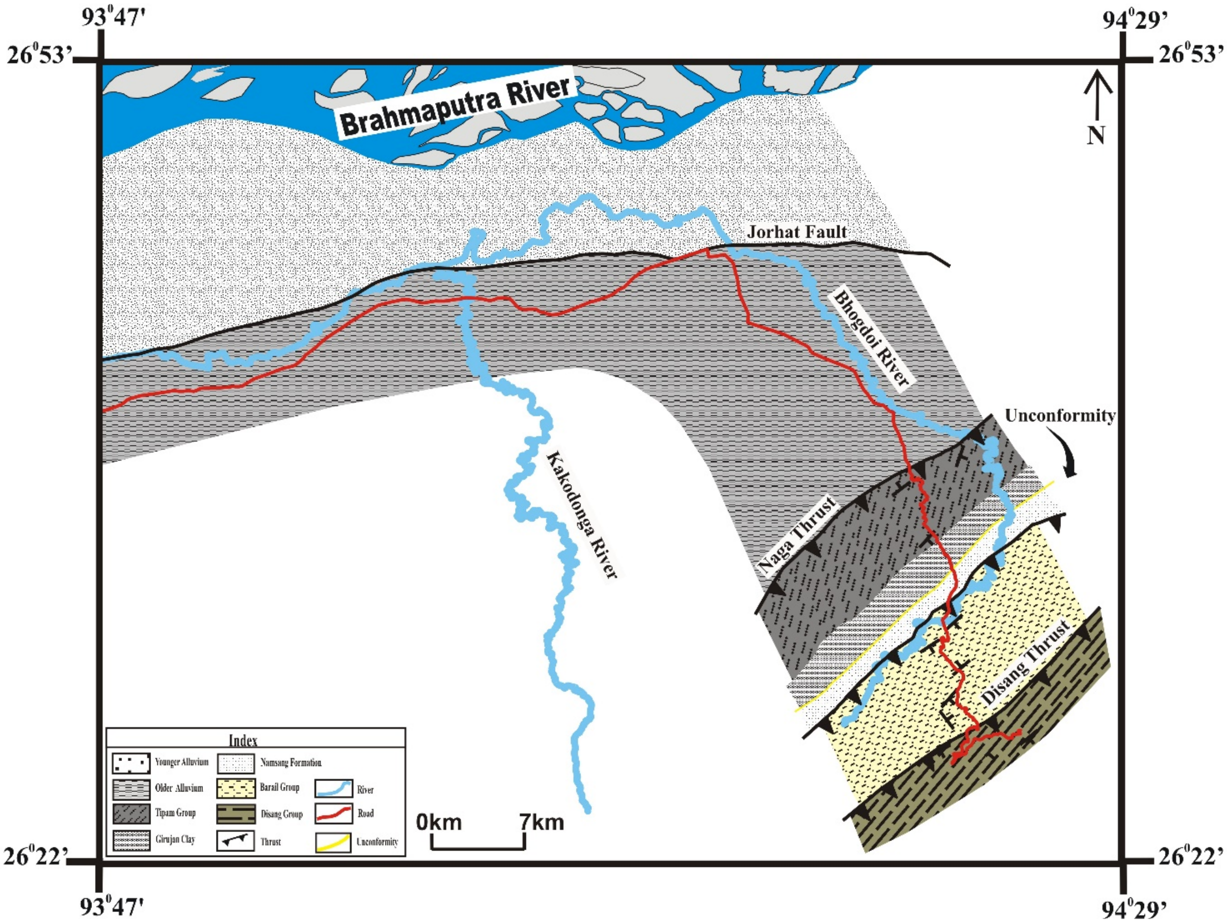

Fig6: Geological Map of the study area

D. Avulsion of meander belt

Earlier Bhogdoi drained from the Naga Hills entered into the plains in Assam and followed an N-S trend to meet the Brahmaputra near NimatiGhat. This older meander belt flows throughHolaungGaon, DulakhariaGaon, and BaghmoriaGaon which lies east of the present meander belt. The river avulsed its older meander belt and it takes its present course (Fig. 7). As the Jorhat Fault is uplifting the Older Alluvium sothere is a tilting of the area owing to which the river avulsed its earlier course.

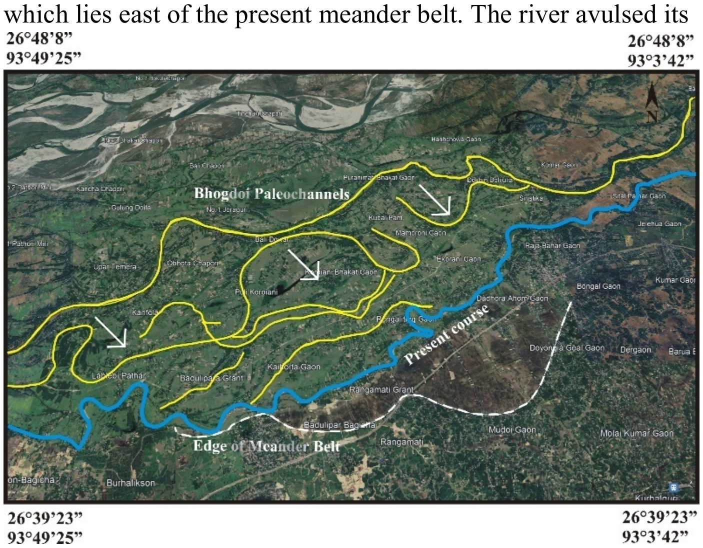

Figure 7: - Avulsion of Bhogdoi river course within the meander belt

E. Presence of Pressure Ridge

Two distinct pressure ridges are observed in the study area from the SRTM image and Google Earth Imagery (Fig. 8 & 9). One at Neghereting where the undulatory topography abruptly changes to an isolated hillock. This area is located just to the north of the Jorhat Fault. Elevation profiles (Fig. 9) EF and GH across the ridge show change in profile relative to the flood plain. This ridge lies in the footwall block of the Jorhat Fault. The thrusting of Older Alluvium over the Younger Alluvium squeezes the recent deposits to the pressure ridge.

The other ridge lies close to Naga Thrust which is the Gibbon Wildlife Sanctuary. This ridge has undergone upliftment due to the dynamics of the frontal thrust of the Naga Patkai Ranges. The deformation is reflected in the elevation profile (Fig. 9) along lines AB and CD. The uplifted surface is due to the folding of sediment owing to the compressional regime into an asymmetric antiform.

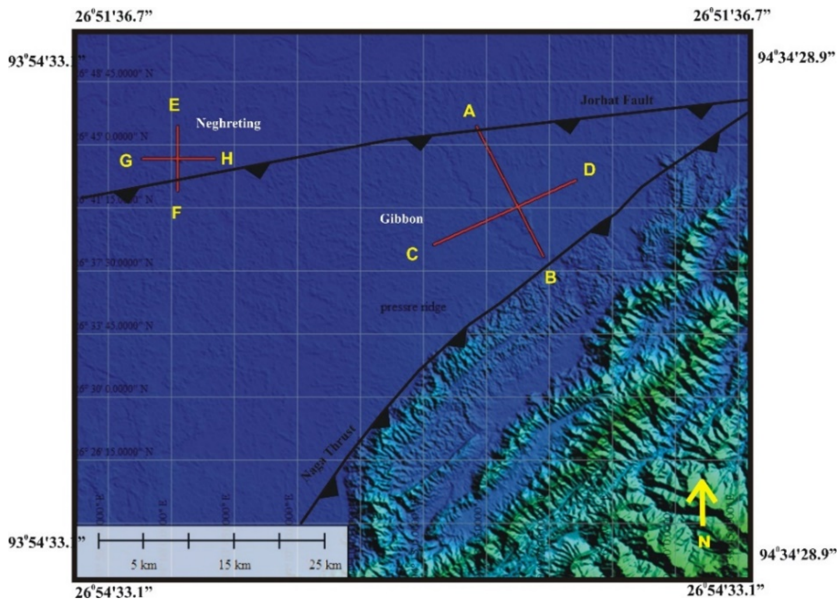

Figure 8: - DEM illustrating the pressure ridges. Gibbon pressure ridge lies close to the frontal Naga thrust. The uplifted region lies to the north of the hill front. Neghreting ridge lies to the north of Jorhat Fault.

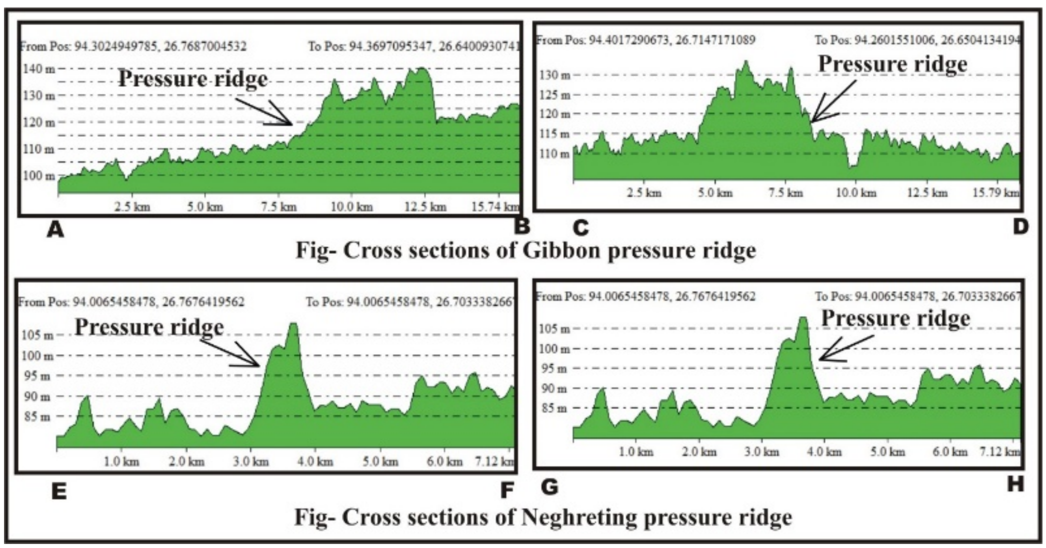

Figure 9:- Elevation profile of Gibbon pressure ridge and Neghreting pressure ridge

F. The sinuosity of Bhogdoi and Kakodonga River

The sinuosity of Bhogdoi and Kakodonga is traced from Google Earth Images of the area for obtaining the present-day sinuosity and SOI toposheets 1974-1975 for the past sinuosity.

The sinuosity of the river is measured in four segments as follows:-

Table I: Sinuosity of Bhogdoi

Sl No	Segment	1975	2022
a	Disang Thrust to Tzurang bridge	1.60	1.72
b	Tzurang bridge to Naga Thrust	2.20	2.43
c	Naga thrust to Jorhat Fault	1.38	1.42
d	Jorhat fault to Dhansiri river	1.36	1.47

The sinuosity of the Bhogdoi river does not show any significant change in the last 47 years while that of the Kakodonga River shows variation from 2.44 (1975) to 2.72 (2022). It implies that the area has undergone topographical modifications which result in a change in the slope of the meander belt during the last 47 years.The change in sinuosity is indicating the active tectonic deformation of the area by the Jorhat Fault which has deformed the Older Alluvium causing variation in the slope of the river and thus the river takesa more sinuous path to maintain equilibrium.

Table II: Sinuosity of Kakodonga

Sl No	Segment	1975	2022
1	Naga Thrust to Brahmaputra River	2.44	2.72

G. Earthquake Triggered Soft Sediment Deformational Structures (seismites)

Structures formed in unconsolidated sediment are known as soft-sediment deformation structures (Mugnier et al. 2013). Structures due to fluidization or liquefactiondisrupt the original layering in the sediment. Shallow water table depth is likely to facilitate the liquefaction of suitable sediments during major earthquakes (Obermeier et.al., 1990).

Liquefaction is induced when the pore water pressure exceeds the confining stress due to the propagation of seismic shear waves through the saturated sediments.The study area lies in the seismic zone V consisting of sediments like fine silt, and clay occasionally with some pebbles and cobbles belonging to the Quaternary Period. Primary ground ruptures have not beenidentified in the area. Secondary ground failure in the form of folding and small-scale faulting is observed in Pukhuriagaon and Koleapani tea gardens. Evidence of paleoseismic deformation like sand dikes, sills, convolute bedding, and small-scale folding are reported from the banks of the Bhogdoi River.

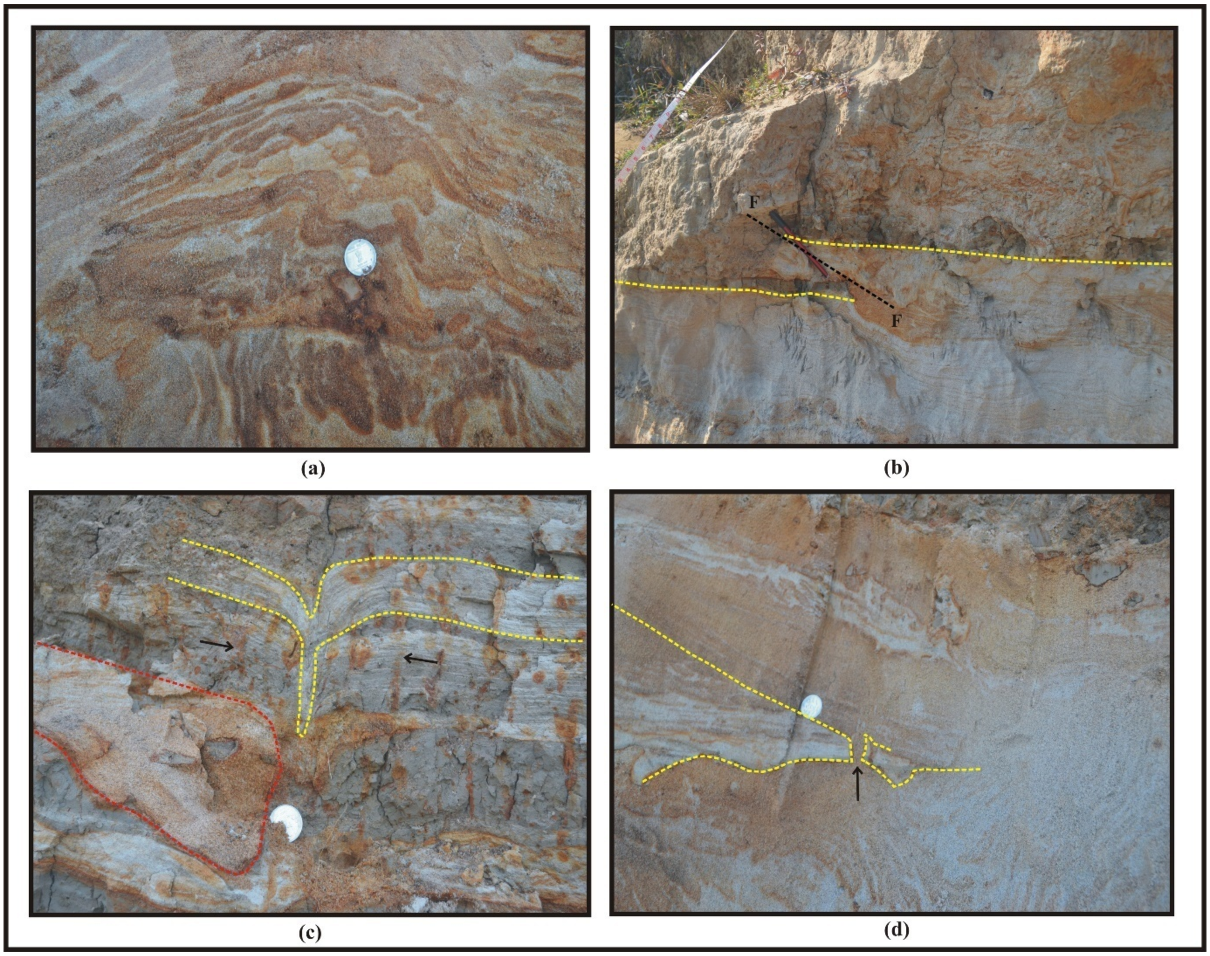

Figure 10:-Liquefaction features observed at right bank of Bhogdoi river (a) Seismites at Gongapur site (b) Displacement of silt layer by a small scale fault (c) Liquefied sand intruding into silt layer with squeezing up of the sediments (d)Small scale sand dyke disrupting the original layering in the sediment

Seismites are also reported from Gongapur and Hatigarh sites. The deformational features indicate a compressive stress regime prevalent in the area (Fig 10).

IV. Discussion and Conclusion

The field survey conducted was in parts of the Golaghat and Jorhat districts of Assam and Mokokchung in Nagaland. Detailed geological mapping of the area has been done (Fig. 6).

Evidence of tectonic deformation in the area wasobserved. Several irregular lakes are aligned around the Naga Thrust. These lakes which once drained through the front were arrested by the upliftment along Naga Thrust. Accumulation of water in these basins led to their formation in the proximity of the thrust. The presence of different levels of terraces within the meander belt of the Bhogdoi River depicts episodic upliftment of the area. The gradual southward shifting of the channel and avulsion of the meander beltindicates that the thrusting of the Jorhat fault had led to the development of sagging due to which the river is preferentially migrating toward the south.

The presence of two pressure ridges inthe study area. The pressure ridge developed in Gibbon is related totranspressional stress that offsets the Naga Hills. While the ridge in the Neghereting is related to the overriding of the hanging wall block of the Jorhat Fault over the Younger alluvium. The presence of these two pressure ridges in the Older Alluvium is direct evidence of active tectonic deformation that the area is undergoing in Post-Pleistocene time.

Bhogdoi and Kakodonga show significant variations in their sinuosity values between Naga Thrust and Jorhat Fault. The sinuosity of the Bhogdoi within the thrust sheet has low values due to human intervention while Kakodonga is more sinuous and shows significant variation in the last 47 years. The change in sinuosity is related to a change in the gradient of the river due to the deformation of the area associated with the Jorhat Fault.

Soft sediment deformation structures results due to changes in the fabric and layering of recently deposited sediments. Earthquake-induced liquefaction structures are reported from many sites close to Naga Thrust and Jorhat Fault. The 1950 Great Assam Earthquake had known to affect several places in Jorhat. The collapse of houses and damage to buildings have been reported.

Primary surface ruptures are not identified yet in the study area. Paleoseismic imprints in support of ongoing tectonism in the form of secondary features are delineated in many sites. The deformation of Quaternary deposits along the river section, offset and discontinuity of the sedimentary layers suggest tectonic modifications of the area in recent times. The area lies near Naga Schuppen Belt, which is tectonically active; so neotectonic study is very crucial to the seismic hazard assessment and infrastructural development.

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