Structural controls on topography and river morphodynamics in Upper Assam Valley, India

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ABSTRACT
The basement in Upper Assam foreland basin exhibits a typical flexure pattern. An elongated continuous subsurface basement high has developed between Himalaya and Naga-Patkai ranges. A few prominent basement lows have developed adjacent to the foothill regions. It is noticed that the general topographic slope near the foothill regions is not only controlled by aggradation process, but also influenced by the flexured basement of the region. The basement lows have influenced the overlying topography significantly. Rivers flowing over those regions have shown unidirectional lateral migration. North bank tributaries like Subansiri, Jiadhal and Dikrang have been affected by the Subansiri basement low. Coseismic subsidence of sediments over Subansiri basement low had resulted subsidence of the North Lakhimpur-Ranga Nadi region in 1950 Assam earthquake. Some south bank tributaries like Disang and Dikhow have been affected by Nazira basement low. Topographic elevation along the Subansiri river is lower than that part of the Brahmaputra located south of Majuli. This typical topographic setting of the region makes the mouth of the Subansiri river and Majuli region highly susceptible to erosion.

1. Introduction
The Upper Assam valley is a part of the Himalayan foreland basin covered by Tertiary sequences and Recent alluvium. Sarma (2005) has given accounts on the fluvial processes and morphology of the Brahmaputra river in Assam valley. Goswami (1985) has studied the channel aggradation process of the river. Bank erosion and channel migration of the Brahmaputra river have been studied by Kotoky, Bezbaruah, Baruah, and Sarma (2003, 2005), Sarma and Phukan (2004, 2006), Sarma and Acharjee (2012) Lahiri and Sinha (2012, 2014). It has been noticed that the bank erosion rate is not similar for both banks of the river. North bank of the river have undergone more erosion at some places relative to that of the south. Coleman (1969), Schumm (1977), Ouchi (1985), Schumm (1986), Holbrook and Schumm (1999), Valdiya (1999), Schumm, Dumont, and Holbrook (2000), Jain and Sinha (2005), Das, Dutta, and Saraf (2007), Burbank and Anderson (2012) have carried out work on response of alluvial rivers to active tectonics. Details on active tectonics of the Brahmaputra valley are given in the works by Das and Saraf (2007), Das et al. (2007), Das (2010), Sarma, Acharjee, and Gogoi (2011), Lahiri and Sinha (2012, 2014), Sharma and Sarma (2013). In contrast to these studies, some basement structures within the valley region have not received adequate attention of the researchers. Anomalies of some south bank tributaries like Disang, Dikhow and Noa Dihing have not been studied till date. The present work involves study of basement structures and their influence on topography and river morphodynamics in Upper Assam valley. It is found that the topography of the valley is not strictly controlled by aggradation rate of the rivers flowing from surrounding hill ranges. The basement lows within the valley region have significantly influenced the topography of the region. Some tributaries of Brahmaputra have been affected by active tectonics of basement structures.

2. Database and methodology
Major data-sets used in the study were Landsat satellite images (1973–2016); 1: 50,000 topographical maps prepared by Survey of India (SOI) surveyed during 1969–1970; 1:250,000 topographical maps prepared by Army Map Service surveyed during 1915–1930 and SRTM-DEM with 30 m spatial resolution. Temporal analysis of the Brahmaputra and its tributaries were done from the toposheets and Landsat images. Palaeochannels of the study area have been delineated from Landsat images, toposheets and ESRI online world imagery. SRTM digital elevation model has been used to collect elevation values. Landsat images are collected from USGS GLOVIS.
and Lohit basement low can be noticed near the foothills of the Himalayas, Naga-Patkai ranges and Mishmi hills, respectively.

Seismic sections along AA′, BB′, CC′ and DD′ show the basement lows and the central basement high (Figure 2). It can be interpreted that the Girujan and underlying formations were deposited prior to the flexure of the basement, as their thickness doesn’t change over basement low/forebulge regions. Rather they are faulted over the basement forebulge. On the other hand, Namsang Formation and overlying sediments have higher thickness towards the basement low regions. This suggests that Namsang and overlying sediments have deposited after the flexure. There was a long deposition hiatus between Namsang and Girujan (Mandal & Dasgupta, 2013). However, the present rate of flexure is very low compared to that during the deposition of the Namsang. Sediment load over the basement and slower convergence rates of Eurasian-Indian-Burma plates (Copley, Avouac, & Royer, 2010) are influencing the flexure rate. Nonetheless, active collision of Eurasian-Indian-Burma plates is still influencing this flexure (Vernant et al., 2014), so as the overlying rocks and sediments of the region.

4. Results and interpretations

4.1. Structural controls on topography

Correlation of topographic elevation and basement depth along selected sections shows some significant correlation between them (Figures 3 and 4). In section AA′, trends of topographic slope and basement slope
Figure 2. Seismic sections (two way travel time) along AA', BB', CC' and DD' (see Figure 1). (Source: Mandal & Dasgupta, 2013). The basement within the valley has flexured by active Eurasian-Indian-Burma collision. Basement depth increases towards Himalayas, Naga-Patkai and Mishmi ranges.

Figure 3. Brahmaputra and its tributaries in 1915–1930 and 2015. The north bank of Brahmaputra river has undergone more erosion relative to the south. Severe erosion has occurred near the mouth of Subansiri river. All north bank tributaries have migrated towards south-west within the last century. Higher erosion near Dibru Saikhowa region has triggered by course change of the Lohit river (Borgohain, Das, Saraf, Singh, & Baral, 2016). Topographic elevation and basement depth have been correlated along AA', BB', CC', DD' and are shown in Figure 4.
The Brahmaputra and its tributaries have undergone significant changes in their courses within the last century (Figures 3 and 5). On the basis of palaeochannel studies using toposheets and satellite images of different years, it is found that the Subansiri river has migrated laterally about 10 km towards east within the period between 1915 and 2015. Comparison of the channels shows that Subansiri, Jiadhal and some other smaller north bank tributaries of Brahmaputra have shown significant migration towards the Subansiri basement low region. The width of the Brahmaputra river within the study area has increased significantly within the last few decades. However, the north bank of the river has been subjected to more erosion than that of the south (Figure 3). Significantly, very high erosion has occurred near Majuli. The mouth of the Subansiri river has undergone severe erosion within the century.

4.2. River morphodynamics

The Brahmaputra and its tributaries have undergone significant changes in their courses within the last century (Figures 3 and 5). On the basis of palaeochannel studies using toposheets and satellite images of different years, it is found that the Subansiri river has migrated laterally about 10 km towards east within the period between 1915 and 2015. Comparison of the channels shows that Subansiri, Jiadhal and some other smaller north bank tributaries of Brahmaputra have shown significant migration towards the Subansiri basement low region. The width of the Brahmaputra river within the study area has increased significantly within the last few decades. However, the north bank of the river has been subjected to more erosion than that of the south (Figure 3). Significantly, very high erosion has occurred near Majuli. The mouth of the Subansiri river has undergone severe erosion within the century.

A few undated palaeochannels have been identified from Landsat images, toposheets and ESRI world imagery (Figure 5). Many of these palaeochannels within the valley can be correlated with their present active channels. Directions of lateral migration of the rivers can be traced from these palaeochannels. Top right part of Figure 5 shows morphodynamics of Siang, Sesseri, Lohit and Noa-Dihing rivers in the Lohit basement low region. All the rivers in that region have achieved their present channels after migrations towards the mountain front. Thus, the general topographic slopes near the foothills of Naga-Patkai and Himalayan ranges are not only controlled by aggradation process, but also influenced by the flexured basement of the region, although it is buried under a thick pile of sediment.
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The lithosphere which has resulted the central basement high and the basement lows near the foothills within the Upper Assam valley. Correlation of topographic elevation and basement depth of the region reveal that topographic slopes along foothills of Himalaya and Naga-Patkai ranges have been greatly affected by Subansiri and Nazira basement lows, respectively (Figures 3 and 4). Figure 6 shows a diagrammatic cross section across Subansiri basement low, the central basement high and Nazira basement low. Continuous convergence has resulted in folding and faulting of the Tertiary sediments over the basement. Some of the induced strain can be released by coseismic displacement along the faults in the overlying Tertiary rocks of Himalaya and Naga-Patkai ranges have been greatly affected by Subansiri and Nazira basement lows, respectively (Figures 3 and 4).

5. Discussions

Tibetan–Himalayan orogenic system represents one of the modern continent–continent collisions and the convergence between these two plates occurred at the rate of ~58 mm/yr (Bilham, Larson, & Freymueller, 1997). Convergence rate remained as high as 118 mm/yr and gradually reduced to 83 mm/yr to current 57 mm/yr in northeastern India between 10 and 20 Ma (Molnar & Stock, 2009). High rate of convergence of the Indian plate against the Eurasian plate coupled with collision with the Burmese plate promoted intense flexure in the lithosphere which has resulted the central basement high and the basement lows near the foothills within the Upper Assam valley. Correlation of topographic elevation and basement depth of the region reveal that topographic slopes along foothills of Himalaya and Naga-Patkai ranges have been greatly affected by Subansiri and Nazira basement lows, respectively (Figures 3 and 4). Figure 6 shows a diagrammatic cross section across Subansiri basement low, the central basement high and Nazira basement low. Continuous convergence has resulted in folding and faulting of the Tertiary sediments over the basement. Some of the induced strain can be released by coseismic displacement along the faults in the overlying Tertiary rocks of the basement high within the valley. Such coseismic stress release in 1950 Assam earthquake might have resulted coseismic subsidence of the sediments of the Subansiri region. As a result, the North Lakhimpur-Ranganadi region, lying over the basement low underwent subsidence during the earthquake. Poddar (1950) reported numerous liquefaction and subsidence between North Lakhimpur town and

Disang river shows channel migration towards Nazira basement low near Nangalamora (Figures 3 and 5 bottom right). The Dikhow river exhibits a palaeochannel 8–11 km south-west from its present course. However, some palaeochannels could not be linked to any present active channel. For example, widths of the palaeochannels near the Diroi river (Figure 5, bottom right) are much higher than any nearby active channel.
Figure 6. Diagrammatic cross section along PQ (see Figure 1) across Subansiri and Nazira Basement lows showing major tectonic structures and stress condition within the Upper Assam valley. Brahmaputra alluvial plain which is sandwiched between Himalayas and Naga-Patkai ranges is experiencing considerable tectonic stress. Some of the induced strain can be released by coseismic displacement along the faults in the overlying Tertiary rocks of the basement within the valley. Under such conditions coseismic subsidence may occur over the basement lows located near foothill regions.

Figure 7. Longitudinal profiles of Brahmaputra and Subansiri rivers in Upper Assam valley. Topographic elevation along the Subansiri river is lower than that part of the Brahmaputra located south of Majuli.
near that region. Major ox-bow lakes and palaeochannels are located along the northern side (Figure 5, bottom right). Moreover, erosion rate of the river is higher along the south bank of the river near Nangalamora. This suggests that the Disang river has achieved the present channel near Nangalamora after a considerable southward migration towards Nazira Basement low region. Sinuosity index of south bank tributaries suggests similar tectonic activity in the region (Figure 8). Sinuosity of Disang and Dikhow rivers increases to 3.1 when they approach the Nazira basement low region. After passing that region, sinuosity of both the rivers decreases abruptly. All other rivers in that region exhibit lower sinuosity than Disang and Dikhow. Relatively higher rate of elevation drop towards Nazira (Figure 4, section AA') is responsible for higher sinuosity of Disang and Dikhow rivers in that region.

6. Conclusion

It is found that unidirectional lateral migrations of some tributaries of Brahmaputra within the study area are triggered by active tectonics of the region. Higher rate of aggradation and channel widening of the Brahmaputra river have been attributed to the huge volume of sediment supply in 1950 Assam earthquake, however more erosion have occurred along the north bank of the river. Prevailed topography of the region is not only controlled by aggradation rate of the rivers flowing from the surrounding mountain/hills ranges of the region, the flexured basement has also played significant role, specially the basement lows and highs. Coseismic subsidence of North Lakhimpur region in 1950 Assam earthquake triggered lateral migrations of some north bank tributaries. On the other hand, historical coseismic subsidence of the Nazira region over Nazira basement low might has led to course change of the Dikhow river and channel modification of the Disang river.

Acknowledgement

We are highly thankful to Council of Scientific and Industrial Research (CSIR) for financial support for this work. We are also thankful to USGS for providing us Landsat images, Digital Elevation Models and information on earthquakes. We would also like to thank Indian Meteorological Department for providing us information on earthquakes. We are also thankful to India Office Library and Records, London, UK, for providing the topographic map of the study area prepared during the period 1915–1930. Finally we want to thank the reviewers for their constructive comments.

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

This work was supported by Council of Scientific and Industrial Research, India Fellowship (CSIR SRF) [grant number 9966-14-44], [Grant recipient Susanta Borgohain].

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