

## Geology of the Shillong Plateau and the Brahmaputra Valley\*

A workshop on the tectonics of the Shillong Plateau and the Brahmaputra Valley was organized recently. It was attended by a number of earth scientists actively working on this region. The programme started with a brief introduction by D. Mukhopadhyay (Raman Centre for Applied and Interdisciplinary Sciences, Kolkata) about the objective of the workshop. The Shillong Plateau is one of the tectonic enigmas on the Indian subcontinent. Its relation with the Himalayan orogenesis, in particular the mechanism of its uplift with respect to the virtually nonexistent Himalayan foredeep to the north and the Bengal Basin to the south has remained a hotly debated topic. A recent GPS study suggests a clockwise rotation of the Shillong Plateau and the Assam Basin with respect to the Indian plate. The objective of this workshop was to brainstorm our current definitive knowledge of the geology and geodynamics of the region to create a clear perspective for addressing the question of evolution of the Shillong Plateau and the Brahmaputra Valley.

V. K. Gaur (Indian Institute of Astrophysics, Bengaluru), presented an account of the GPS-derived surface velocities of sites across the Himalaya and on the Indian shield to its south. The surface velocities of sites in southern Tibet and Nepal show a steady convergence with Bengaluru at the rate of 14–18 mm/year. This steadily decreases southwards to become near zero in the southernmost ~100 km of the Himalayan belt, which implies that the southern ~80–100 km wide Lesser Himalaya is now friction-locked to the under-thrusting Indian plate. There is a distinct difference in the style of deformation of the Indian plate in the region east of Sikkim from that in the west. In the region to the west, surface velocities of the sites on the southern front of the Himalaya and the craton to their south show <3 mm/year convergence with Bengaluru, testifying to the

rigidity of the plate. But, surface velocities of cratonic sites in the northeast, e.g. Tezpur and Guwahati are about 11 and 8 mm/year respectively, requiring this part of the plate to be moving southward with respect to Bengaluru. This raises the question: Has NE India broken from the Indian plate somewhere underneath Himalaya–Tibet? Vernant *et al.*<sup>1</sup> have determined the pole of rotation of the hypothetical micro NE Indian plate. They identified two different regions separated by the dextral Kopili fault and called these the Shillong and the Assam blocks respectively. They recorded an increase of southward velocities from ~3 mm/year at the western Dauki fault to ~6 mm/year in the east, indicating a rotation of the Shillong Plateau and perhaps of the whole Assam block which was upthrust over the Bengal basin crust. However, the data are sparse and this underlines the desirability of designing a comprehensive research project to constrain the geodynamics of NE India. Gaur also referred to the new findings of Supriyo Mitra (IISER, Kolkata) on crustal structure in this region. The challenging questions that the newer findings raise are: (i) what possible structural model(s) of NE India will explain these observations, and (ii) what geological and geophysical investigations would provide discriminating evidences to resolve the most admissible model as well as its implications to hazard assessment and other geological features of the region, notably its tectonic and kinematic relationship with the larger Indian shield?

Supriyo Mitra presented results of the investigation of his group on the crustal structure beneath NE India and discussed how to combine it with earthquake focal mechanisms and GPS-derived velocity vectors to study the kinematics of the Eastern Himalayan System. An array of 13 broadband seismographs was set up and the team used P-receiver functions and joint inversion with Rayleigh wave group velocity dispersion to model the crust and upper mantle structure. It has been observed that the crust beneath the Shillong Plateau, the Mikir Hills and the Eastern Himalayan foreland has similar  $V_s$  and  $V_p/V_s$ , and is felsic in nature.

However, the crustal thickness varies three-dimensionally. The central Shillong Plateau and Mikir Hills have the thinnest crust ( $31 \pm 2$  km). The crustal thickness increases abruptly by  $10 \pm 2$  km north of the Mikir Hills, while it increases gradually north of the Shillong Plateau. The earthquake source mechanisms show that the crustal thickness variation is associated with thrusting of the Shillong Plateau and the Mikir Hills over the Eastern Himalayan foreland. The Kopili fault zone between the Shillong Plateau and the Mikir Hills is marked by dextral strike-slip earthquakes, whose slip vectors match the GPS-derived relative velocity vectors. Across the southern edge of the Plateau, marked by topographic break and surface trace of Dauki fault, the Moho down-steps abruptly from  $36 \pm 2$  km (south Shillong Plateau) to  $48 \pm 2$  km (north Bengal Basin). Further south the crustal thickness decreases to  $20 \pm 2$  km and is associated with a sharp transition from felsic to mafic crust. This mafic crust resembles thinned passive continental margin crust, and underlies the entire eastern Bengal Basin. This crust in the entire Bengal Basin (south of the Shillong Plateau) is overlain by the thickest pile (18–20 km) of continental sedimentary strata. Moderate earthquakes south of the Shillong Plateau originate within the Bengal Basin crust and have strike-slip mechanism. These earthquake faults obliquely accommodate a part of the GPS-inferred convergence between the Plateau and the Bengal Basin. Mitra's team concluded that the uplift of the Shillong Plateau and Mikir Hills is controlled by flexure and faulting of the Indian crust to the north and by abrupt change in crustal structure to the south.

K. S. Krishna (NIO, Goa) presented key results related to the basement morphology of the Eastern Continental Margin of India (ECMI) and adjoining deep-water region and sediment depositional pattern in time and space in the Bay of Bengal. The basement morphology in the vicinity of shelf-slope region of the ECMI reveals that the margin is traversed by major Gondwana graben structures as an extension of onshore rift/

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shear zones. The ancient structures are found to extend from coastline to offshore region for about 100–125 km, where the graben structures get terminated against the proto-oceanic crust. In deep-water region, the 85°E Ridge is identified as an elevated feature of >3 km rise from the adjacent basement floor. It is found that the ridge structure is discontinuous in the vicinity of 16°N and finally terminates at around 18°N. Krishna highlighted the continuity of the rift-related continental shelf-slope feature along the ECMI and its absence in the region of offshore Bengal Basin; instead the shelf-slope feature seems to be continuing onshore and possibly connects with the Eocene palaeo-shelf boundary that lies on the southern side of the Rajmahal and Sylhet traps. These inferences tend to support the view regarding the presence of transitional or oceanic crust beneath most part of Bangladesh. He pointed out that these new insights will have a bearing on the tectonics of the Shillong Plateau. He also discussed the sediment deposition pattern from rivers of peninsular India and Bengal Basin, and found new age constraints for the time of initiation of Bengal Fan sediments and sediment accumulation in response to the strengthening of the monsoons at 7–8 Ma.

Malay Mukul (IIT, Bombay) briefly outlined the first-order questions that remain unresolved in the Shillong Plateau and indicated that these were submitted as a part of an integrated, multi-institutional project to SERB, DST under an initiative by A. Sarkar (IIT Kharagpur). Mukul pointed out that the nature of the bounding faults of the Shillong Plateau needs to be resolved. While the Dauki fault is recognized as the south-bounding fault of the Shillong Plateau, its kinematics is not clearly understood. The north-bounding fault of the Plateau has been recognized as the Oldham Fault<sup>2</sup> or the Brahmaputra Fault<sup>3</sup>. Surface signatures of these faults have not been reported; therefore it is possible that these are blind. Subsurface geophysical imaging may be able to resolve the geometry of these faults and establish the north bounding fault of the Shillong Plateau. In addition, the presence or absence of a decollement in the subsurface of the Shillong Plateau needs to be established to determine if the style of deformation in the Plateau is thick-skinned<sup>2,4</sup> or thin-skinned. The geometry of surface and

shallow subsurface structures in the Shillong Plateau also need to be carefully analysed through surface-mapping and subsurface geophysical imaging for a better understanding of the kinematics of deformation in the region. It was also pointed out that the convergence estimates obtained from GPS data suggest that the eastern and western parts of the Shillong Plateau are experiencing E–W and N–S shortening respectively.

Sujit Dasgupta (formerly Geological Survey of India) mentioned that during the 80 years time span between 1869 and 1950, eight large earthquakes struck NE India, but no co-seismic surface rupture was shown to be produced by any of them. He drew attention to the fact that NE India is located between two advancing deformation fronts, the Himalayan and the Indo-Burmese orogenic belts. Anomalous geomorphic features indicating neo-tectonic activity are abundant along the Himalayan foothills. Geomorphic landscape and late Quaternary geological attributes from the Raidak–Manas interfluvium in the foothills of Kokrajhar district, Assam led towards identifying an east–west trending, south dipping, 30 km long active Frontal Back Thrust (FBT), well within the foredeep south of the Main Frontal Thrust (MFT). Spectacular north-facing tectonic scarp along with a complementary, subdued south-facing scarp defines the terrain as a pop-up structure. Clay beds deposited in lakes along the footwall of the FBT have formed due to blockade of south-flowing rivers by episodic uplift of the hanging wall block; three such episodes of uplift since 16 k years correspond to three morphogenic earthquakes of magnitude ~6.9 rupturing the FBT during late Pleistocene–Holocene.

Sarajit Sensarma (Lucknow University) discussed about the tectonics–lithology–climate interactions in developing weathering profiles in the Shillong Plateau. The basement was submerged under sea until Mio-Pliocene transition (6–4 Ma ago), and ongoing chemical and physical weathering may have been taking place since late Pliocene (<4 Ma ago). The geochemical changes accompanying chemical weathering are described. On the basis of saprolite production rate of ~2 m/Ma (the least value of weathering rate obtained in the humid tropics over different lithologies in different parts of the world), 5 m thick saprolite development on Shillong quart-

zite would require 2–3 Ma. This implies that chemical weathering on Shillong quartzite is dominant without much erosion since Pliocene in a transport-limited condition, suggestive of long-term tectonic quiescence in the area. Similarly assuming weathering rate of ~10 m/Ma over granite, ~30 m thick saprolite would develop on granitoid gneiss in the last ~3 Ma. However, 7–8 m thick saprolite is now preserved on granitoid gneiss in the Shillong Plateau. This calls for aggressive erosion in the area which stripped away about two-third of the saprolite formed, suggesting tectonic instability and movement. The apparent discrepancy has to be resolved by independent measurement of erosion rate *vis-à-vis* chemical weathering rate in the area using short-lived isotopes.

Mallika Mullick (Raman Centre of Applied and Interdisciplinary Sciences, Kolkata) presented GPS data from stations set up on the Quaternary sediments in the Darjeeling–Sikkim Himalaya foothills and the Bengal Basin. The shortening rate of Bangalore–Lhasa and Bangalore–Baradighi (close to MFT) baselines is  $13.6 \pm 1.8$  and  $2.0 \pm 1.8$  mm/year respectively. This implies that the Indian shield behaves as a nearly rigid plate right up to MFT. The Baradighi–Ambioke (close to MCT2) baseline is shortening at the rate of  $11.1 \pm 1.5$  mm/year, indicating that most of the orogenic shortening is taking place in the frontal part of Himalaya rather than in the internal part. Analysis of GPS data from the Bengal Basin is in progress.

Chandreyee Chakrabarty (University of Calcutta) described geomorphic features, in particular the drainage pattern and river terraces, associated with active faults in the Quaternary sediments in front of the Himalayan foothills. She illustrated that several of the E–W trending scarps within the Quaternary sediments represent the front limb of ramp anticline (fault bend fold) above blind thrusts. Geomorphic features testify active movement both on orogen parallel and transverse faults. She suggested that the Manabhum anticline within the Quaternaries of Eastern Arunachal is formed as an effect of both Himalayan and Naga–Patkoi tectonism.

There were lively discussions on the presentations and the workshop concluded by noting down a few major problems to be addressed by future inter-institutional research projects:

(1) What model of tectonism would explain the surface velocity data in NE India, particularly in the region between the Himalayan and Indo-Burman fold-and-thrust belts? More dense coverage of GPS stations in the region between the Himalaya and the Bangladesh plains is necessary.

(2) Nature of the Bounding Faults of the Shillong Plateau and determination of the geometry of deformation in the Plateau have to be established by surface (geology) and shallow subsurface (geophysics) data. Is the deformation in the Plateau thin-skinned or thick-skinned? This will involve fine-scaled intracrustal imaging in the Shillong Plateau and the Eastern Himalayan foreland and will aim at working out whether a basal decollé-

ment is present under the Shillong Plateau or not.

(3) Gravity field in the area has to be studied from the seismotectonic point of view.

(4) Understanding the Moho geometry and to assess how long it has been there. What are its implications to the shallow subsurface tectonics of the region?

(5) Climate–tectonics coupling and erosion and exhumation rates in NE India and, in particular, the Shillong Plateau.

(6) Study of convergence rates in the Indo-Burman fold-and-thrust belt and its geometry and kinematics. Understanding the coupling of thrust and strike–slip tectonics in the region. Does part of the Indo-Burman fold-and-thrust belt extend into the Bay of Bengal? Working out

submarine geometry of the thrust belt is an important task. Is E–W compression in the Indo-Burman thrust belt still active? Could that activity produce tsunamis in the northern Bay of Bengal?

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