could befall them. In the Mayurakshi basin alone, the length of embankment is 377 km. The efforts in this direction have interfered with the natural course of drainage across the region. At some places, IWD has undertaken construction of drainage channels to relieve certain areas from drainage congestion and waterlogging. However, these efforts have had a reverse effect exacerbating the flood condition.

Physiographic features of the study area favour natural generation of floods. By comparing the elevation pattern of the study area with that of inundation pattern of the year 2000, recorded as one of the biggest flood events ever to hit the block, it is found that topography plays the most important role in inundation. Outflows of a huge volume of extra water from Hijal Beel during rainfall and loss of carrying capacity of the Mayurakshi River are also responsible for flood severity in the Kandi block. So it is impossible to control the occurrence of floods in the region. We must adopt a preparedness-driven approach relating to flood and vulnerability analysis; improving the community's adaptive capacity, etc. are much more significant management options. In West Bengal all the flood control measures are structure-oriented in examining only the physical exposure. The socio-economic structure of that area is overlooked during formulation of any flood management plan at the district level. It is evident that the people involved in flood management conceived building structures like embankment, barrage, canals, etc. as the sole control. Non-structural approaches always remained obscure. We must develop proper flood management plans which will consider the social aspect along with biophysical aspect.

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Glossifungites ichnofabric signifying Crustacean colonization in early Permian Barakar Formation, Talchir Coal Basin, India

Biplab Bhattacharya[1,]*, Sudipto Banerjee[2] and Sandip Bandyopadhyay[2]

[1]Department of Earth Sciences, Indian Institute of Technology, Roorkee 247 667, India
[2]Department of Geology, Hooghly Mohsin College, Chinsurah 712 101, India

Early Permian Barakar Formation (Gondwana Supergroup) in peninsular India was earlier interpreted as deposited in braided-meandering fluvial system. Intense burrowing by decapod crustaceans of marginal marine affinity led to *Thalassinoides–Ophiomorpha–Rhizocorallium* ichnoassemblage, belonging to *Glossifungites* ichnofacies, within the sandstone–mudstone heterolithic facies near the upper part of the Barakar sedimentary succession, Gouduni River, Talchir coal basin, Odisha, India. An early cementation of the sandstone–mudstone interbeds under changed salinity condition is attributed to mixing of fluvial channels with tide-wave influenced marine depositional systems. This resulted in a semi-consolidated firmground, favouring incipient crustacean colonization during prolonged phases of marine incursion within a fluvial–marine interactive estuarine system during the early Permian in eastern peninsular India.

Keywords: Crustacean trace fossils, coal basin, estuarine firmground, fluvial system, *Glossifungites* ichnofacies.

ICHNOFOSSIL assemblages in sedimentary successions provide convincing evidences of sediment–organism interactions under different substrate conditions and changing palaeoecological control parameters[1,2]. Ethological

*For correspondence. (e-mail: bb.geol.dgc@gmail.com)

attributes of arthropods, especially the decapod crustaceans of Palaeozoic and post-Palaeozoic ages have attracted the attention of the ichnologists[1–3]. *Thalassinoides*, *Ophiomorpha*, *Spongeliomorpha*, *Rhizocorallium*, *Macanopsis*, *Gyroliths*, etc. are common burrows produced by decapod crustaceans like crabs and shrimps in shallow marginal marine[4,5], subtidal[6] or intertidal environments[2,3,7]. Crustaceans producing *Thalassinoides* are ascribed as the most common organisms from estuarine (brackish to saline) settings of the Permian age all over the world[2,8,9].

Several studies have addressed the trace fossil assemblages from the late Paleozoic Lower Gondwana successions in peninsular India[10–15]. Trace fossils of various types are abundant within the coal-bearing upper Barakar succession (early Permian) in peninsular India[10–12,15]. Studies on the Barakar Formation depict a *Skolithos*–*Thalassinoides*-dominated ichnoassemblage, interpreted as characteristic of a marginal marine setting[16,17]. On the basis of prevalent facies architecture at different stratigraphic levels, a fluvial depositional system is envisaged at the lower part of the succession, followed by a fluvio-marine interactive system in the upper part of the succession, with increasing influence of marine processes on fluvial systems[15–17]. Signatures of marine influences on fluvial processes attest to a mixed, deltaic to estuarine depositional system during the upper Barakar sedimentation[16–18].

This communication reports evidences of colonization by decapod crustaceans of the early Permian from the upper Barakar sedimentary succession, Gouduni River, Talchir Basin, Odisha, India. The present work documents an example of animal–substrate interaction in response to changed palaeoecological–palaeodepositional controls during the early Permian in eastern peninsular India.

Coal-bearing Barakar Formation (early Permian) in Talchir Gondwana Basin, Mahanadi Valley, eastern peninsular India, is represented by ~1000 m thick continental fluvial sedimentary succession[19]. The present study reports *Thalassinoides* and associated trace fossils from a section of approximate lateral length 65.5 m and vertical thickness ~8.2 m, exposed along the western bank of the Gouduni River near Dahibar village, Odisha, India (lat. 21°5′35.78″N, long. 84°54′18.8″ E) (Figure 1).

Sedimentologically the Barakar Formation is represented by (i) lenticular conglomerate facies (facies A), (ii) coarse- to medium-grained, massive sandstone facies (facies B), (iii) trough cross-stratified sandstone facies (facies C), (iv) ripple cross-laminated sandstone facies (facies D), (v) sandstone–mudstone heterolithic facies (facies E), (vi) laminated shale facies (facies F), and (vii) coal facies (facies G). Trace fossils are abundant in the ripple cross-stratified sandstone facies, sandstone–mudstone heterolithic facies and the laminated shale facies. Facies architecture in the lower part, consisting of facies A–C and G, suggests braided to meandering fluvial depositional processes with formation of coal-forming mires in the flood plains. Association of facies D–F, characterized by signatures of marine tide-wave influences on fluvial channel sedimentation in the upper part of the succession indicates a fluvial–marine mixed (estuarine) depositional set-up[15,16] in the middle–upper part of the succession, with increasing marine influence towards the top. Thin coal seams (of Facies G) are present at different stratigraphic horizons within this facies succession.

The sandstone–mudstone heterolithic facies is the main repository of the studied crustacean trace fossils. Sandstone is ripple cross-stratified with mud-draped forests. Bidirectional ripple cross-strata and flaser beddings are also common. Petrographically, the sandstone is feldspathic arenite (Figure 2 *a*) with abundant pore spaces filled by carbonate cement (Figure 2 *b*–*f*). Two generations of carbonate cement are recognized, viz. an early phase represented by isopachous microcrystalline rims around detrital quartz and feldspar (Figure 2 *b*), and a late-phase sparitic carbonate that occurs within secondary irregular/tubular cavities or fenestrae (Figure 2 *c*). Externally the fenestrae are often lined with fine pellets (Figure 2 *d*). Sparitic carbonate infilling has a drusy mosaic fabric (Figure 2 *e*). First-generation microcrystalline cement is responsible for the resorption and partial alteration of the detrital grains along with floating quartz and feldspar within carbonate mosaic (Figure 2 *f*). The overall appearance of the rock is similar to calcareous soil (calcrete)[20].

The sandstone–mudstone heterolithic facies with mud-draped foresets and development of flaser bedding indicate a low-energy sand–mud depositing environment[16,18]. Bi-directional cross-strata attest to deposition under mutually opposite tidal current. Stacking of such tidal sediments suggests the influence of tidal currents of varied intensities[18]. Sand-dominated and mud-dominated lithounits within such stacked facies sequences indicate deposition in the distributory channels and the tidal flats, respectively[16,18].

Abundant isopachous micritic rinds indicate early carbonate cementation of the sediments under subaqueous condition before significant burial and compaction of sand. Such early cementation possibly produced a relatively hard substrate (firmground) on which various organic activities took place, followed by subaerial exposure indicated by the development of calcareous soil in marine influenced environment[20]. Desiccation of the sediments and/or burrowing by organisms produced fenestrae within the firmground. Further submergence led to the infilling of the cavities with drusy sparitic calcite. Such textural architecture with signatures of repeated water-level fluctuation indicates tidal influence within an estuarine depositional system.

The studied succession is dominantly bioturbated by trace fossils of the ichnogenera *Thalassinoides* isp., *Ophiomorpha nodosa*, *Teichichnus rectus* and *Rhizocorallium jenense*, mostly concentrated in the sandstone–mudstone heterolithic facies.

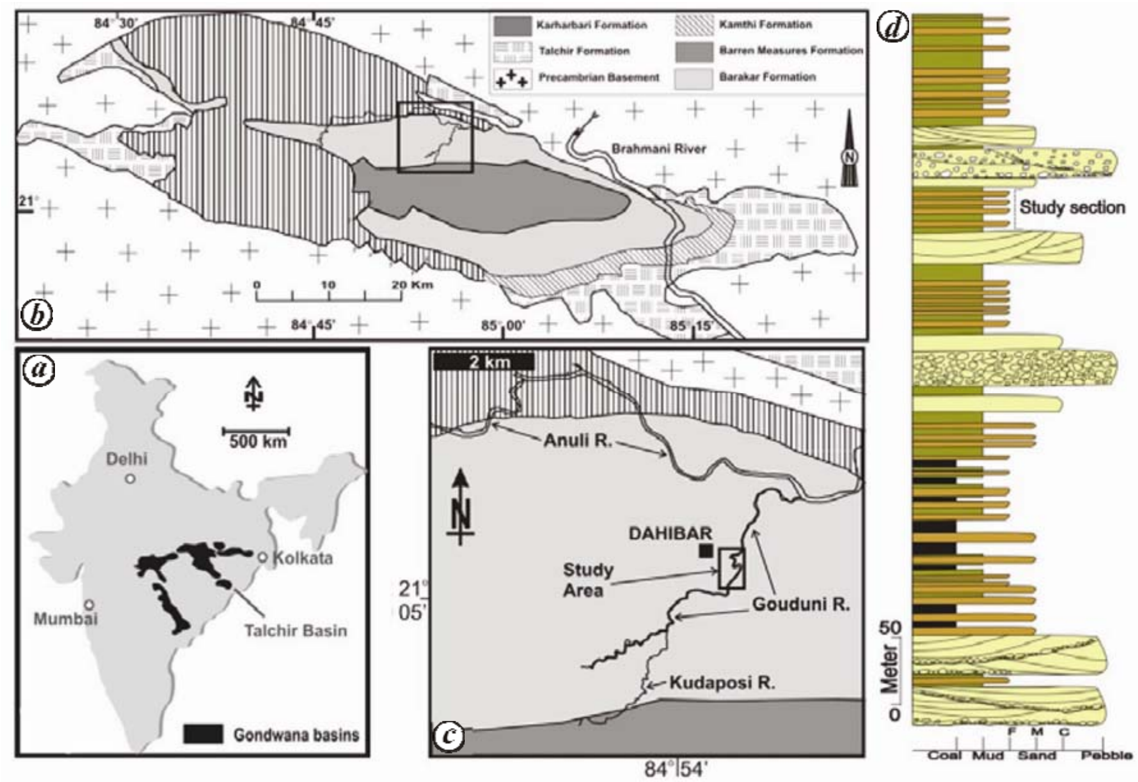

Figure 1. ***a***, Map of India showing the location of the Talchir Basin. ***b***, Geological map of the Talchir Basin showing the distribution of different lithounits. ***c***, Detailed map showing the study area (shown within the box in (***b***)) and location of the village Dahibar. ***d***, Generalized sedimentological log of the Barakar sedimentary succession as exposed along the Gouduni River section, Talchir Basin.

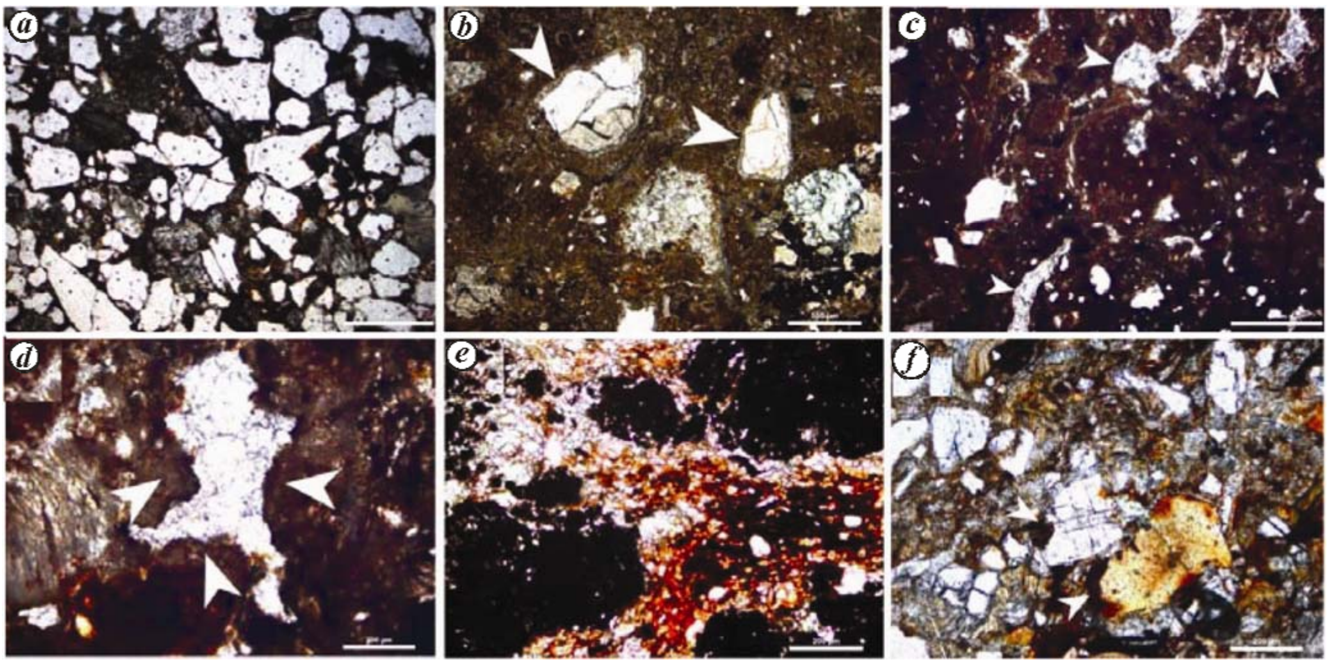

Figure 2. Photomicrographs. ***a***, Coarse-grained feldspathic arenite indicating the general petrographic character of sandstone within the sandstone–mudstone heterolithic facies. ***b***, Presence of isopachous rinds (arrows) around sparite-filled pore spaces within the sandstone. ***c***, Secondary pore spaces filled up by sparitic cement (arrows) of later generations within the sandstone. ***d***, Sparite-filled cavities with micropelloidal linings (arrows) around the pores. ***e***, Development of drusy mosaic within sparite-filled pore spaces. ***f***, Resorption and partial alteration (arrows) of the detrital feldspar grains by the micro-crystalline carbonate cement within the sandstone.

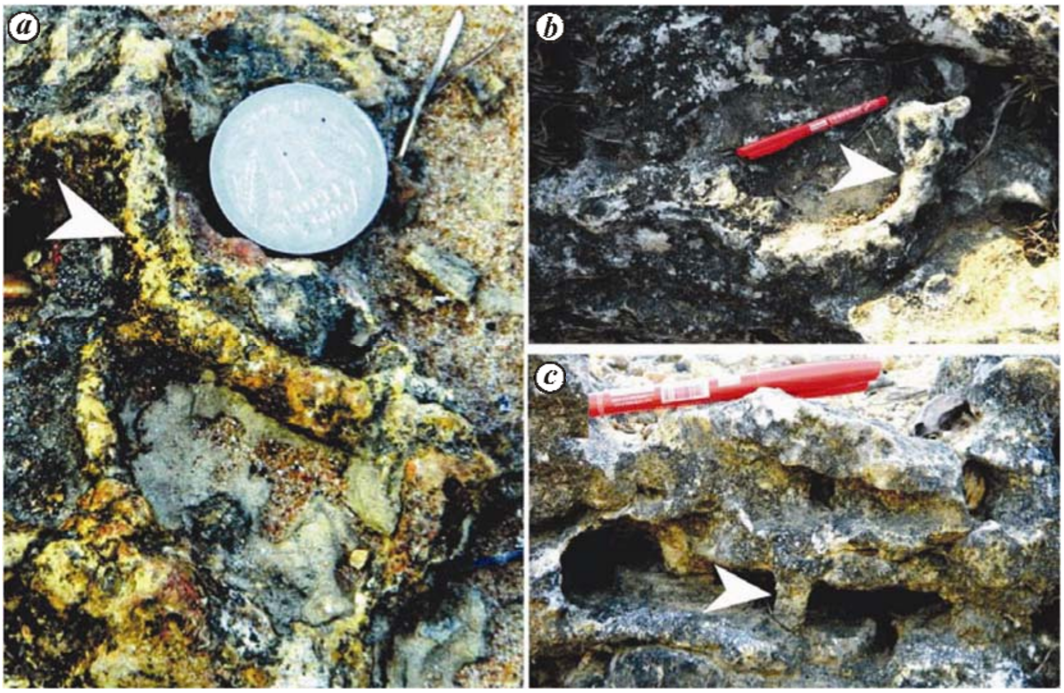

Figure 3. ***a***, *Thalassinoides* isp. (arrow) showing *Y*-shaped and *T*-shaped branching. Diameter of the coin is 2.3 cm. ***b***, *Thalassinoides* isp. showing beaded, horizontal tubes preserved on bedding plane. Length of the pen is 14.2 cm. ***c***, *Ophiomorpha nodosa* showing vertical shafts (arrow). Length of the pen is 14.2 cm.

Thalassinoides isp. (Figure 3 *a* and *b*) is the most abundant ichnoform, commonly preserved at the sandstone–mudstone interface or within mudstone (Figure 3 *a*). It is characterized by an unlined, smooth-walled, epichnial and/or endichnial horizontal tunnel system, filled with yellow/red-coloured carbonate mud, and show *U*-turn and *T*/*Y*-shaped branching (Figure 3 *a* and *b*). Swellings at points of bifurcation and vertical shafts are common, producing bead-like forms (Figure 3 *b*).

O. nodosa (Figure 3 *c*) occurs in mudstone and medium- to coarse-grained sandstone. In mudstone, it is commonly associated with *T. rectus* and *Thalassinoides* isp. *O. nodosa* (Figure 3 *c*) is identified by *Y*-branched, rough/scratched-walled, vertical/inclined tubes filled with coarse-grained sandstone, exposed as small mounds on medium-grained sandstone bedding surface. *T. rectus* is continuous, unlined, epichnial to endichnial, vertical to inclined, sand-filled tunnelled burrow with characteristic retrusive spreiten laminae in vertical column, preserved as hypo-relief. Apart from these, ichnotaxon *Rhizocorallium jenense*, characterized by retrusively spreiten, horizontal *U*-tubes with spreiten laminae between two parallel arms of the *U*-tube, is present on the mudstone bedding surface associated with abundant faecal pellets.

Bioturbation index is moderate (BI ≥ 3) in the mudstone beds and the mudstone-dominated heteroliths, causing partial destruction of the original sedimentary fabrics. Distinct phases of development of the ichnofabrics are observed. *R. jenense*, *T. rectus* and few *Thalassinoides* isp. represent the early-formed, shallow-tiered ichnocoenoses developed on softgrounds. These are commonly penetrated and partly destroyed by a late phase, deep-tiered *Thalassinoides–Ophiomorpha* ichnoassemblage that developed on partly cemented (firmground) sandstone–mudstone heteroliths.

Amongst the firmground (omission surface) ichnoforms, *Thalassinoides* isp. is produced by facies-crossing crustaceans[1], preferably on semi-consolidated/firm substrate to avoid burrow collapsing[7]. Swellings at branching indicate turning by the organisms. *O. nodosa* is produced by Callianassid crustaceans in modern shallow marine environments[21]. In the study area, the burrow system of *O. nodosa* is found as deep-tiered omission surface (firmground) ichnoform, in contrast to its common occurrence in pre-omission surface (softground)[6]. Amongst the softground (pre-omission) ichnoassemblage, *T. rectus* is regarded as shallow, near-surface 'equilibrichnia' of annelids or worms[22], formed by upward migration of horizontal to sub-horizontal tunnel while the organism moves back and forth in the same vertical plane for food. However, its association with deposit feeders in the study area and the regular spreiten laminae attest to fodinichnian origin. It is associated with *R. jenense*, which may form by suspension-feeding crustaceans[23] or annelids[24] on softgrounds in medium- to low-energy environment[25]. The spreiten laminae between the two arms of the *U*-tube indicate the previous positions of the advancing tube through the sediment[12,14].

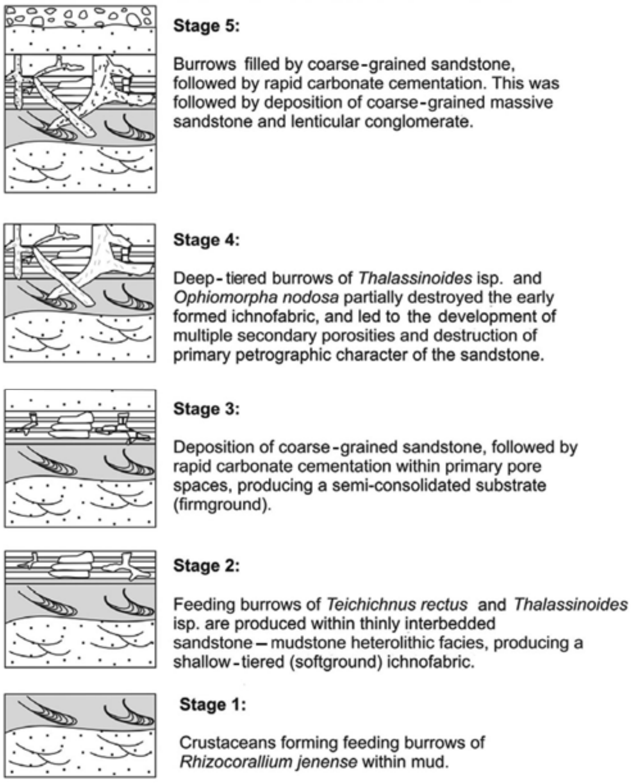

Figure 4. Schematic diagram showing phases of development of different substrate conditions and associated ichnofabrics in the study section.

Lower Barakar succession is characterized by braided fluvial depositional system, followed by development of a meandering channel system with rapid migration of the channels and lateral accretion/coalescing of bars during upper Barakar sedimentation[11,15–17]. Signatures of tide and wave influences on the channel-fill sediments during upper Barakar sedimentation attest to downcurrent debouching of these channels into a transgressive sea, which was adjacent to the peninsular Gondwanaland during the early Permian[16–18,26].

Such transition and mixing up will definitely cause a gradation of saline to freshwater condition with intermittent mixed, low-salinity zones (brackish water) within the estuary system depending on the relative influence of transgressive marine water[16–18].

Non-impoverished *Thalassinoides–Ophiomorpha–Rhizocorallium* ichnoassemblage in the study area indicates ethologic changes of decapod crustaceans with corresponding change of substrate from softground to firmground[27] (Figure 4). *Thalassinoides* is produced by decapod crustaceans of the superfamily Thalassinidea, including *Upogebia affinis*, ghost shrimp *Callianassa*, shrimps (e.g. *Glyphaea*, *Alpheus*), lobsters and crabs[2,7]. *O. nodosa* is produced exclusively by crustaceans of marine affinity[5]. *R. jenense* reflects periods of minimum disturbance and probably high influx of organic matter within the sediment[2]. Mutually exclusive occurrence of these ichnoforms with *Thalassinoides* in vertically adjacent beds implies that the ethological attribute of the trace makers changed significantly under varying energy conditions. Moderate ichnodensity with moderate to high bioturbation index, low ichnodiversity, near-absence of trace-making organisms other than crustaceans are possibly due to their adaptation to wide salinity variance and changed substrate conditions (softground to firmground)[8,28]. Wide lateral distribution within a small stratigraphic window of the ichnoforms and their preferable concentration in fine-grained siliciclastic softground–firmground attest to short-span colonization by the decapod crustaceans in the study area. Such an ichnoassemblage is classified under the *Glossifungites* ichnofacies, representing burrows in 'firm but unlithified marine littoral and sublittoral omission surfaces, or stable, coherent substrates'[8,27,28]. Firmground *Glossigungites* ichnofacies are common in modern fluvial–marine interactive systems (e.g. in estuaries)[28]. Thus, the inferred crustacean colonization complements the development of fluvio-marine mixed (estuarine) ecosystems in certain parts of the eastern peninsular India during the early Permian.

Signatures of dwelling and feeding activities of the early Permian decapod crustaceans, belonging to the *Glossifungites* ichnofacies, are documented from the Barakar sedimentary succession of the Talchir coal basin, Odisha, India. Exclusive crustacean activities within the carbonate cemented siliclastic firmgrounds indicate their short-span colonization. The Permian is well-known for global crustacean radiation[7–9]. Crustacean colonization in Barakar sediments is a possible manifestation of such global phenomenon.

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Ascertaining the neotectonic activities in the southern part of Shillong Plateau through geomorphic parameters and remote sensing data

Watinaro Imsong[1], Swapnamita Choudhury[1] and Sarat Phukan[2,*]

[1]Wadia Institute of Himalayan Geology, Dehradun 248 001, India
[2]Department of Geological Sciences, Gauhati University, Guwahati 781 013, India

Study of quantitative morphometric parameters was taken up in four major river valleys in the southern part of Shillong Plateau using SRTM DEM in GIS. The study indicates that the region is undergoing differential uplift. This is evidenced by preferential tilting towards east, while the central part of the plateau exhibits higher rate of uplift than the eastern and western segments. We ascribed the higher rate of uplift in the central segment of Shillong Plateau to the activity along the Dapsi Thrust and Dauki Fault.

Keywords: Active tectonics, geomorphic parameters, morphometry, remote sensing, river basins.

THE Shillong Plateau is considered as a detached block of a subducted wedge of the peninsular India in front of the Indian and Tibetan continental mass[1]. It is bounded by the Dauki Fault in the south, the Himalayan Orogenic Belt in the north, the Kopili Fault in the east and the Dhubri Fault in the west (Figure 1). Beyond the Dhubri Fault lies the Bengal Graben further to the south[2–4]. The Shillong Plateau is considered as a tectonically active popup continental block[1,5–8]. The existence of the proposed Oldham Fault[7] (Figure 1) representing the northern margin of the pop-up tectonics is, however, debatable[8]. The Dauki Fault which runs along the border between the

*For correspondence. (e-mail: saratphukan@gmail.com)