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REBUTTAL

Morphological signatures of fault lines in an earthquake prone zone of southern Baromura hill, north-east India: a multi source approach for spatial data analysis. A critical review

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Abstract In a recent work, Dey et al. (Environ Earth Sci 59:353–361, 2009) presented some new observations on the southern part of one of the anticlinal ridges of Tripura, viz. the Baromura range. The work incorporated a number of irregularities and misinterpretations that need to be addressed to avoid future confusion. The present article critically reviews Dey et al.'s paper to bring out its inaccuracies.

Keywords Chittagong-Tripura Fold Belt · Plunging anticline · Lineament · Spectral signature

Introduction

The Chittagong-Tripura Fold Belt (CTFB), Bangladesh and India, consists of a series of westward-convex N–S trending anticlinal ridges formed of Bengal Basin sedimentaries. It was accreted on remnant oceanic crust of the subducting Indian plate by flysch formations derived from the peripheral highlands in an arc-trench setting. The CTFB is a relatively young region of deformation and may be viewed as a westward extension of the more matured Indo-Burman Ranges (Gani and Alam 1999). The Indian state of Tripura occupies the northern part of the CTFB and consists of five major ridges (250–950 m a.s.l.) with progressively higher elevation and intensity of folding towards the east. Crests of most anticlinal ridges in the CTFB have varied altitudes and are double plunging. Crustal shortening rate of the northern CTFB is estimated to be 1.5 mm $year^{-1}$ (Jade et al. 2007). Most major earthquakes of the region are deep-seated and are relate to the ongoing subduction process (Steckler et al. 2008).

Dey et al. (2009), in a recent work published in the Environmental Earth Sciences, presented some observations on the southern part of one of the anticlinal ridges of Tripura—the Baromura. However, this work incorporated a number of irregularities and misinterpretations that need to be addressed to avoid future confusion. These are as follows.

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Issues related to methodology

- Dey et al. stated that a major hindrance to their research was 'the inaccessibility of homogeneous digital data of the whole study area' and that it was 'really very difficult to collect the high-resolution satellite images or air borne photographs in the developing countries especially in this restricted zone of Indo-Bangladesh border' (p. 355). They also found it 'remarkable' that most of the images available for their study area are 'monospectral or radiometric data' and stated that 'multispectral data of only few parts of the study area were found'.

  Contrary to the above view, a large number of Landsat scenes covering Tripura since mid 1970s are freely available from the United States Geological Survey (glovis.usgs.gov). In various missions of Landsat, one MSS scene (path-146, row-43), and two TM or ETM+ scenes (path-136, row-43 and -44) cover the entire CTFB. Additionally, data from the Indian Remote

Sensing Satellite (IRS) missions are available in various sensor or band combinations since 1988 and have been widely used in northeast India by many workers such as Roy and Tomar (2000), Roy and Joshi (2002), Chand and Badrinath (2007) and Chakraborty (2009). High-resolution monospectral data of Tripura from IRS series of sensors—LISS-4 (pixel size: 5.6 m) and Cartosat-1 Pan (2.5 m)—are also available for a long time from India's National Remote Sensing Centre (http://www.nrsc.gov.in) and there is no restriction in purchase of these scenes. Aerial photography in India is carried out by Survey of India and the photos are mostly considered as classified. However, Corona space photos have recently been declassified by the US Government and at least two 1962 images of Tripura, covering parts of the Baromura range, are available (No. DS009048070D-A272 and -F269). It is also not clear why the authors specially mentioned 'radiometric data' because all satellite data are radiometric.

- The authors repeatedly stated that they used an 'old' Digital Elevation Model (DEM) prepared from a 1999 IRS LISS-3 FCC for final mapping (p. 353, 356, 361). It is obvious that to prepare a DEM one would require some information on elevation from topographical maps, stereo images or radar interferometry data like Shuttle Radar Topographic Mission (SRTM). It is not possible to extract altitude information from conventional satellite sensors like LISS-3 and it is beyond comprehension how the authors could do it.
- Principal application of the four- to six-band Advanced Very High Resolution Radiometer (AVHRR) sensor is to map the cloud and thermal emission of the earth. It has a spatial resolution of 1.1 km at nadir and has little geological usefulness. Eidenshink (1992) developed an algorithm for radiometric calibration and solar illumination correction of AVHRR bands 1 (red) and 2 (near infrared) for preparing normalised difference vegetation index (NDVI) composites. Despite this, Dey et al. based one of the main premises of their paper on Eidenshink's calibrations although they were using a 2007 SPOT Panchromatic image in their study, usually having a resolution of 2.5–5 m (SPOT-5) or 10 m (SPOT-1 to -4). The authors nowhere mentioned the exact date of pass and spatial resolution of their data. SPOT has different orbital characteristics from the TRIOS/NOAA satellites that carry the AVHRR sensors. Thus, the calibrations meant for the latter cannot be applied to the former.
- The statement that 'scanned toposheets of 1:50,000 scale provide a pixel resolution of 5 m' (p. 355) hardly makes any sense because the authors did not mention the value of pixels-per-inch (ppi) in which the maps were scanned. Moreover, the sharpest lines shown in Survey of India topographical maps are not finer than 0.2 mm. On a 1:50 k map this is equivalent to 10 m. Therefore, no advantage is gained from decreasing the pixel size of the scanned maps, georeferenced and resampled, beyond 10 m. The authors also stated that they had 'redrawn' and converted the 1:63,360 maps to 1:50 k to 'get 5 m resolution in digital format'. But georeferencing the two maps in a digital environment would have automatically brought them to similar scale and made them compatible to each other. It is also not apparent what purpose two topographical maps of the same area served to their research.
- Dey et al. stated that Fig. 1 of their paper showed 'location and environs of the study area'. Southern limit of this map is a few km south of 23°45′N and it covers the northern part of the Baromura Hills. However, the study conducted by the authors concentrated on the southern Baromura area which is situated in the area south of 23°45′N.
- The scale of reflectance and DN values of different rocks in the study area, as depicted in Fig. 2 of Dey et al., is also open to question. In it, landcover of the study area was shown to change from sandstone through clay, shale and vegetation within a space of 15 pixels. It is not clear how the authors determined the association between the greyscale values with the described landcover types without performing any field verification. It is also not apparent what use was made of the ETM+ Band 5 (near infrared) data that formed a part of Dey et al.'s 'main digital dataset' (p. 356).
- The flowchart of 'methodology for integrated digital operation' shown in Fig. 3 has little logical basis. For example, it is difficult to understand why georeferencing of satellite images was done *after* visual and DN analysis or why the topographical and geological maps were digitised without performing georectification first. In the article, there is no discussion of the nature of data that were digitised from these maps or how they were utilised.
- Dey et al.'s Table 3 showed morphological signatures of physical features of the Baromura Range which, the authors claimed, were sourced from GPS survey during December 2007–February 2008. In it, 12 latitudinal and 16 longitudinal values were displayed in a matrix of rows and columns. The data were measured in degrees up to six decimal places. Interestingly, a particular latitude (e.g., 23.075210°N) was recorded by GPS in 3–6 different longitudinal positions (e.g., from 91.425032°E to 91.523404°E—a linear distance of about 10 km). Similarly, a given longitude (e.g., 91.499480°N) was measured in up to 8 different latitudinal positions (e.g., from 23.574825°N to 24.075210°N—a distance of some 55 km). This

translates into following 12 or 16 individual straight lines, arranged in a grid, for 10 s of km without deviating even for a metre from their intersection points. Such accuracy is nearly impossible to achieve in an inaccessible hill range covered with dense tropical vegetation that inhibits a clear view of the sky resulting in high dilution of precise positioning. The sub-metre accuracy of GPS positioning also calls for differential operation with post-processing of data from base and rover receivers. The types of GPS equipment and software used by Dey et al. have nowhere been mentioned.

- Finally, although the authors stated that fieldwork with dumpy level and clinometer was carried out (p. 355), no evidence of that is found in their paper.

Issues related to results and discussions

- Stating that geology of Tripura received 'passing reference in the scientific literature' at the outset of their article (p. 354), Dey et al. had chosen not to refer to any of the well-known works on structural geology of the CTFB that include Sinha and Sastri (1973); Nandi (1977); Ganguly (1983, 1993); Nandy (1980, 1981, 2001); Nandy et al. (1983); Ray and Asthana (1989) and Gani and Alam (1999, 2003) among others.
- The structure of the Tripura fold belt is not a 'synclinorium' like Dey et al. described (p. 357), but represents a series of discontinuous and plunging anticlines and synclines as mentioned earlier.
- In Table 1, Dey et al. included Bhuban Formation in their description of geological succession of western Tripura but did not state that there is no exposure of Bhuban in the Baromura hills.
- The sedimentary rocks constituting the western CTFB are mostly erodible materials with little consolidation. Nandy (2001), for example, described their arenose components as 'sand rocks' instead of sandstones. Therefore, it is highly unlikely to find any fresh surface exposed by fault ruptures in Baromura as they would be rapidly modified by vegetation and slope processes in a tropical monsoon climate. However, fresh exposures of stratigraphic discontinuities are quite common along road cuttings across all anticlinal ridges of Tripura. The slope faces shown in two photographs of Dey et al.'s Fig. 2 could not possibly get 'exposed by Udaipur faulting' as they envisaged. In fact the roads for which the excavations were made are clearly visible in both photographs. In the same photomosaic, horizontally bedded mudstones were described as showing 'tidal ripples' of Bokabil Formation. Sedimentary structures like ripples or cross-stratification can only develop in sands, not in muds. The Bokabil mostly consists of argillaceous rocks with little occurrence of sandstones.
- Two fault lines were identified by Dey et al. on the western limbs of the discontinuous Baromura anticlines based on linear dispositions of lighter shaded pixels detected in the SPOT Pan image. The authors claimed that the structures were reported for the first time and named them Udaipur Fault and South Tripura Fault. Indeed, these faults were never identified in any map or work depicting the geological structure of the Baromura hills.

Satellite images and DEM of the region show that the features identified as faults closely follow trend of the fold axes and take U-shaped bends at the southern end of the two southward plunging anticlines constituting the Baromura Range (Fig. 1, this work). This suggests that both lineaments were developed as softer strata of the folded formations became preferentially eroded and got occupied by rivers. Farmlands developed along their narrow floodplains have higher reflectance and appear in the images as prominent lineaments flanked by forested dip and anti-dip slopes (Fig. 2, this work). In areas where the floodplains are not deforested, signatures of these features become difficult to detect. Geology of western Tripura has been studied by many workers for quite a long time. Geological Survey of India, for example, mapped the entire southern part of Baromura range on 1:50 k between 1969 and 1982 (Goswami and Das Gupta 1969–1970; Nandy and Das Gupta 1970–1971, 1972; Nandy 1973; Sarkar and Nandy 1977; Banerjee 1976–1977; Das Gupta 1982). Individual segments of these maps were later compiled to prepare the complete structural and stratigraphic map of southern Tripura in 2003–2004 (GSI 2003–2004). This map remains unpublished but is available for inspection and does not show the faults described by Dey et al. It is obvious that it is hardly possible for any fault line that follows such prominent and easily accessible lineament to remain undiscovered up till now.

Issues related to concluding remarks

- Dey et al. pointed out that 'a comparative study using Survey of India (SOI) toposheets of 1976 and recent satellite data on drainage pattern surrounding the faults shows that the streamlets of this area have changed their courses distinctly'. They also asserted that 'It can also be considered as an evidence of geophysical dynamism of southern part of Baromura hill' (p. 359). First, the $15' \times 15'$ metric topographical maps of this region were surveyed not in 1976 but during the

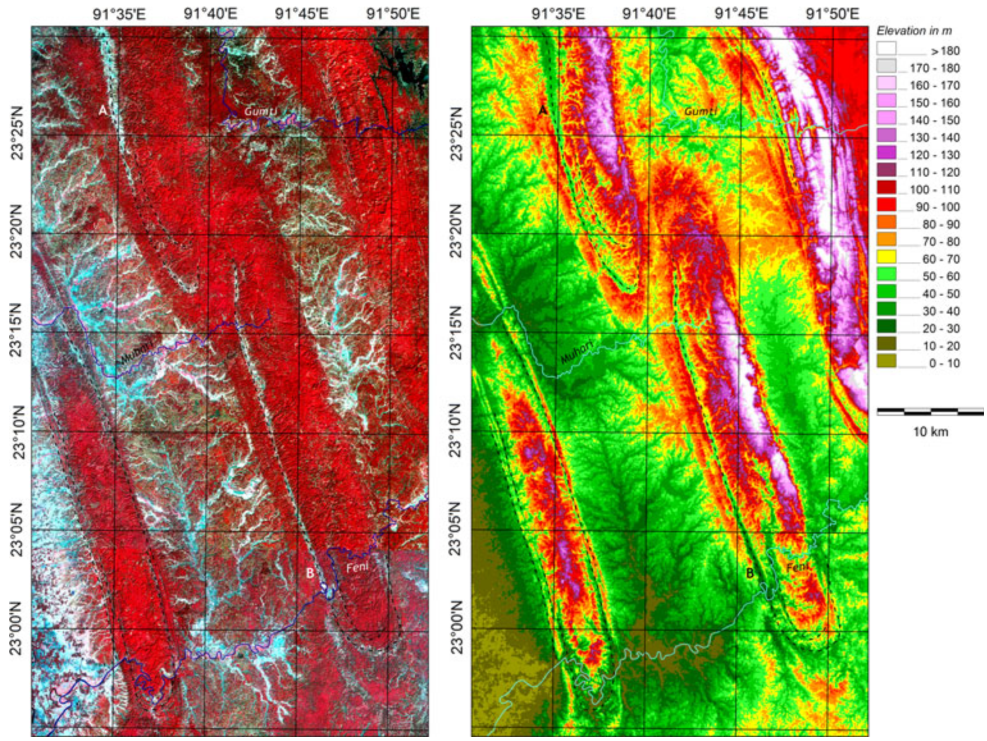

Fig. 1 *Left* Standard FCC of southern Baromura range prepared from a mosaic of IRS-P6 LISS-3 data of 30 Jan 2009 (upper 75%) and Landsat-7 ETM+ data of 7 Feb 2001 (lower 25%). *Right* DEM of the same area prepared from SRTM data of 2000. Two lineaments, marked by *A* and *B*, were identified by Dey et al. (2009) as 'Udaipur Fault' and 'South Tripura Fault', respectively, but actually are farmlands developed over deforested narrow alluvial valleys. *Dashed lines* show similar lineaments in the Baromura and other anticlinal ridges of the CTFB. These features are generally formed by preferential erosion of softer strata lodged between more resistant formations. U-shaped bends of the lineaments point the direction of plunge of the antiforms

Fig. 2 A valley developed by differential erosion of soft sediments intercalated between two resistant strata at the western limb of the Baromura anticline. Areas like these are used for cultivation and show up as bright lineaments between forest-clad dip slopes (background) and anti-dip slopes (foreground). Looking southeastward from *B* of Fig. 1, at Baishnabpara

1971–1976 period. Secondly, comparison of these maps with satellite data of 7 Feb 2001 (Landsat-7 ETM+) and 30 Jan 2009 (IRS-P6 LISS-3) shows no significant change in river courses that can be attributed to 'geophysical dynamism' of the lineaments developed on the western flanks of the Baromura anticlines.

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