Tectonophysics 592 (2013) 130–140

Contents lists available at SciVerse ScienceDirect

Tectonophysics

journal homepage: www.elsevier.com/locate/tecto

Seismic landscape from Sarpang re-entrant, Bhutan Himalaya foredeep, Assam, India: Constraints from geomorphology and geology

Sujit Dasgupta [a], Kiron Mazumdar [b], L.H. Moirangcha [c], Tanay Dutta Gupta [d], Basab Mukhopadhyay [d,*]

[a] Geological Survey of India (GSI), India
[b] Geological Survey of India, Chandigarh 160 033, India
[c] Geological Survey of India, Shillong 793 003, India
[d] Geological Survey of India, 27 Jawaharlal Nehru Road, Kolkata 700 016, India

ARTICLE INFO

Article history:
Received 6 March 2012
Received in revised form 2 February 2013
Accepted 7 February 2013
Available online 20 February 2013

Keywords:
Bhutan Himalaya
Sarpang
Ultapani
Backthrust
Active fault
Foredeep

ABSTRACT

Geomorphic landscape and late Quaternary geological attributes from the Raidak–Manas interfluve in the Bhutan–Himalayan foothills, Kokrajhar District, Assam led towards documenting the 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 6–50 m high tectonic-scarp generated by the north-propagating emerging thrust front along with a complementary subdued south-facing scarp defines the terrain as a pop-up structure. The entire belt is made up of 5 to 8 km wide six distinct blocks, separated by antecedent rivers/streams. Scarp parallel east–west drainage along with linear lakes characterises the emerging thrust front. Field evidence for a major fault-propagation fold structure along with thrust faulting within the late-Quaternary fluvial sediments is ubiquitous. Clay beds deposited in lakes along the footwall of FBT have formed due to blockade of south flowing rivers by episodic upliftment 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. In light of geomorphological and geological studies, neotectonic activity has been modelled as an active south dipping backthrust that originates at shallow crustal depth from south vergent basal Himalayan Decollement in response to the advancing Himalayan wedge.

1. Introduction

The scenario has not changed much so far as logistic facilities are concerned for studying the geology of eastern Himalaya beyond Sikkim, particularly the foothills region since Gansser (1964) published his monumental work on the Geology of the Himalayas. In contrast to western and central Himalaya where 'easier access, better exposure, climate and less political restrictions' are conducive to geological investigation, 'these conditions change drastically from Sikkim to the east with difficult field conditions, more intense monsoon with over 10 m of rain in Assam, restrictions for foreign investigators and border disputes' (Gansser, 1993), etc. In spite of these difficulties, Geological Survey of India (GSI) completed systematic mapping of Bhutan (in 1:50 k scale) that resulted some comprehensive publications including the compilation volume edited by Bhargava (1995). In all such earlier studies including the most recent one by Long et al. (2011), exploration was focused on the geology of the lesser and greater Himalaya with cursory reference to the foothill structures, which evidently bears the signatures of Quaternary deformation, key to downstream analysis on neotectonics, active faults and seismic hazard. It so happens that entire Indo-Bhutan border traverses criss-cross the foothill region and could neither be studied effectively either from the Bhutan or from the Indian side. This is the reality in spite of the fact that Bhutan outer Himalaya is one of the identified seismic prone zones (Bilham et al., 2001). Dense tropical forest, ethnic disturbances and lack of communication network have compounded the problem resulting in paucity of geological information from the most part of the Bhutan Sub-Himalaya. This is in contrast to a wealth of publications on the Himalayan foothill structure from western and central Himalaya foredeep including Nepal (see among others; Kumar et al., 2006; Malik et al., 2010; Powers et al., 1998; Yeats and Thakur, 2008).

Nakata (1972, 1989) in his pioneering contribution on the geomorphic history and crustal movements along the Himalayan foothills, studied two re-entrant segments from the eastern Himalaya; the western one, the Jaldhaka re-entrant between Chel-Gish River in the west and Daina River in the east, bordering West Bengal–Bhutan foothills and the eastern one, Hatisara (hereafter referred as Sarpang) re-entrant along the Assam–Bhutan border (Fig. 1). In the former, except a narrow patch of Siwalik sandstone in the mountainous reaches of the Jaldhaka River, the geology of the re-entrant is dominated by post-Siwalik fluvial fan deposits dissected by a number of east–west tectonic fault scarps, origin of which evidently dates between 33 k and 22 k Ybp (Guha et

* Corresponding author. Tel.: +91 33 22520742; fax: +91 33 22861625.
E-mail addresses: sujitdasgupta@yahoo.com (S. Dasgupta), basabmukhopadhyay@yahoo.com (B. Mukhopadhyay).

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http://dx.doi.org/10.1016/j.tecto.2013.02.021

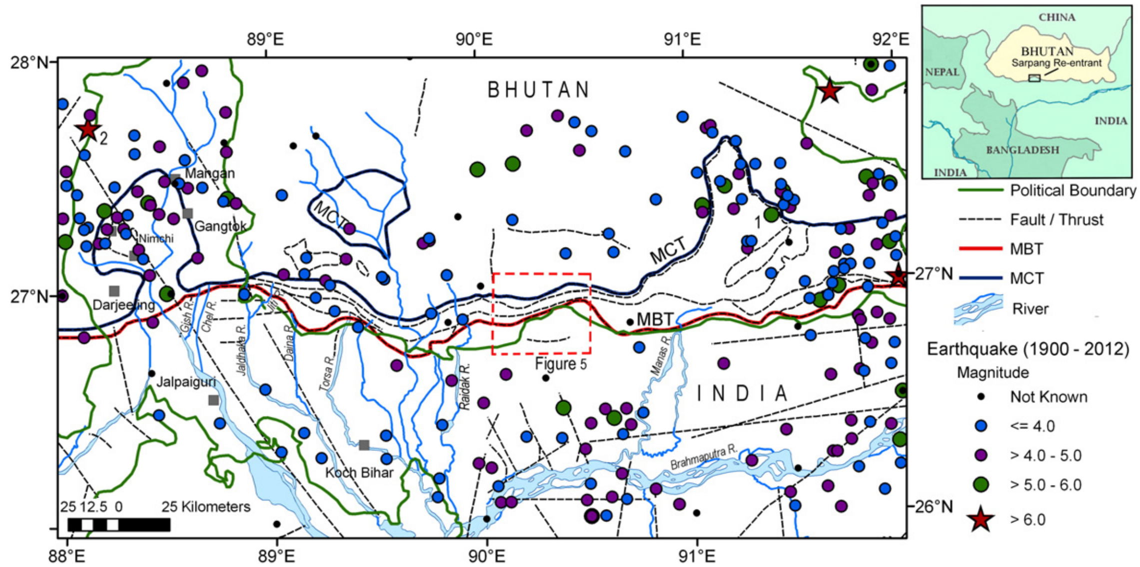

Fig. 1. Seismicity Map of Sikkim–Bhutan Himalaya and its foredeep; data source cited in text. Other features are from Dasgupta et al. (2000). Two recent damaging earthquakes are 1 September 2009, Bhutan and 2 September 2011, Sikkim. The red rectangle at the centre is the study area of Sarpang re-entrant.

al., 2007) and possibly represents different strands of the Main or Himalayan Frontal Thrust (MFT or HFT). Some of the important fault scarps mapped by Nakata (1972, 1989) include the Matiali and Chalsa south facing scarps while Bharadighi and Thaljhora north facing scarps. The latter scarp between the Jiti River and Bhutan border is a gigantic 60 m+ high cliff above the Jiti River bed, 6 km wide (within India) from west to east and can be traced for about 8 km from the scarp tip to Nagrakata in the south before it merges with younger alluvium. A notable feature in the vicinity of the north-facing scarps is the presence of lake–marshy land immediately north of the scarp indicating blocking of the south bound Himalayan Rivers, which could only result from sudden and episodic uplift of the block to dam the river.

The geomorphology of the western part of the Sarpang re-entrant (red box in Fig. 1) was also studied by Nakata (1972, refer to Fig. 15 in Nakata, 1989). He named the different geomorphic blocks from west to east as Ripu–Singimajli–Lalbheti–Saralbhanga and Ultapani blocks, all characterised by and terminated to the north by north-facing scarps with height decreasing from west to east and the presence of marshy land–lake to the immediate north of the scarp. Nakata (1972) further mapped different geomorphic surfaces which were classified as 1) Alluvial Plain, 2) Saralbhanga River Surface, 3) Singimajli Surface and 4) Lalbheti Surface primarily based on the colour profile developed on the surfaces. He described the scarps as tectonic but stopped short of drawing inferences on the nature and origin of the structures in the overall framework of the Outer Himalayas, to the foreland of the Main Boundary Thrust (MBT).

In the present paper, we intend to summarise the geomorphological and geological work carried out by GSI intermittently between 2006 and 2010 within the Indian part of the 'Sarpang' re-entrant to highlight active fault features (that is, the seismic landscape of the area; e.g., see Michetti et al., 2005) in the area in terms of seismic hazards. Our primary goal is to document the morphotectonic features from the area and interpret the major structure as an active 'backthrust' (dipping towards foreland), which is not commonly documented from the Himalayan foredeep.

2. Seismicity in the Region

Earthquake activity from the region (26°–28° N/ 88°–92° E) was compiled from Reviewed ISC Bulletin for the period 1900–2010; the catalogue was updated to include events till March 2012 from NEIC database. The reviewed ISC bulletin also includes data from local network (RRLJ), thus threshold magnitude from the mid nineties is around 3.0 mb. A total of 260 earthquakes are plotted (Fig. 1) on a map showing major faults, adopted from the Seismotectonic Atlas of India (Dasgupta et al., 2000). Concentrations of moderate magnitude earthquakes locate in the Higher Himalaya domain both in the northwest (Sikkim) and northeast (eastern Bhutan). In the former area, the most recent damaging earthquake is that of 18th September 2011, M 6.9 that killed more than 100 lives; in eastern Bhutan the earthquake of 21st September 2009, M 6.0 was also damaging. The foredeep region is characterised by the occurrence of dispersed smaller magnitude earthquakes; though not very conspicuous, a concentration of events is located south of the present study area around the inselbergs (Fig. 3).

3. Geomorphology and geology of Sarpang re-entrant

The spectacular geomorphic and structural features within the western portion of the Sarpang re-entrant between Pinkhua *Khola* in the west and Leu *Pani* in the east (Figs. 1 and 5) were revisited for the first time after Nakata (1972) who worked in the area in the mid nineteen sixties. While Nakata did not have access to Bhutan during working from India, Gansser who was working in Bhutan in the thirties and after, possibly did not have direct entry facility across the border. In the area, Siwalik rocks are exposed in the salient up to the western fringe of the Sarpang re-entrant across the Indian border and then disappear below the alluvium cover of the Saralbhanga River along with the northerly retreat of the mountain front. That the central Bhutan Sub-Himalaya structures were out of sight of Gansser is clearly brought out from his sketch (Fig. 2, Gansser, 1964, p 194); evidently hidden by the lesser Himalaya ranges when viewed from Bhutan. As can be seen from the DEM, the central Bhutan foredeep is quite narrow, around 35 km between the Indian shield Precambrian inselbergs and the foothills (Fig. 3). The raised but dissected alluvial blocks extending from west (from west-central part of the image frame) to east for about 30 km and around 5 to 8 km across clearly show the advancing foreland deformation front in this part of the Outer Himalaya. Maximum elevation of the easternmost Ultapani structure is around 200 m (above msl), while it is of the order of 240–260 m in other western blocks; this is in contrast to 60 m elevation of the alluvial plain in front of the inselbergs. South of the inselbergs, bank elevation of