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State of tectonic stress in Shillong Plateau of northeast India

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ABSTRACT

Tectonic stress regime in the Shillong plateau, northeast region of India, is examined by stress tensor inversion. Some 97 reliable fault plane solutions are used for stress inversion by the Michael and Gauss methods. Although an overall NNW-SSE compressional stress is observed in the area, the stress regime varies from western part to eastern part of the plateau. The eastern part of the plateau is dominated by NNE-SSW compression and the western part by NNW-SSE compression. The NNW-SSE compression in the western part may be due to the tectonic loading induced by the Himalayan orogeny in the north, and the NNE-SSW compression in the eastern part may be attributed to the influence of oblique convergence of the Indian plate beneath the Indo-Burma ranges. Further, Gravitational Potential Energy (GPE) derived stress also indicates a variation from west to east.

1. Introduction

The Shillong plateau in North East Region, India (here after called NER, India), is one of the most active tectonic zones in the world; the region is buttressed by the Himalaya collision zone to the north and Indo-Burma subduction zone to the east (Fig. 1). While the former accommodates the convergence between the India and Eurasia plates, the latter accommodates an oblique convergence between the Indian plate and Burmese micro-plate, respectively (e.g. Chen and Molnar, 1990; Nandy, 2001; Clark and Bilham, 2008; Kayal, 2008). The southern boundary of the plateau is defined by the long E–W trending Dauki fault that separates the Shillong massif and the Bengal basin sediments; the Bengal basin is considered to be the largest deltaic basin in the World. The western boundary of the plateau is demarcated by the N–S trending Dhubri fault. The Shillong plateau is considered to be the largest (~400 km long) intra-plate active basement fold structure in the World, 5 to 10 times larger than that in the Laramide orogeny of the western US or the Sierras Pampeanas of the Andean orogen (Allmendinger et al., 1983; Clark and Bilham, 2008). There is a general observation that the tectonic stress within Indian plate is mainly due to the plate movement, but the stress direction varies spatially as well as with depth (Gowd and Rao, 1992; Rajendran et al., 1992). An average N–S compression in the eastern Himalaya thrust belt and NE–SW compression in the Indo-Burma ranges are reported from fault plane solutions of earthquakes by several authors (e.g. Le Dain et al., 1984; Ni et al., 1989; Chen and Molnar, 1990). Existence of complicated thrust/reverse fault systems to the northern and southern boundary of the Shillong plateau (Bilham and England, 2001; Clark and Bilham, 2008) and strike-slip fault systems in its eastern as well as western boundary make the intraplate plateau tectonics enigmatic and more so in understanding its stress pattern (e.g. Nandy, 2001; Kayal et al., 2012).

An isolated fault plane solution may not represent a regional tectonic stress pattern. In such a situation, large number of fault plane solutions are inverted to estimate the most plausible regional stress pattern and its spatial variation (e.g. Angelier, 1984; Zoback and Zoback, 1980; Chen and Molnar, 1983). In NER India, Angelier and Baruah (2009) first made such attempt and depicted the stress variation for nine selected tectonic blocks. Their data set for

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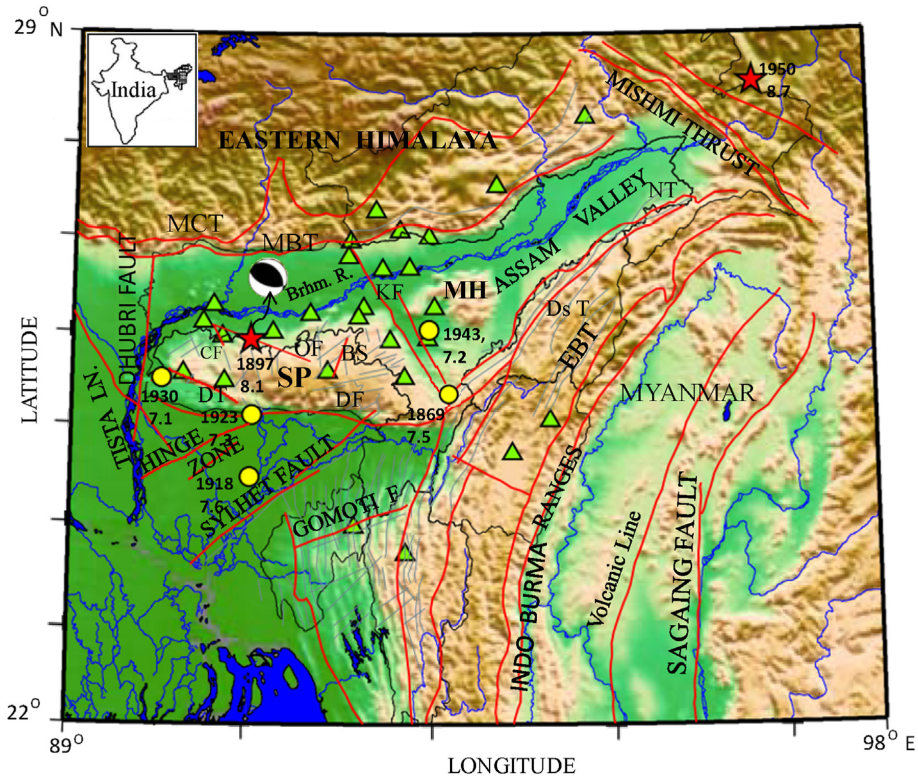

Fig. 1. Map showing major tectonic features of northeast India region (after Kayal et al., 2006). Two great earthquakes (M > 8.0) are shown by stars, and the large earthquakes (M > 7.0) by circles; the year of occurrences is annotated. The digital seismic stations are shown by green triangles. The model fault plane solution of the 1897 great earthquake is shown (after Bilham and England, 2001). The major tectonic features in the region are indicated; MCT: Main Central Thrust, MBT: Main Boundary Thrust, DF: Dauki Fault, DT: Dapsi Thrust, OF: Oldham Fault, CF: Chedrang Fault, BS: Barapani Shear Zone, KF: Kopili Fault, NT: Naga Thrust, DsT: Disang Thrust, EBT: Eastern Boundary Thrust, Brhm. R.: Brahmaputra River, SP: Shillong Plateau and MH: Mikir Hills. Inset: Map of India showing study region. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

the Shillong plateau area was, however, much scanty with only 25 fault plane solutions, and they could not resolve any spatial variation of the stress pattern in the plateau area. Here, we have obtained some 97 fault plane solutions of recent earthquakes ($2.5 \leq M_D \leq 5.3$, where M_D is duration magnitude) (Fig 1), and made a comprehensive study of spatial stress variation. In addition, we examined the Gravitational Potential Energy (GPE) (Bucher, 1956), i.e. the stress change associated with the surface elevation as well as with the sub-surface density distribution (e.g. Flesch and Kreemer, 2010). These combined results shed new light in understanding the tectonics and stress regime of the plateau, which are found to be different from west to east within the plateau.

2. Tectonic setting and large earthquakes

The NER India is marked as zone V (PGA ~ 0.37 g) in the seismic zoning map of India compiled by the Bureau of Indian Standards (BIS, 2002), that produced two great earthquakes, the 1897 great Shillong earthquake (Ms 8.7) (Oldham, 1899), revised Mw 8.1 (Bilham and England, 2001), at the northern boundary of the plateau and the 1950 great Assam earthquake (Ms 8.7) in the eastern syntaxis zone (Tandon, 1954) (Fig. 1). In addition to the two great earthquakes, some 20 large earthquakes ($M \geq 7.0$) are reported in the region since the 1897 great earthquake (Kayal, 2008); most of these occurred beneath the Indo-Burma ranges. In addition to the 1897 great earthquake Mw 8.1, the Shillong plateau and its adjoining Bengal basin produced five large intraplate earthquakes (M > 7.0), and it is considered to be the most active intraplate region in India (Kayal, 2008). The Shillong plateau, a part of the Indian shield, is fragmented by the long NW–SE trending Kopili fault and separated the Mikir massif to the northeast (Fig. 1). The Kopili fault produced two large earthquakes; one in 1869 (Mw 7.7; Szeliga et al., 2010) and the other in 1943 (M_L 7.1), respectively (Nandy, 2001; Kayal, 2008). To the west of the plateau lies the long N–S trending Dhubri fault that produced the 1930 large earthquake (M_L 7.1). In addition to these, two more large earthquakes were recorded in the intraplate Bengal basin to the south of the plateau, the 1923 earthquake (M_L 7.3) at the northeast end of the subsurface hinge zone and the 1918 earthquake (M_L 7.6) at the Sylhet fault zone (Fig. 1). The subsurface hinge zone, identified by gravity survey, is marked as the boundary between the continental crust to the west and the oceanic crust to the east, and the Sylhet fault, on the other hand, is identified as a strike slip fault along the Sylhet trough (Verma et al., 1976; Kayal, 2008).

Although no fault plane solution was available, the 1897 great earthquake was interpreted to be a thrust event by a north dipping thrust fault (Oldham, 1899). Based on microearthquake survey, Kayal (1987, 2001) and Kayal and De (1991) supported Oldham's (1899) interpretation. Bilham and England (2001), however, based on GPS data proposed a pop-up tectonic model of the plateau, and argued that the 1897 great event occurred on a south dipping fault at the northern boundary of the plateau; they named it Oldham fault (Fig. 1). They further argued that the Shillong plateau earthquakes are caused by the pop-up tectonics between the south dipping Oldham fault and north dipping Dauki fault. Pop-up tectonics of the plateau was, however, first hypothesized by Rao