Tectonophysics 589 (2013) 142–150

Contents lists available at ScienceDirect

Tectonophysics

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

Transverse tectonics in the Sikkim Himalaya: A magnetotelluric study

A. Manglik [a,*], G. Pavan Kumar [a,b], S. Thiagarajan [a]

[a] CSIR-National Geophysical Research Institute, Uppal Road, Hyderabad 500007, India
[b] Institute of Seismological Research, Raisan, Gandhinagar 382009, India

ARTICLE INFO

Article history:
Received 3 August 2012
Received in revised form 25 December 2012
Accepted 29 December 2012
Available online 12 January 2013

Keywords:
Sikkim Himalaya
Seismotectonics
Magnetotelluric
Electrical properties

ABSTRACT

The tectonics of seismically active Sikkim Himalaya, as inferred by numerous seismological studies, is distinct from the conventional thrust tectonics proposed for the Himalayan collision belt. Here, focal mechanisms of several moderate magnitude earthquakes and composite fault plane solutions of microearthquakes have revealed strike–slip motion along faults transverse to the northward convergence direction of the Indian plate. In the present study, we analyze broadband magnetotelluric data of 12 sites located along an approximately N–S profile cutting across major geological sub-domains of Sikkim to test whether magnetotelluric strikes also support such transverse tectonic nature of the region. We have performed strike analysis of the data by two decomposition approaches as well as by phase tensor method. The study has revealed local variations in the strike directions within the region consistent with the geological and tectonic setup and the presence of transverse tectonic features in the region of Main Central Thrust Zone (MCTZ) where major axis of phase ellipses align in NNW–SSE to NW–SE direction. This trend coincides with the one obtained by microseismic data recorded after the September 18, 2011 earthquake (Mw 6.9). Magnetotelluric strike analysis thus supports the presence of NNW-to-NW trending transverse tectonic zone in MCTZ.

1. Introduction

The seismically active Himalayan mountain belt, about 2500 km long arc extending from Kashmir Himalaya in the west to Arunachal Himalaya in the east, is considered to be formed by the collision of the Indian plate with the Eurasian plate about 50 m.y. ago (LeFort, 1975; Molnar and Tapponnier, 1975). The Sikkim Himalaya in the eastern segment of this mountain belt has experienced a number of earthquakes exceeding magnitude 4.0 (http://earthquake.usgs.gov/earthquakes/eqarchives/epic/), the recent one being the 18 September 2011 earthquake of Mw magnitude 6.9 (http://www.imd.gov.in/section/seismo/; http://earthquake.usgs.gov/earthquakes/eqarchives/epic/) and its aftershocks (Ravi Kumar et al., 2012). The region falls in the zone IV of the seismic zone map of India (IS, 1893–2002). The occurrence of frequent earthquakes, albeit of moderate magnitude, makes this region seismically vulnerable. The tectonics of the region, as revealed by the focal mechanism solutions of these earthquakes and composite focal mechanisms from microearthquake surveys (De and Kayal, 2004; Hazarika et al., 2010; Nath et al., 2005; Ravi Kumar et al., 2012), is predominantly of strike–slip nature with conjugate fault planes having strikes transverse to the northward direction of the Indian plate motion. This tectonic setup differs from the conceptual thrust tectonic models of the Himalaya based on northward movement of the Indian plate and its collision with the Eurasian plate (Kayal, 2001; Ni and Barazangi, 1984; Seeber et al., 1981). Similar results of transverse tectonics have also been reported from the Bhutan Himalaya (Drukpa et al., 2006) based on the study of moderate-sized earthquakes that occurred in that region between 1937 and 1998.

The region also has geological and tectonic features distinct from the general tectonic setup of the Himalaya. Fig. 1 shows the geological structure of the study area. Here, the Main Central Thrust (MCT) is not parallel to the E–W trending Main Boundary Thrust (MBT). Its outcrop takes rather an Omega shape, with a narrow neck at the southern end, encompassing a dome-shaped structure the core of which exposes vast expanse of pre-Tertiary rocks (Dasgupta et al., 2004). Mitra et al. (2010) discussed a duplex model, the Lesser Himalayan Duplex (LHD, please note that 'D' here represents 'Duplex'), for the crustal shortening and intense deformation leading to the formation of the dome-shaped structure. MCT is also not a well demarcated sharp boundary but it occurs as a several-km-wide ductile zone, often referred as the Main Central Thrust Zone (MCTZ) bounded between MCT-1 and MCT-2, and consists of schists and gneisses representing both the Lesser and the Higher Himalaya (Dasgupta et al., 2004; Sinha-Roy, 1982). Besides MCT and MBT, several approximately N–S trending gravity faults are also present in this region (Nath et al., 2005). The region is also traversed by NNW–SSE trending sub-parallel Gangtok and Tista lineaments and NW–SE trending Golpara lineament extending from southwest Bhutan to the Sikkim province (Narula et al., 2000). These transverse lineaments, along with the NE-SW tending Kangchendzonga lineament west of Sikkim, appear to have significant influence on the tectonics and seismicity of the region.

* Corresponding author at: CSIR-National Geophysical Research Institute, Uppal Road, Hyderabad 500007, India. Tel.: +91 40 23434684; fax: +91 40 23434651.
E-mail address: ajay@ngri.res.in (A. Manglik).

0040-1951/$ – see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.tecto.2012.12.040

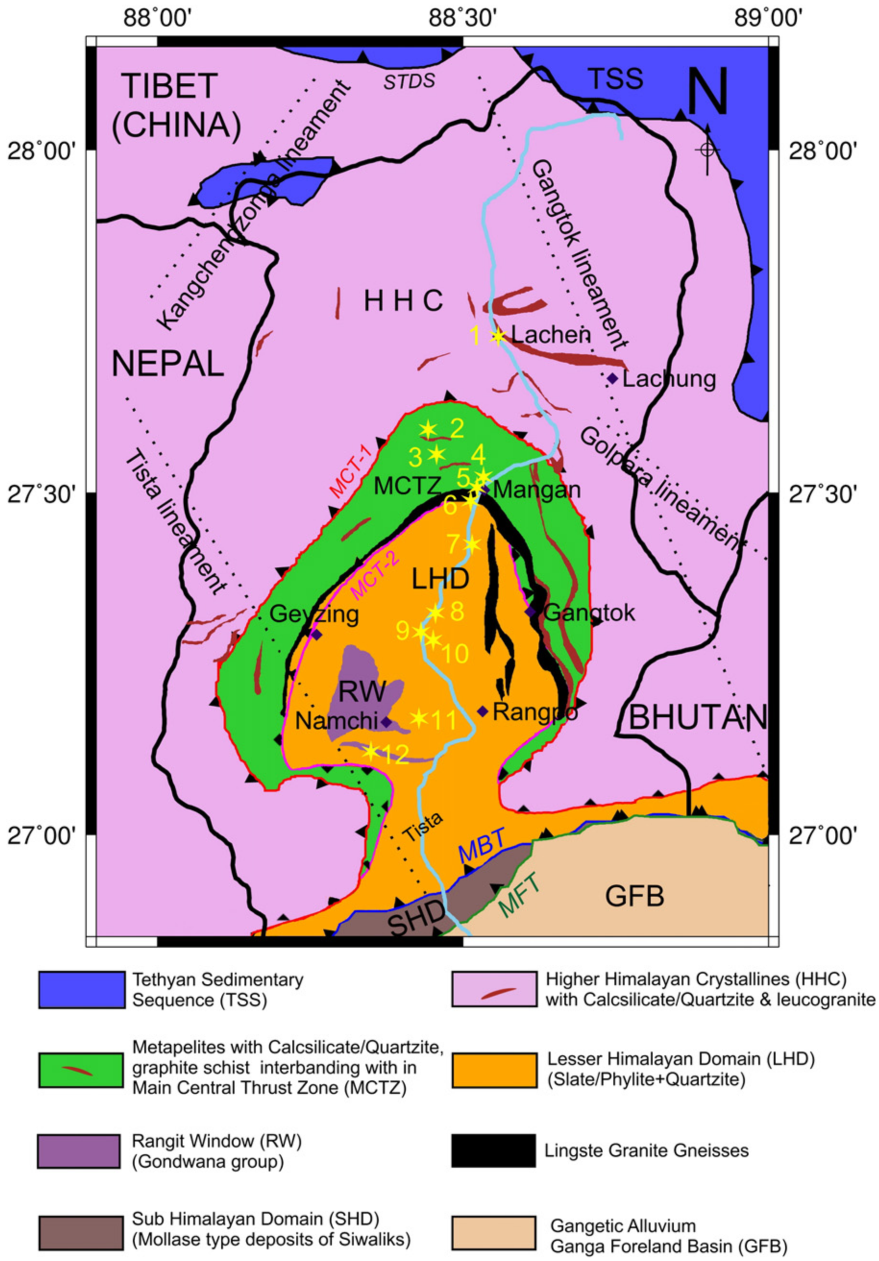

Fig. 1. A simplified geological map of Sikkim along with major lineaments (modified after Dasgupta et al., 2004). Yellow stars are MT stations and MCT-1, MCT-2 are Main Central Thrusts bounding MCTZ. STDS is South Tibetan Detachment System. MBT and MFT are Main Boundary Thrust and Main Frontal Thrust, respectively. Other acronyms are defined in the legend.

Despite its seismic vulnerability and complex tectonic setting, very little geophysical information other than seismological is available for the Sikkim Himalayan region. Patro and Harinarayana (2009) carried out magnetotelluric (MT) study in this region and developed a two-dimensional (2-D) model of the crustal structure along Siliguri–Yumthang profile considering the regional strike direction of N80°E obtained by regional strike analysis. This study revealed the presence of electrically conductive zones north of MBT in the depth range of 2–15 km. The complex transverse tectonic nature of the Sikkim Himalaya, however, is unlikely to be captured in 2-D models. Therefore, in the present work we have performed detailed analysis of local MT strikes to test whether these strikes have some correlation with the seismotectonic model of the region dominated by transverse tectonics.

We have analyzed MT impedance tensors of 12 sites located along an approximately N–S profile that cuts across the Lesser Himalayan Domain (LHD) and MCTZ, and ends in the Higher Himalayan Crystallines (HHC). We have performed strike analysis of impedance tensors by two different tensor decomposition techniques proposed by Groom and Bailey (1989) and LaTorraca et al. (1986), respectively. Further, we have performed phase tensor analysis because phase tensor is considered to be unaffected by localized galvanic distortions and is independent of any presumptions about the dimensionality of the subsurface structure (Caldwell et al., 2004; Heise et al., 2006) unlike decomposition techniques that rely on minimizing these distortions assuming the structure to be regionally two dimensional. Here, we first briefly mention a seismotectonic model of the region obtained by various seismological studies and then discuss the results of MT strike analyses.

2. Seismotectonic model

In Sikkim, seismic activity is mainly clustered to the north of MBT and focal mechanisms of moderate earthquakes (M 4.8–6.8) show dominantly strike–slip faulting (Fig. 2). A number of microearthquake surveys carried out in the region also support strike–slip nature of the