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Full length Article

Shear wave splitting and crustal anisotropy in the Eastern Ladakh-Karakoram zone, northwest Himalaya

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ABSTRACT

Seismic anisotropy of the crust beneath the eastern Ladakh-Karakoram zone has been studied by shear wave splitting analysis of *S*-waves of local earthquakes and *P*-to-*S or Ps* converted phases originated at the crust-mantle boundary. The splitting parameters (Φ and δ*t*), derived from *S*-wave of local earthquakes with shallow focal depths, reveal complex nature of anisotropy with NW-SE and NE oriented Fast Polarization directions (FPD) in the upper ~22 km of the crust. The observed anisotropy in the upper crust may be attributed to combined effects of existing tectonic features as well as regional tectonic stress. The maximum delay time of fast and slow waves in the upper crust is ~0.3 s. The *Ps* splitting analysis shows more consistent FPDs compared to *S*-wave splitting. The FPDs are parallel or sub parallel to the Karakoram fault (KF) and other NW-SE trending tectonic features existing in the region. The strength of anisotropy estimated for the whole crust is higher (maximum delay time δ*t*: 0.75 s) in comparison to the upper crust. This indicates that the dominant source of anisotropy in the trans-Himalayan crust is confined within the middle and lower crustal depths. The predominant NW-SE trending FPDs consistently observed in the upper crust as well as in the middle and lower crust near the KF zone support the fact that the KF is a crustal-scale fault which extends at least up to the lower crust. Dextral shearing of the KF creates shear fabric and preferential alignment of mineral grains along the strike of the fault, resulting in the observed FPDs. A Similar observation in the Indus Suture Zone (ISZ) also suggests crustal scale deformation owing to the India-Asia collision.

1. Introduction

The continued India and Eurasia continental collision since ~50 Ma have given rise to the Himalaya-Tibet orogenic system (Molnar and Tapponier, 1975; Rowley, 1996). The Ladakh-Karakoram zone of the trans-Himalaya is the southwest extremity of this orogenic system that bears a signature of this collisional process in the form of well-exposed suture zone (Indus Suture), exhumed block that underwent deep subduction (e.g. Tso-Morari Crystalline Complex) and an intra-continental crustal-scale fault (Karakoram Fault). Structural developments and surface deformation processes owing to the continent-continent collision in the Ladakh-Karakoram zone have been the subject of several geological studies (e.g. Thakur and Misra, 1984; Weinberg and Dunlap, 2000; Rutter et al., 2007; Epard and Steck, 2008). The region is composed of geological structures amalgamated along NW-SE that have been consequently thickened to present day crustal thickness of ~70–80 km, as observed by passive seismic studies (Rai et al., 2006; Hazarika et al., 2014). Several studies suggest dextral transpressive movement in the NW-SE trending KF and also propose that the fault possibly cuts through the middle and deep crustal rocks (e.g. Rutter et al., 2007; Leech, 2008; Rolland et al., 2009; Klemperer et al., 2013; Sen and Collins, 2013). The focal mechanism solutions of local earthquakes near the KF also support the fact that the KF penetrates down to the lower crust with dextral transpressive movement (Hazarika et al., 2017). The dextral transpressive movement of the KF in the southern margin of the Tibetan plateau and sinistral movement in the Altyan Tagh fault in the northern boundary of the plateau facilitate eastward extrusion of the Tibetan plateau out of the way of northward indenting Indian crust (Molnar and Tapponier, 1975; Peltzer and Tapponnier, 1988; Meyer et al., 1996). In contrast to extensive studies in the Tibetan plateau to characterize crustal deformation (e.g. Wu et al., 1996; Ozacar et al., 2004; Sherrington et al., 2004; Sun et al., 2012; Chen et al., 2013; Yang et al., 2015; Cai et al., 2016), the Ladakh-Karakoram zone is largely unexplored by any high-resolution geophysical data. A few Receiver function (RF) studies were carried out in the Ladakh-Karakoram zone for obtaining shear wave velocity structures and crustal thickness (Rai et al., 2006; Oreshin et al., 2008, 2011; Hazarika et al., 2013, 2014). However, all these studies considered

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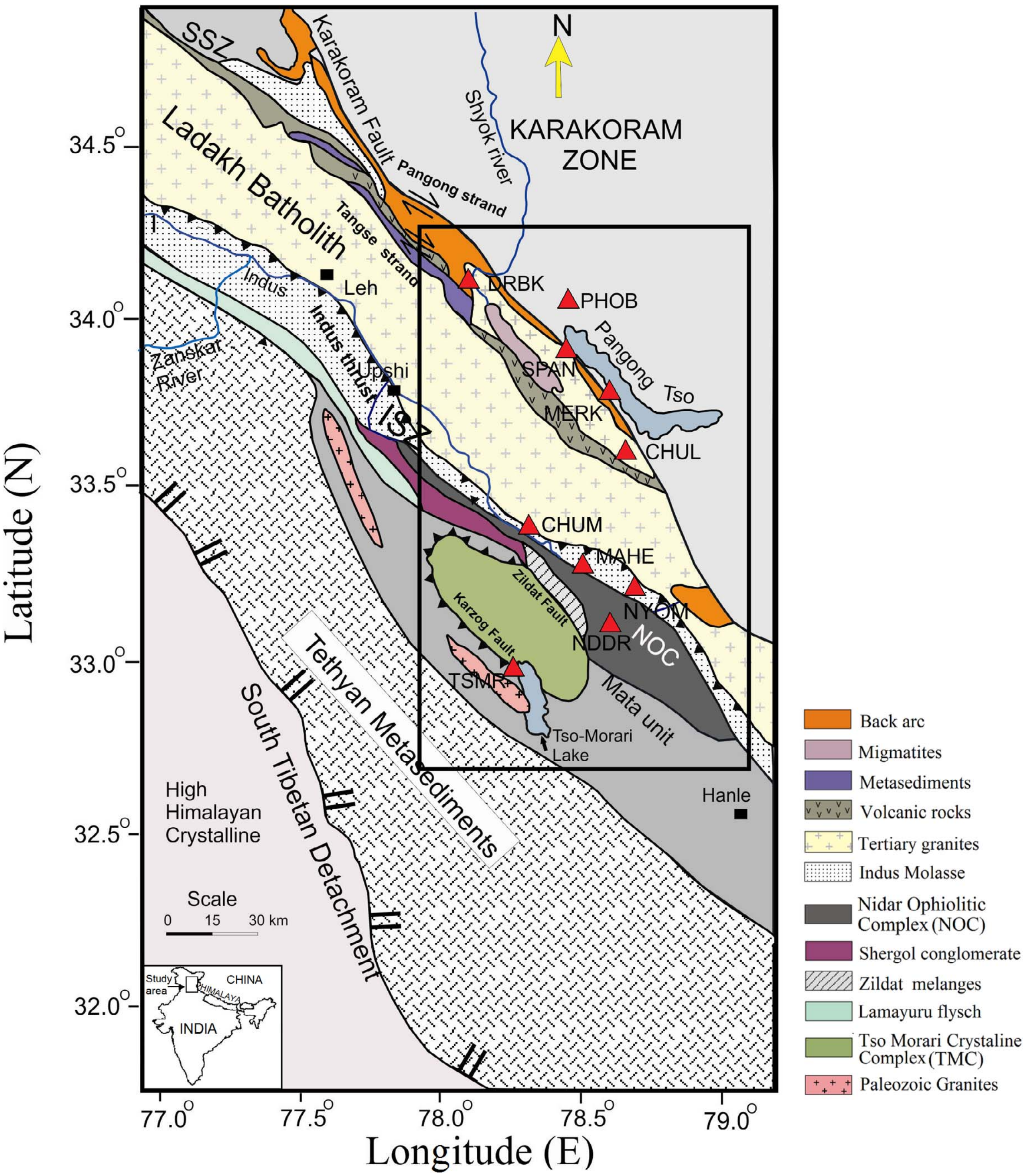

Fig. 1. Simplified geological map showing parts of the Tethayan Himalaya, Indus suture zone (ISZ) and Karakoram zone (modified after Maheo et al., 2004; Sen and Collins, 2013; Hazarika et al., 2014). The Karzok and Zildat faults are marked according to Epard and Steck (2008). The Shyok Suture Zone is indicated as SSZ. The seismological stations are shown by red triangles. The study area is marked by a black rectangular boundary. An inset map of India and adjoining regions is shown at the bottom left corner with a rectangular box indicating the study area.

the subsurface structure as comprised of horizontally stratified homogeneous layers for mathematical simplification and did not emphasise on the crustal deformation processes and the possible presence of crustal anisotropy.

Characterization of deep crustal deformation processes can be facilitated by detection and interpretation of seismic anisotropy (Crampin and Lovell, 1991; McNamara and Owens, 1993; Silver, 1996). Anisotropy is a common feature of rocks that leads to directional dependence of seismic velocity (Babuska and Cara, 1991; Savage, 1999). When a shear wave travels within an anisotropic medium, it split into two orthogonally polarized waves with different velocities. The orientation and magnitude of the anisotropic layer are measured in terms of the polarization of the fast wave (Φ) and the time lag between fast and slow waves (δt). The cause of anisotropy is primarily the ordered features like fractures with preferential alignments and lattice preferred orientation (LPO) or shape preferred orientation (SPO) of minerals that forms due to tectonic stress or deformation. Therefore, anisotropy parameters provide important constraints on deformation, and hence, on the geodynamic processes in a region. In this study, we made an attempt to exploit *S*-wave of local micro earthquake data for studying upper crustal anisotropy and *P*-to-*S* (or *Ps*) Moho converted phase for exploring bulk anisotropy of the entire crust underneath 10 broadband seismological stations located in eastern Ladakh (Fig. 1). Our results provide a new information regarding seismic anisotropy in