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Frequency-dependent body wave attenuation characteristics in the Kumaun Himalaya

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ABSTRACT

We have analyzed a data set consisting of 23 well located local earthquakes to study the seismic attenuation characteristics of the Kumaun Himalaya region. These events were recorded at 9 digital seismic stations in this region during 2004–2008. The frequency-dependent attenuation of *P* and *S* waves are estimated using the extended coda-normalization method for the frequency range of 1.5, 3, 6, 8 and 12 Hz. The values of Q_P and Q_S show a ubiquitous observation of frequency dependence for the studied frequencies. We obtained $Q_P=(22\pm5)f^{(1.35\pm0.04)}$ and $Q_S=(104\pm10)f^{(1.3\pm0.03)}$ by fitting a power-law frequency dependence model with the estimated values over the whole region. Both *Q* values indicate a strong attenuation in the crust of Kumaun Himalaya. The ratio of $Q_S/Q_P>1$ obtained for the entire analyzed frequency range may suggest that the crust is characterized by a high degree of heterogeneity.

1. Introduction

Knowledge of attenuation characteristics of a region is a necessary factor in the earthquake hazard assessment studies (Anderson et al., 1996) and for understanding the source processes (Abercrombie, 1997). The attenuation property of a medium is expressed by a dimensionless quantity called quality factor *Q*, which represents the decay of wave amplitude during its propagation in the medium caused by heterogeneity or anelasticity or both in the crust (Lay and Wallace, 1995). The quality factor can be estimated by using rate of time decay of the direct *P* (Q_P), *S* (Q_S) or *Lg* (Q_{Lg}) wave amplitude (Aki, 1969; Kim et al., 2004; Ma'hood et al., 2009; Sato, 1977; Singh et al., 2011; Yoshimoto et al., 1993). Low *Q* has been observed for seismically active regions compared to stable area (Sato and Fehler, 1998). The attenuation characteristics of *S* waves have been studied more intensively compared to *P* waves mostly due to the requirement of the engineering seismology. There are very few studies of frequency dependent Q_P such as Fedotov and Boldyrev (1969), Hough et al. (1988) and Kohketsu and Shima (1985). Yoshimoto et al. (1993) proposed a new method for the simultaneous measurement of Q_P and Q_S by extending the conventional coda-normalization method. This method is successfully applied further to obtain both *P* and *S* wave attenuation for a few places in the world such as Kanto, Japan by Yoshimoto et al. (1993); Western Nagano, Japan by Yoshimoto et al. (1998); South-Eastern Korea by Chung and Sato (2001); central South Korea by Kim et al. (2004); Koyna, India by Sharma et al. (2007); Bhuj, India by Padhy (2009); Cairo metropolitan area by Abdel-Fattah (2009) and East-Central Iran by Ma'hood et al. (2009).

An attempt is made here to understand the attenuation characteristics of the Kumaun Himalaya region by estimating *Q* values of body waves (Q_P and Q_S). This part of Himalaya is seismically very active which manifests strong deformation and reactivation of some of the faults, thrusts during Quaternary times. The only previous study on attenuation in the Kumaun region by Paul et al. (2003) is based on the attenuation of coda waves using the waveform data of only eight local earthquakes for a single lapse time window. Recently Singh et al. (under review) attempted to understand the frequency and lapse time dependence of coda wave attenuation of this region by using a larger dataset. To extend our knowledge further on the seismic attenuation properties in this area, we applied the extended coda-normalization method to determine Q_P and Q_S. This is the first estimate of these parameters made for this region. We also investigate the Q_S/Q_P ratio and its probable significances. The results are being compared with those obtained in the other regions in the world.

2. Seismotectonics of the region

Himalaya is a large geodynamic laboratory of nature where orogeny is still in youth to early mature phases of evolution. It is one of the most active orogens of the world and is the consequence of the collision of the Indian plate with the collage of previously sutured microcontinental plates of central Asia during mid to late Eocene. The Kumaun region of the Himalaya lies near the center of the Himalayan fold-and-thrust belt and is situated between the Kali River in the east and Sutlej in the west, including a 320 km stretch of

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mountainous terrain. This part of Himalaya exposes all the four major litho-tectonic subdivisions of the Himalaya from South to North. They are a) Sub-Himalaya, b) Lesser Himalaya, c) Great Himalaya and d) Tethys Himalaya. All the lithotectonic zones are bound on either side by longitudinally continuous tectonic surfaces such as Main Boundary Thrust (MBT), Main Central Thrust (MCT), South Tibetan Detachment (STD) system and Indus Tsangpo Suture Zone (ITSZ) (Fig. 1). The Sub-Himalaya includes the molassic Siwalik Supergroup of Mio-Pliocene ages. The lesser Kumaun Himalaya exposes a thick pile of highly folded Proterozoic sedimentary strata together with a few outcrops of older crystalline rocks. It is bounded by the MBT to the south and the MCT to the north. The Great Himalaya exposes a massive pile of high grade metamorphic rocks and the Tethys Himalaya includes a thick pile of sedimentary rocks of Cambrian to Lower Eocene ages. The extension of Aravalli structures into the Himalayan regions has played a role in the tectonics of the Kumaun Himalaya, and probably is the cause of the complex nature of seismicity of the region. In Kumaun Himalaya region the groups of rocks are known as Vaikriti group (Valdiya, 1980). According to the model of Srivastava and Mitra (1994), the Kumaun Himalaya evolved by an overall forelandward progression of thrusting, with some reactivation along the Munsiari thrust (MT), the Main Boundary thrust (MBT), and the Main Central thrust (MCT). In this part the maximum strain-energy release is related to the Main Central Thrust (MCT). It is among the least understood parts of the Himalayan fold-and-thrust belt. Valdiya (1980) gives the most comprehensive account yet published on the geology of the region. It has been found that the large scale thrusts recognized in the Kumaun lesser Himalaya are boundary thrusts defining the limit of the various litho-tectonic units. There are large numbers of local thrusts less than 50 km in length, which have severed the tightly folded rock formations along the axial plane and brought the older rocks over the younger. This sector evidenced reactivation of some of the faults and thrusts during Quaternary times. This is amply evident by the recurrent seismicity patterns, geomorphic developments and by geodetic surveys (Valdiya, 1999).

3. Data

We have used 23 well located local earthquakes of Kumaun Himalaya region recorded at nine stations containing four three-component short period seismometers and five strong motion accelerographs during 2004–2008. Fig. 1 shows the epicenters of selected earthquakes along with the digital stations. The signal-to-noise ratio for the selected events is greater than two for P and S waves and coda wave windows at all frequency bands. The local magnitudes of those events are less than 4.5 and the hypocentral distances of the events are within 90 km. All the earthquakes are crustal and with focal depths less than 40 km.

4. Method

4.1. Extended coda normalization method

The Q_P and Q_S for Kumaun Himalaya region are estimated by applying the extended coda normalization method (Yoshimoto et al., 1993). The basic idea of this method stands on the following proportionality among the coda spectral amplitude A_C, the source spectral amplitude of S waves S_S and the source spectral amplitude of P waves S_P:

$$A_C(f, t_C) \propto S_S(f) \propto S_P(f) \quad (1)$$

where f is the frequency in Hz and t_c is the reference lapse time measured from the source origin time. The lapse time is chosen to be greater than 2 times the S-wave travel time. The first proportionality implies that $A_C(f, t_C)$ is independent of the hypocentral distance (Aki, 1980). The second proportionality is deduced from the assumption that the ratio of P to S-wave source spectra is constant for a small range of magnitudes. In this method the source effects, common instrument, and site responses are removed by normalizing the direct wave spectra to those of coda.

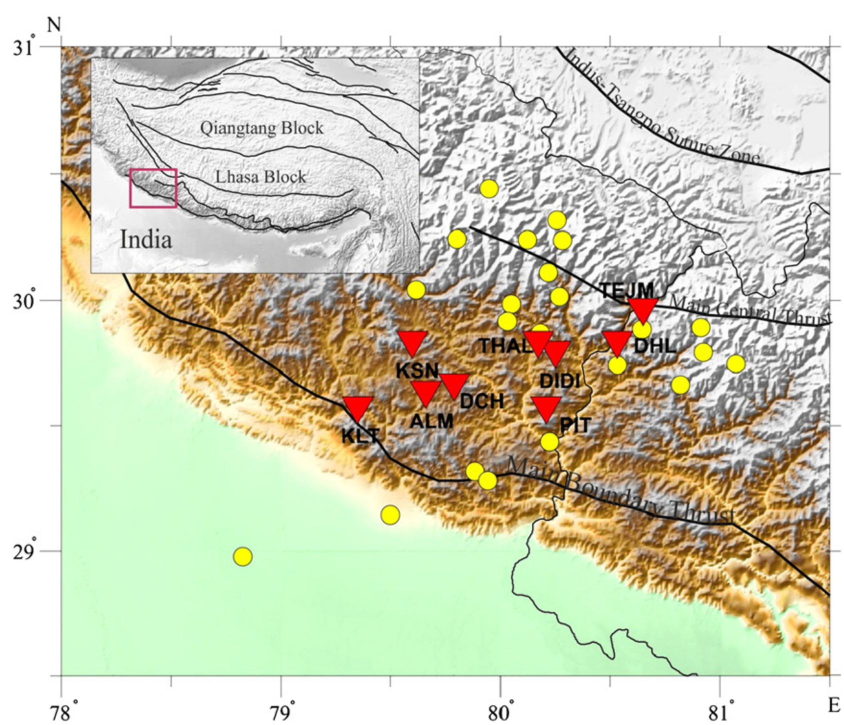

Fig. 1. Tectonic map of Kumaun region with distribution of epicenters of selected events (circles) and nine stations (inverted triangles). MBT: Main Boundary Thrust, MCT: Main Central Thrust, ITSZ: Indus-Tsangpo Suture Zone, STD: Southern Tibet Detachment. Small square in the inset represents the study area.