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Lapse time and frequency-dependent coda wave attenuation for Delhi and its surrounding regions

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ABSTRACT

Attenuation of seismic wave energy of Delhi and its surrounding regions has been estimated using coda of local earthquakes. Estimated quality factor (Q_c) values are strongly dependent on frequency and lapse time. Frequency dependence of Q_c has been estimated from the relationship $Q_c(f) = Q_0 f^n$ for different lapse time window lengths. Q_0 and n values vary from 73 to 453 and 0.97 to 0.63 for lapse time window lengths of 15 s to 90 s respectively. Average estimated frequency dependent relation is, $Q_c(f) = 135 \pm 8f^{0.96 \pm 0.02}$ for the entire region for a window length of 30 s, where the average Q_c value varies from 200 at 1.5 Hz to 1962 at 16 Hz. These values show that the region is seismically active and highly heterogeneous. The entire study region is divided into two sub-regions according to the geology of the area to investigate if there is a spatial variation in attenuation characteristics in this region. It is observed that at smaller lapse time both regions have similar Q_c values. However, at larger lapse times the rate of increase of Q_c with frequency is larger for Region 2 compared to Region 1. This is understandable, as it is closer to the tectonically more active Himalayan ranges and seismically more active compared to Region 1. The difference in variation of Q_c with frequencies for the two regions is such that at larger lapse time and higher frequencies Region 2 shows higher Q_c compared to Region 1. For lower frequencies the opposite situation is true. This indicates that there is a systematic variation in attenuation characteristics from the south (Region 1) to the north (Region 2) in the deeper part of the study area. This variation can be explained in terms of an increase in heat flow and a decrease in the age of the rocks from south to north.

1. Introduction

A fundamental property of the Earth is the attenuation of seismic waves by which material and physical conditions of the Earth's interior can be inferred (Aki, 1980). The term attenuation refers to the reduction in amplitude of a seismic wave which is caused by anelasticity and heterogeneity properties of the Earth medium. The attenuation of a seismic wave is quantitatively described by an inverse of a dimensionless quantity called quality factor Q (Knopoff, 1964) which is the ratio between the dissipated energy and the stored energy during one cycle of the wave oscillation (Toksöz and Johnston, 1981). The values of the Q^{-1} factor allow us to understand the relationship between the loss of seismic energy carried by a wave as it propagates through the lithosphere (Aki, 1969; Dainty and Toksöz, 1981; Kumar et al., 2005; Mohamed et al., 2010; Mukhopadhyay and Sharma, 2010; Akyol, 2015). For a quantitative study of the seismic hazard assessments and a better understanding of source processes, tectonics and seismicity in a particular area, the knowledge of Q distribution is essential (Singh and Herrmann, 1983; Pulli, 1984; Jin and Aki, 1986; Herraiz and Espinosa, 1987; Sato and Fehler, 1998; Paul et al., 2003; Kumar et al., 2005; Mukhopadhyay and Tyagi, 2007; Mukhopadhyay and Sharma, 2010; Brahma, 2012; Akyol, 2015). The purpose of our study is to investigate the attenuation characteristics of Delhi and its surrounding regions (Fig. 1) by examining frequency and lapse time dependencies of the coda wave attenuation. Delhi and its surroundings lie in a seismically active region. It falls in zone IV of seismic hazard zonation map (IS 1893-Part 1, 2002). A possible large earthquake would put a population of millions, and could cause a large amount of damage in the area.

In the current study lapse time and frequency dependent coda wave attenuation characteristics of Delhi and its surrounding regions are studied using the coda of local earthquakes recorded by Delhi Telemetry Network operated by the India Meteorological Department (IMD), Delhi. The method used for this study is known as single backscattering model (Aki and Chouet, 1975). A huge amount of work has been done by a very large number of researchers all over the world using this method. They have shown that coda Q (Q_c) is strongly frequency-dependent (Rautian and Khalturin, 1978; Tsujiura, 1978;

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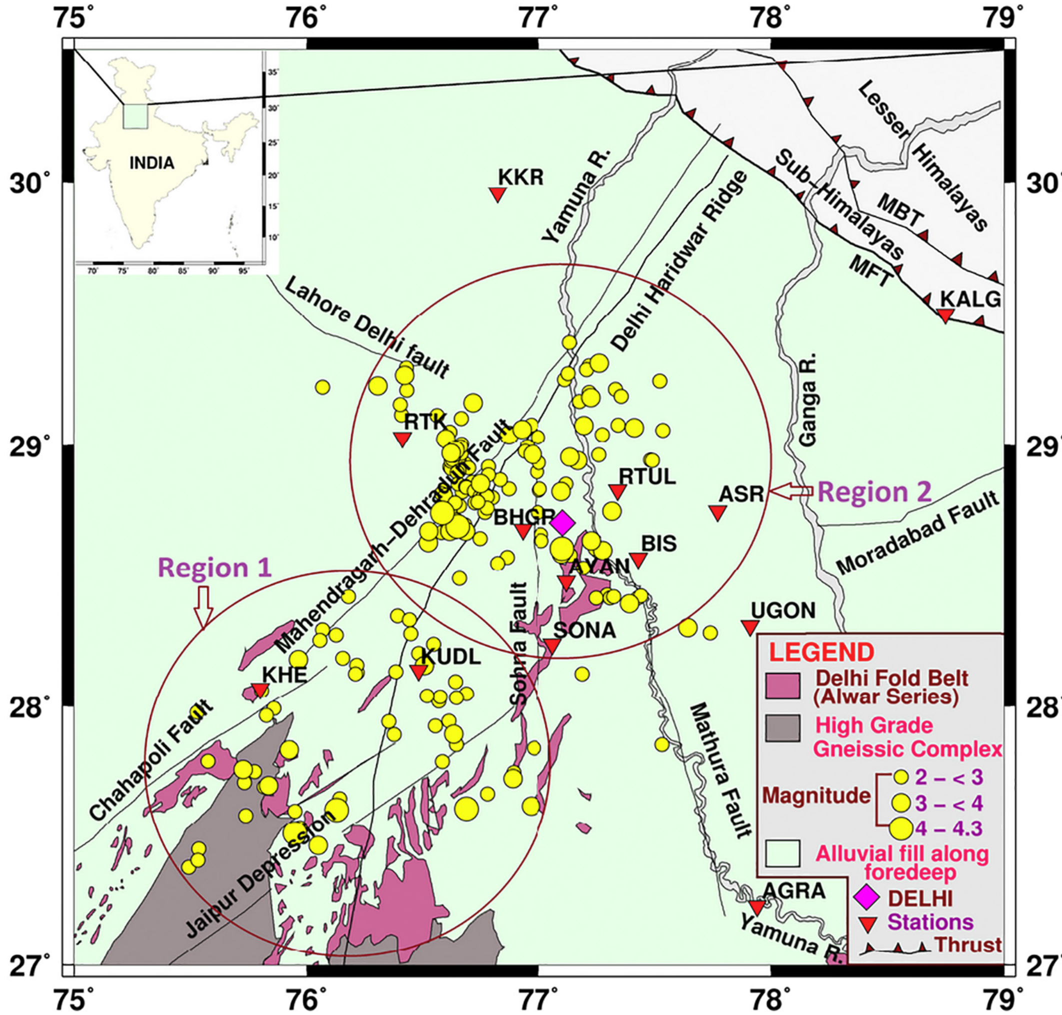

Fig. 1. Map showing main tectonic features of the study region (modified after GSI, 1963; Bansal and Varma, 2012), station locations (red inverted triangles) and the distribution of earthquakes (yellow circles). The two big circles show Region 1 and 2 for which Q_c values were estimated separately. Abbreviations - MFT: Main Frontal Thrust; MBT: Main Boundary Thrust; AYAN: Ayanagar; SONA: Sohana; BHGR: Bhadurgarh; RTUL: Rataul; BIS: Bisrakh; KUDL: Kuldal; ASR: Asauara; UGON: Unchagaon; KKR: Kurukshetra; KALG: Kalagarh; AGRA: Bainpur; KHE: Khetri; RTK: Rohtak. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Roecker et al., 1982; Jin and Aki, 1986; Ibáñez et al., 1990; Mukhopadhyay et al., 2008; Sertçelik, 2012). In this region, very few studies were carried out to estimate the attenuation characteristics (Mohanty et al., 2009; Sharma et al., 2015). To develop an attenuation relationship in the study region, a variation of Q_c with both frequency and lapse times is estimated. Further, the depth variation of coda Q is also examined. The results are compared with available information to help assess the interpretation.

The entire study region is divided into two sub-regions as shown by the two big circles (Regions 1 and 2) in Fig. 1 according to the geology and heat flow variation in the area (Gupta, 1982) to investigate if there is a spatial variation in the attenuation characteristics in this region. Region 1 covers areas where Aravalli Ridge shows up very prominently, whereas, Region 2 covers the northern tip of this ridge, also known as DHR. However, Region 2 is mostly covered by the recent alluvial deposits of the Indo-Gangetic sedimentary basin. As discussed in Section 2, there is a variation in rock type, the age of rock as well as heat flow in these areas. It is also to be noted, that more earthquakes occurred in Region 2 compared to Region 1 and the former is closer to the tectonically more active Himalayan Ranges. Only the events and stations within the borders of sub-regions are used for region-wise analysis. The entire region includes 190 events whereas Region 1 and Region 2 include 57 and 133 earthquakes respectively.

2. Geology and seismotectonic settings

Delhi and its surrounding regions are bounded by the Indo-Gangetic alluvial plains. The rock formation of this area is mainly quartzite of the Alwar series of the Delhi Super group (~1500 million years in age) exposed in the Delhi Haridwar ridge (Fig. 1). The Quaternary to Recent sediments (< 1.65 Ma) unconformably overlie the flanks of this ridge. Older alluvium consists of silt, clay and minor lenticular fine sand and kankar bodies. The flood plains of the Yamuna River contain recent alluvium comprising of sand, silt and clay deposits. Alluvial deposit thickness varies on both flanks of the ridge, but it is generally thicker on the western flank of the ridge. The age of the exposed hard rocks in the Aravalli Ridge on the southern part of the study area is Archaean to lower Proterozoic and, that in the Delhi Hardwar Ridge to the north is upper Proterozoic (Gupta, 1982). The rock type also changes from Gneissic in the Aravalli Ridge to the south to Quartzite with Schist in the Delhi Hardwar Ridge (GSI, 1963; Biju-Sekhar et al., 2003 and Bhowmik et al., 2010). Gupta (1982) also showed that heat flow increases from south to north along this ridge system.

In the past, several researchers (Mohanty, 1997; Bansal and Verma, 2012; Prakash and Shrivastava, 2012) carried out different geophysical studies to delineate different fault systems and proposed that a large number of faults are present in this area. The major tectonic setting of