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A comparative study of Lg wave attenuation in the Arunachal Himalaya and Mishmi Massif and the Indo-Burman Ranges of northeast India

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Abstract: *The study encompasses two tectonically active areas of northeast India viz. the Arunachal Himalaya and Mishmi Massif and the Indo-Burman Ranges (IBR). The former is governed by collisional tectonics of the Himalayas and the latter by the subduction tectonics. This work aims at looking into the characteristics of Lg wave attenuation for earthquakes sourced in these two tectonic domains. The regional average of* Q_{Lg} *was computed for both the study areas by using the method given by Ottemöler et al. (2002). It is found that both the study areas are tectonically active and attenuation of Lg is governed by frequency which is indicative of scattering attenuation. But then, IBR is relatively less attenuative than the Arunachal Himalayas and the Mishmi Massif, given the low value of* Q_o *for the latter.*

Keywords: *Attenuation, Collision, Lg, Scattering, Subduction*

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I. Introduction

The attenuation of seismic waves is gauged by a parameter called crustal quality factor "Q". Q is inversely proportional to attenuation. Lg waves may be understood as multiple reflected shear waves which is crustally-guided and is composed of superposition of post-critical reflections in the crust such as between a free surface and the Mohorovicic discontinuity (Moho) [1]. Lg are almost routinely used to study the crustal quality factor, Q_{Lg}, which is a direct measure of attenuation [2]. Attenuation of Lg in terms of its correlation with large scale crustal structure has been studied by various workers like [3], [4], [5], [6], [7] and [8]. From these studies it has come to light that Lg wave attenuation possesses strong correlation with the age of the crust, variations in crustal thickness, the nature of the crust-mantle transition, sediment thickness and crustal complexity. This work is an attempt to look at the characteristics of Lg wave attenuation characteristics of two important tectonic entities of the northeast India viz. the collision tectonics of the Arunachal Himalaya and the Mishmi Massif and the subduction tectonics of the Indo-Burman Ranges (IBR) [9]. The Arunachal Himalaya and the Mishmi Massif is a part of the India-Eurasian plate collision and forms the eastern extension of the Himalayas known as the eastern Himalayas [9]. The study areas a have been shown in Fig. 1

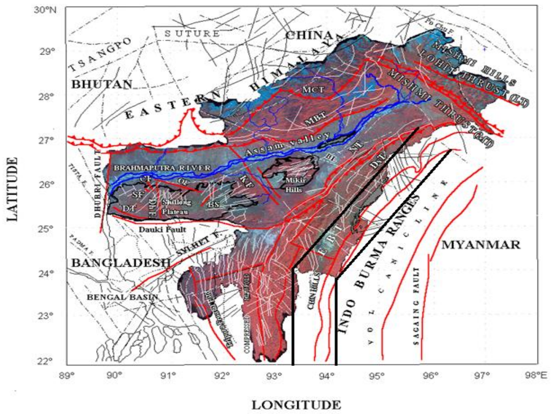

Figure 1: A GIS Based Tectonic Map of NE India [10]. In correlation with LISS-3 imagery (modified after [11];[12] and [13]).

II. Data And Method

The broadband data used in this study belongs to the seismic network of CSIR-North East Institute of Science & Technology (CSIR-NEIST), Jorhat, India recorded between the period 2008 to 2012. The major concentrations of the stations are in Assam valley and in Indo-Burma region (IBR) and a few in Shillong Plateau and Arunachal Pradesh making it to a total of 12 broadband seismic stations. Stations are equipped with Trillium-40 sensors and 24-bit Reftek 130 data loggers. The data have been recorded in continuous mode at 50 sps (samples per second). At all the stations the time signals have been electronically impinged using GPS, which ensures the accuracy of the time for an event recorded at any of these stations.

The minimum epicentral distance was set to be 200 km to ensure the clear observation of Lg waves [17] and the maximum at 600 km. Sn coda contamination can have a marked effect on determinations of Q_{Lg}, particularly at long distances and high frequencies [14] and [15]. Following the technique adopted by [2] it has been validated that if Lg is visible above the coda of Sn. The examination showed that Lg amplitude is conspicuous in arrival at all frequencies for distances less than 600 km but is not visible in the Sn coda at higher frequencies (> 7 Hz) and longer distances. Consequently, a maximum distance of 600 km was specified for all frequencies. Therefore, to avoid contamination of Lg wave by Sn a frequency range from 0.5 to 5 Hz was chosen so as to clearly segregate Lg from Sn in time ([16]. Also to avoid wrong identification of Lg, each record was visually checked and Lg was identified with reference to Jeffrey-Bullen travel time table. The duration magnitude (M_D) of the events considered range from 3.9 to 4.5 for Arunachal Himalaya and Mishmi Massif and 3.1 to 4.6 for Indo-Burman region. Large magnitude events were avoided to prevent affects of rupture complexity associated with larger events [17]. The average crustal thickness of northeastern region (NER) of India is around 35-45 km approximately [9], [18] & [19]. Therefore, only those crustal earthquakes with depth $\leq$ 35 km were selected. In this study the depths of the events considered range from 8.50 to 33.2 km for Arunachal Himalaya and the Mishmi Massif and 6.79 to 35.2 km for Indo-Burman Ranges. Further, from these events only those records with an epicentral distance larger than twice the critical distance for SmS, which is about 170 km for a 35-45 km thick crust could have been adopted, but to ensure clear observation of Lg phase the minimal epicentral distance of 200 km was considered. The final dataset comprises of 36 source-receiver paths from 07 regional crustal earthquakes for Arunachal Himalaya and Mishmi Massif and 19 events along with 66 source-receiver paths traversed by Lg from IMR to rest of NER of India. All records chosen for this study exhibit excellent signal to noise ratio (>2) and were free from glitches and spikes. The recorded seismograms have been corrected by using an instrument response based on the electrodynamic constant, critical damping, natural frequency of seismometers and bit weight of unit gain of each recording unit for all stations. Precision of hypocentre determination depends not only on the distribution of the recording stations but also on velocity structure between source and stations, particularly in an area where lateral heterogeneities are extreme [20]. The epicentres are determined using the HYPOCENTRE location programme of [21] based on the crustal velocity model of [22]. The uncertainties involved in the estimates of epicentral locations and origin times are of the order 0-4 km and 0-0.5 sec respectively. To determine the Lg attenuation, first we measure the spectral decay of Lg. For this the horizontal component of seismograms are corrected for instrumental response and ground displacement is obtained and then rotate them to produce radial and transverse component seismograms. The average group velocity of the Lg peak amplitude was found to be 3.35 kms^{-1} and, therefore, the Lg group velocity window was selected between 3.0 and 3.7 km s^{-1}. The Lg phase was then defined by the velocity window as stated above on the transverse component-displacement seismograms. [23] found for a similar frequency range that the Lg phases propagating across the Tibetan Plateau exhibited more consistent energy on the transverse component than on the radial horizontal components. The Fourier spectra of windows containing Lg ground displacement with signal-to-noise ratio greater than 2 were used in the analysis. Q_{Lg} was derived from the decay of spectral displacement amplitude with distance for a range of individual frequencies following the method described by [24]. This approach has been successfully applied in southern Mexico [24], Central America [17] and Colombia [16]. Regional average Q for the Arunachal Himalaya and Mishmi Massif and IBR of NE India was determined for six frequencies from 0.5 to 5 Hz. The Lg-wave displacement spectrum amplitude $A_{kl}\,(f)$ for the event *k*, at the recording site *l*, after removal of the instrument response, is given by

$$A_{kl}(f) = S_k\,(f)L_l\,(f)G(R)\exp\,\left(-\pi f R Q_{Lg}^{-1}/v\right) \tag{1}$$

where $S_k\,(f)$ is the source term, $L_l\,(f)$ is the local site term, R is the hypocentral distance, v is the average Lg-peak velocity (3.35 kms^{-1}), Q_{Lg} is the quality factor and $G(R)$ is the geometrical spreading, which is given by [25]

$$G(R) = \begin{cases} R^{-1} & R \leq R_x \\ (R_x R)^{-1/2} & R > R_x \end{cases} \tag{2}$$

This form of G(R) implies dominance of body waves for $R \leq R_x$ and of surface waves for $R > R_x$. [25] showed that R_x is twice the crustal thickness, which for the region of study is approximately 35-45 km and has been set as R_x = 100 km for this study. [14] reported that the observed geometrical spreading of Lg waves in the time domain,$R^{-0.83}$, is equivalent to $R^{-0.5}$ in the frequency domain. Taking the logarithim of (1) for distances larger than R_x gives

$$\log A_{kl}(f) + 0.5\log(R_x R) = \log S_k(f) + \log L_l(f) - (\pi f R log(e)/v)/)Q_{Lg}^{-1} \tag{3}$$

Since we selected records with epicentral distances larger than 200 km, we consider Lg as a crustal trapped wave with a constant geometrical spreading factor [16]. It has been observed that at distances less than 100 km, the attenuation is dominated by geometrical spreading [26], [27] & [28]. But then for distances greater than 100 km, frequency-dependent attenuation associated with Q(f) becomes significant [29].

We do not consider the radiation pattern of the source in this formulation since we assume that it has minimal effect on the spectral measurements at high frequencies, and any such effect would tend to average out over multiple events and paths [30]. In addition, [31] show that the estimate of Q is not strongly effected by the radiation pattern. The effect of the source radiation pattern is minimized because the Lg phase is constructed as a superposition of many higher-mode surface waves [32], [33] & [34] sampling a major portion of the focal sphere.

As a constraint for the site terms we required that

$$\sum_l \log L_l(f) = 0 \tag{4}$$

Therefore, equation (3) assumes the form of

$$\log A_{kl}(f) + 0.5\log(R_x R) = \log S_k(f) + (-\pi f R log(e)/v)/)Q_{Lg}^{-1} \tag{5}$$

This is the equation of a straight line, whose intercept is given by the source term and slope by the Q term. For each earthquake, we plot log A $_{kl}$ (f) + 0.5log (R_xR) versus hypocentral distance (R) and perform a linear regression to determine Q at each central frequency.

Q_{Lg} values follow a power law relation of the form [35] and [36]

$$Q_{Lg}(f) = Q_o f^{\eta} \tag{6}$$

where Q_0 is the quality factor at 1 Hz and 'η' is the power of frequency dependence. The power law has been obtained using power curve fitting of 'Q' values with respect to central frequencies, which depicts the variation of Q_{Lg} in linear scale as shown is Equation (7 & 8) below in the results and discussion.

III. Results And Discussion

The data for Arunachal Himalaya and Mishmi Massif of Arunachal Pradesh and Indo-Burman Ranges (IBR) have been analyzed employing the method to determine the regional average Q_{Lg} given by [24]. The computation for a regional average of Q_{Lg} was done at frequencies between 0.5 and 5.0 Hz by separately calculating the Q values of Lg for each frequency. The model of Q_{Lg} devised for Arunachal Himalaya and Mishmi Massif from our dataset for frequencies between 0.5 and 5 Hz by this method is shown in relation (7) and depicted by Figure 2 is given as follows [37].

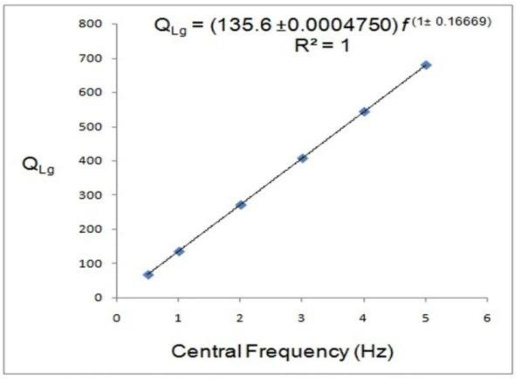

Figure 2: Q_{Lg} attenuation model for Arunachal Himalayas and Mishmi Massif

$$Q_{Lg} = (135.6 \pm 0.0004750) f^{(1 \pm 0.16669)} \quad (7)$$

The model of Lg attenuation shown in relation (7) is highly frequency dependent (given the high value of 'η' =1). Therefore, Lg attenuation in the frequency range of 0.5 to 5 Hz in the studied area is mainly expected to be caused by scattering attenuation as intrinsic attenuation is less frequency dependent [38] & [39]. It is reasonable to expect high scattering and hence low Q in regions of recent tectonic activity [38], which means a high attenuation. The value of Q_0 in the attenuation model devised shows a medium heterogeneity (Q_0 =135.6) which is mostly contributed by neotectonic activities and corresponds to the tectonically active regions of the world. Other reasons could be attributed to the fact that the eastern Himalayas in Arunachal Pradesh is characterized by a mix of soft and hard rock terrain. The lithology of Arunachal Himalaya describes younger strata in the sub-Himalayas dominated by less consolidated Neogene sedimentary rocks. The Lesser Himalayas contains predominantly Gondwana sediments and are overlain by geologically older sequence of metamorphic rocks. The 'Central Crystallines' of Higher Himalayas are essentially described by the hard rock terrain which comprises of high grade schists, gneisses and patches of granite. The Mishmi Massif is a diorite-granodiorite complex with multiple intrusion of batholithic dimension along with a wide sequence of metamorphic assemblage of different grades along with migmatites. The paths in the sub-Himalayas and the Lesser Himalayas for Lg could be inefficient owing to soft semi consolidated sedimentary terrain as compared to that of Higher Himalayas and the Mishmi Massif. Also, given the diversity in the geological age of the rocks in the studied region which ranges from Precambrian to Cenozoic, some parts of the terrain traversed by Lg comprises of geologically young Neogene loose and semi-consolidated lithology which are thrusted over the Alluviums of the Brahmaputra consisting of boulders, cobbles, pebbles and sandy matrix whereas other paths are defined by hard rocks like the Central Crystalline (dominantly of Precambrian age). The hard rock terrain could have caused a hike in the Q_{Lg} values. It is reported that high Q_0 values of ~ 720 for Higher Himalayas and ~ 724 for Tethys zone and ~ 439 for Indus Zangbo Suture (IZS) zone [40]. But the soft rock terrain of sub-Himalayas and the Lesser Himalayas cause a dip in the Q values of Lg causing a high attenuation of Lg which might offer inefficient paths for Lg. Faults and lineaments criss-crossing the studied terrain introduces inhomogeneity to a large extent which causes further attenuation of the Lg waves by scattering. Thus, given the recent collisional tectonics of the Himalayas and the neotectonic activities suggest that it is expected to have a low Q_0 value [24] for this region, which is a departure from the moderate value obtained in this study. This may be understood in the light of the fact that, a mix of geologically older and younger sequences of hard and soft rocks offers a moderate level of attenuation to Lg waves. The hard rock terrain causes a hike in the Q values of Lg which is neutralised by the presence of softer terrain and to add upon the presence of neotectonic activities introduces marked heterogeneities in the crust causing Lg to attenuate further.

The, regional average value of Q_{Lg}^{-1} has been determined for IBR and power law governed Lg attenuation relation established for the IBR area for central frequencies ranging from 0.5 and 5.0 Hz which has been shown in relation (8) and depicted by Fig 3 [41].

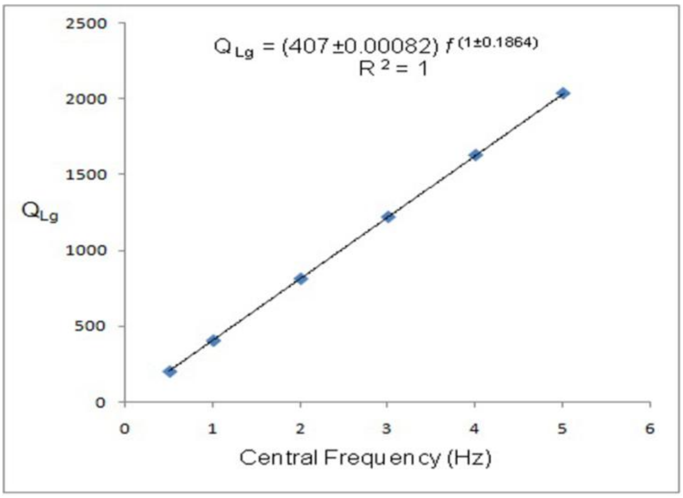

Figure 3: Variation of Q_{Lg} for IBR from central frequencies 0.5 to 5 Hz.

$$Q_{Lg} = (407 \pm 0.00082) f^{(1 \pm 0.1864)} \quad (8)$$

The regional average Q_0 value of 407 obtained in this study (Figure 3) is in concurrence with the tectonically active regions of the world. This is also supported by a high value of 'η' in this study area, which stands at 1. The value of 'η' also reflects the fact that the attenuation in the IBR is highly frequency dependent. This is possible only when the attenuation mechanism is dominantly contributed by scattering, and not by intrinsic mechanism of attenuation, because the latter is not likely to be affected by frequency. Therefore, it may be inferred that the crust beneath IBR must be heterogeneous to a large degree, which causes the Lg energy to scatter. The currently active subduction tectonics of IBR must have introduced the heterogeneity in the crust underneath IBR.

Thus, the derived moderate Q_o value is indicative of the fact that Aruanchal Himalaya and the Mishmi Massif (Q_o = 135.6) is more attenuative than the IBR region (Q_o = 407), albeit the fact that in both the study areas the attenuation of Lg is frequency dependent and hence governed mostly by scattering attenuation. Q_o for both the study areas are indicative of tectonically active regions.

IV. Conclusion

Thus, it may be concluded that both Arunachal Himalayas and Mishmi Massif as well as Indo-Burman Ranges (IBR) are tectonically active and the attenuation of Lg in both the cases are frequency dependent and hence, attenuation is dominantly governed by scattering mechanism. But then IBR is relatively less attenuative as compared Arunachal Himalaya and Mishmi Massif. The lower Q_o value at Arunachal Himalayas and the Mishmi Massif indicates the probable region for occurrence of large earthquakes as observed for the Tangsheng region by [42]. This is supported by the seismic history of northeast India which says that the Great 1950 earthquake was seated in the Mishmi Massif area of Arunachal Pradesh [9] and till date northeast India did not experience any great devastating earthquake (M > 8) sourced at IBR. These attenuation models hold lots of importance in earthquake and civil engineering practices.

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