TOMOGRAPHIC MAPPING OF LG Q IN EASTERN EURASIA

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ABSTRACT

Several thousands of Lg spectra have been collected in eastern Eurasia, from many seismic stations in China and its neighboring countries such as Mongolia, Russia, Khyrghistan, and Kazakhstan. Many spectra are recorded by pairs of two stations that are aligned with the sources, permitting estimates of inter-station Lg Q with either the standard two-station method, or the reversed two-station method of Chun et al. (1987). We select about 600 repeatedly sampled two-station paths with inter-station distances greater than 300 km to estimate Lg Q robustly. The estimated inter-station (Lg Q at 1 Hz) values are input to a back-projection algorithm to obtain a tomographic map of Q_0. Values of the mapped Q_0 vary laterally by about a factor of 10 across eastern Eurasia. Q_0 values are below or around 100 in much of the Tibetan Plateau, and are moderate (about 300-500) in eastern and central China. In regions of northeast China and the southeast coast of China, Q_0 values reach about 500 and are somewhat higher than in adjacent regions. Q_0 values generally increase northwards, to above 500 in Mongolia, Siberia, and eastern Europe. In two broad high latitude (>50 °N) regions in Siberia and eastern Europe, Q_0 values are larger than 800. The Q_0 map correlates well with the tectonic evolution history of eastern Eurasia, and is generally similar to the previous map of Q_0 developed using an Lg coda Q method. We are less confident on the individual power-law frequency dependence (η) values measured using the two-station methods because many spectral ratios are measured in relatively narrow frequency ranges, owing to the loss of high-frequency signals at the more distant stations. Often the highest available frequencies for the spectral ratio calculations are near 1 Hz. Nevertheless, there is a clear trend for the measured η values to be low. The mean η estimated over the 600 inter-station paths is about 0.2, with a spread (standard deviation) of about 0.3. These η values tend to be lower than the previously estimated values using Lg coda Q method, or a method of simultaneous inversion of source spectra and path Q. These previous estimates tend to have higher median values of about 0.4 to 0.5, but are obtained under idealized stochastic modeling which contain more assumptions than that used in the two-station methods.

OBJECTIVE

The objective of this research is to map lateral variations of regional wave Q in eastern Eurasia using data from various sources, including the IRIS DMC and other data centers. The regional waves to be used include Lg, Pg, Pn, Sn and long-period Rayleigh waves. The target is to develop regionalized Q models that have lateral resolutions as high as the data and methods permit. For some waves such as Lg and Pg, the resulting Q model will be in a form of a tomographic Q map; for other waves such as Sn, the resulting Q models may be region-specific by dividing eastern Eurasia into several (or more) subregions. The resulting Q models can be used for (a) estimating seismic source spectra, source energy radiation and seismic moments, (b) inferring source spectral scalings, stress drops and apparent stress of earthquakes; (c) inferring fundamental properties of the crust and upper mantle such as their temperature fields, and (d) evaluating the magnitude threshold of seismic events that can be recorded and studied using any set of seismic stations.

Because the Q models are of such fundamental and practical importance for scientific research and earthquake hazard mitigation, and because the new Chinese National Digital Seismic Network (CNDSN) has a large number of stations providing data to Chinese seismologists, the Lamont-Doherty Earth Observatory (LDEO) established a collaboration with the Data Management Center of the Chinese National Digital Seismic Network (DMC/CNDSN) through a mutually beneficial mode to generate high-quality Q models. A LDEO seismologist (Jiakang Xie) installs software on the DMC/CNDSN computers and trains the local personnel to collect and process regional wave spectra. Eventually the large number of regional wave spectra collected at the Incorporated Research Institution of Seismology (IRIS) Data Management Centers (DMC) by the LDEO, and at the DMC/CNDSN by the Chinese seismologists, will be merged and the seismologists from both LDEO and China will jointly invert these spectra to obtain Q models and source spectral scalings using high-frequency regional waves and long-period Rayleigh waves from eastern Eurasia.

RESEARCH ACCOMPLISHED

Background

The Lg is typically the most prominent short-period seismic phase observed over continental paths at distances greater than 200 km. Lg can be treated as a sum of higher mode surface waves, or multiple supercritically reflected S waves in the crust. The properties of Lg phase, such as its group velocity and Q, closely resemble those of the crustal average of shear waves. Whereas the Lg velocity varies by about 10% or less cross major continents, the Lg Q can vary by up to an order of magnitude. Such large variations are brought by the fact that Q is strongly affected by crustal properties such as fluid contents and temperature, both vary significantly from one region to another. Reliable measurements of Lg Q are difficult because the Lg amplitudes are affected by complications of source spectra and 3D velocity structures whose effects are difficult to fully account for, resulting in errors in Q measurement. Values of Q may be measured using the long duration of Lg coda under the assumption that coda is singly scattered Lg by crustal heterogeneities that are distributed stationarily (e.g., Mitchell, 1997). Values of the Lg coda Q can be measured with single seismograms and approximates those of Lg Q. There have been various attempts to measure Q using direct Lg waves (e.g., Philipps et al., 2000, 2002). Among methods of measuring Q using the direct Lg waves, the standard two-station method has the advantage in that it allows the source spectra to be canceled in Q measurements. The reversed two station method (Chun et al., 1987) further allows the cancellation of site responses. These methods, while being the most reliable, require restricted recording geometries and hence denser station and event coverages.

The eastern part of Eurasian continent that includes regions in and around China has a complex tectonic history. Currently the collision between Indian and Eurasian plates to the southwest results in the uplifting of the Tibetan plateau. The underthrusting of the Pacific plate from east is related to the extensions along the east coast of China. These processes provide the primary driving force of the current motions and deformations of a collage of blocks with diverse evolution histories. Timing of the last significant tectonic activity that modified the crustal blocks range between Paleozoic to current. Mitchell et al. (1997) found that the Lg coda Q values throughout Eurasia tend to correlate with the length of time that has elapsed since the last major tectonic activity. In the past decades, there have been a steady accumulation of digital Lg waveforms from eastern Eurasia brought by the installation of various broad band seismic networks and the high seismicity in the region. In this paper we report a tomographic mapping of Lg Q in the region, obtained by applying the most reliable, two-station methods to about 6,000 recently collected Lg spectra.

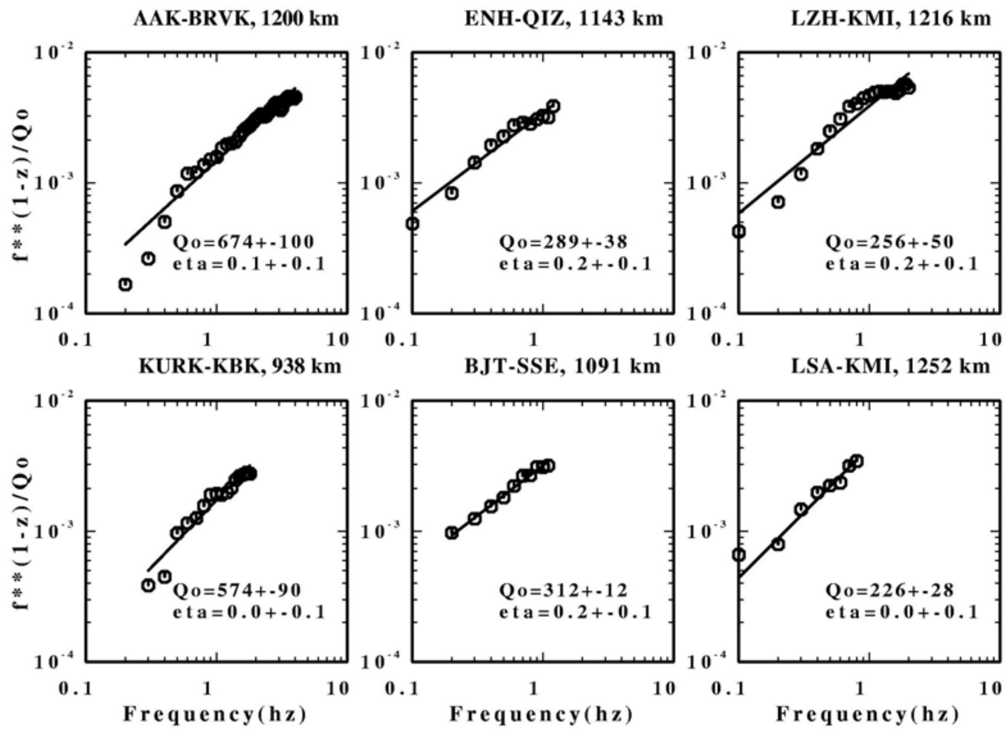

Figure 1. Average inter-station spectral ratios (circles) and the best fit Lg Q models (lines). Station codes, interstation distances and the estimated Q_0, η values are written in the panels. The first 3 ratios sample station-pairs from sources located in the same direction, so the standard two-station method (e.g., Xie et al., 2004) is used. The last 3 ratios sample station-pairs from sources located in opposite directions, so the method of Chun et al. (1987) is used.

Data and method of Q measurement

One hundred and sixty-two broad-band seismic stations are used in this study. The network affiliations include the Global Seismic Network (GSN) and various national or portable networks such as the Chinese National Digital Seismic network (CNDSN), the Kyrghistan and Kazakhstan seismic networks, and the three passive networks deployed in the Tibetan Plateau (e.g., Xie et al., 2004). Vertical component Lg waveforms from 186 events between 1988 and 2004 are retrieved from the DMC of IRIS and CNDSN. Most events are moderately sized (with magnitudes larger than 5.0). Fourier spectra of Lg are obtained using a well-established procedure (e.g., Xie et al., 2004). More than 6,000 Lg spectra are collected. From these, 5,787 pairs of spectra are selected from two stations that are (1) approximately aligned with at least one event, (2) separated far enough (> 250 km), permitting the use of the standard two-station method for Lg Q measurement. A subset of these spectral pairs further satisfies the criterion of the reversed two-station, two-event condition, permitting estimation of both inter-station Q free of site responses, and ratios of site responses (Chun et al., 1987). By examining the latter ratios we found that a few stations have non-unity site responses and/or erroneously documented instrument responses. These stations are screened out not in subsequent analysis. This results in 5,265 useful spectral ratios that collectively sample 594 inter-station paths. Average spectral ratios are calculated over these paths to estimate interstation Lg Q, which are assumed to follow the power-law frequency dependence ($Q=Q_0 f^{\eta}$ where Q_0 is Q at 1 Hz and η is the power-law frequency dependence). Typically, the lowest frequencies that yield usable spectral ratios are between 0.1 and 0.2 Hz. The highest usable frequencies are primarily controlled by the signal/noise ratio threshold of 2 used in this study, and typically vary between about 1 and 2.5 Hz. Figure 1 shows examples of spectral ratios and the best fit Lg Q models.

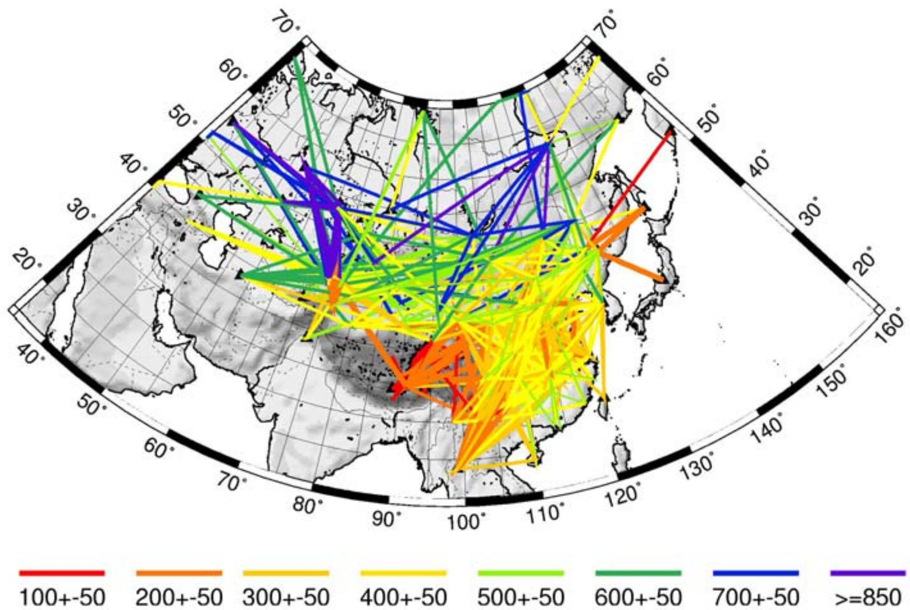

Figure 2. Two-station paths used in this study. Colors are coded to indicate Lg Q_0 values.

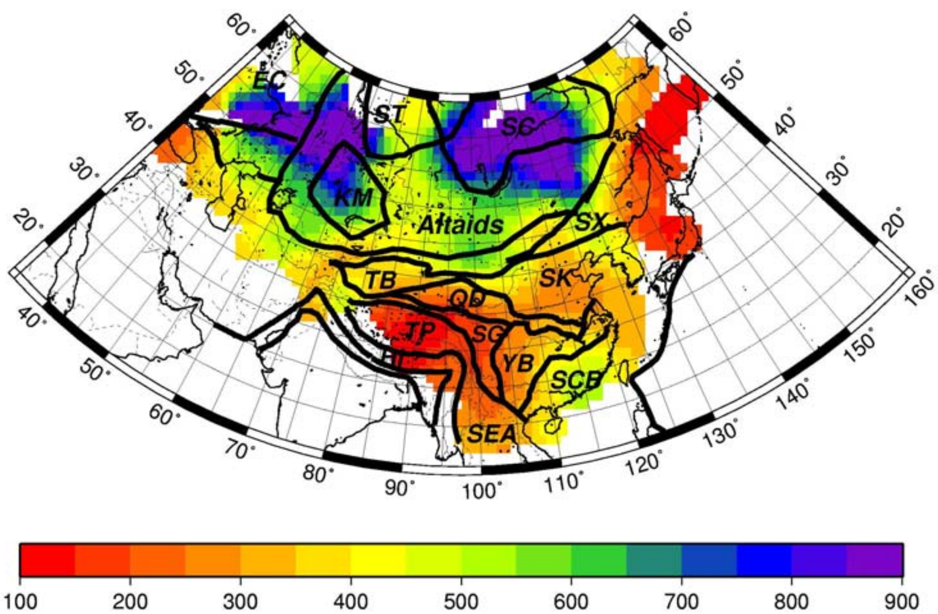

Figure 3. Lg Q_0 map for eastern Eurasia obtained in this study, and simplified tectonic boundaries (e.g., Mitchell et al., 1997; Wu et al., 1997; Hearn et al., 2004, Liang et al., 2004). Abbreviations are as follows: Tibetan Plateau (TP), Tarim Block (TB), Himalayas (HI), Songpan-Ganzi Belt (SG), Southeast Asia subplate (SEA), Yangtze block (YB), South China Block (SCB), Sino-Korean block (SK), Suolun-Xiamulun block (SX), Kazak Massif (KM), Siberia Craton (SC), Siberia Trap (ST) and Eastern Europe Craton (EC).

Result

Figure 2 shows the 594 two-station paths with colors to indicate the values of the Q_0 measurements. These values tend to be coherent at large scale and are input to a tomographic back-projection algorithm (e.g., Xie et al. 2004) to invert for the lateral variations in Q_0. To parameterize the spatially varying Q_0, the study area is divided into about 2,300 cells with constant Q_0 values and a size of 2 by 2 degrees. Figure 3 shows the resulting Q_0 model. The random errors and resolution associated with the model are estimated using the algorithm of Xie and Mitchell (1990) and Xie at el. (2004). The estimated random errors for the Q_0 model in Figure 3 is typically about 10-15%. The resolution, as measured by the point spread functions, varies between about 4 degrees in eastern China and about 10 degrees in higher latitudes (>=55°N).

The most striking low Q_0 region in Figure 3 is that in and around the Tibetan Plateau where Q_0 is at the level of 100 to 200. Toward east, Q_0 increases to about 300 in the Songpan-Ganzi Belt and Qaidam Basin, and to 350-550 in the Yangzi and south China blocks. To the north of these regions there is a band of moderate Q_0 regions (300-450) that covers the Tarim Block, the Ordos and the Sino-Korean Platforms. To the north of this band Q_0 increase with increasing latitude in the Altaids, to between about 400 and 600. Much of the Kazak Massif contains Q_0 values that are greater than 600. Variations of Q_0 in the northernmost regions can be resolved only at scales of about 10 degrees, with two broad regions of high Q_0 values of greater than 700, and up to 900, in the Siberian and Eastern Europe Cratons. Between these regions lies the Siberian Trap, a province that was affected by wide-spread volcanism and rifting in late Paleozoic-Mesozoic time. Values of Q_0 in the Trap are relatively lower (about 400-500) than in the Cratons. In general, Lg Q_0 values in Figure 3 exhibit a good correlation with the time length measured from the last major tectonic events that modified the blocks, as found by Mitchell et al. (1997) for Lg coda Q_0 values. The variations in Lg Q_0 in Figure 3 in the southern and eastern portions are more drastic than those of Lg coda Q_0, as would be expected if Lg coda is generated by an Lg-scattering process, which naturally smears out the spatial variations of Lg coda Q measurements.

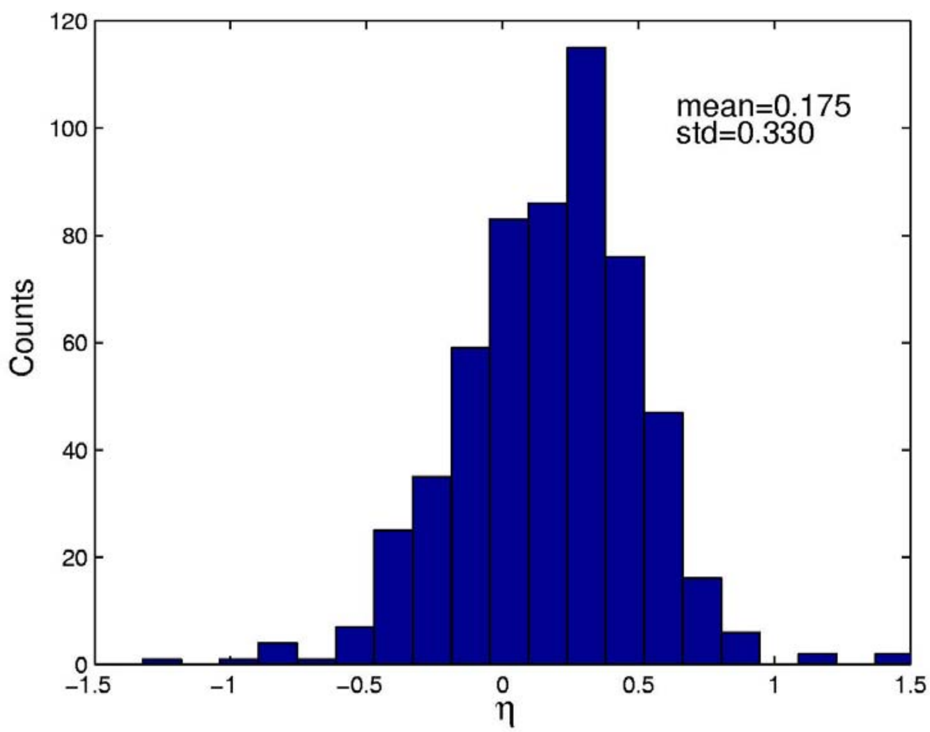

Figure 4. Distribution of the measured inter-station η values, with means and standard deviation indicated.

The frequency dependence (η) values are measured using the slopes of the logarithm of the inter-station spectral ratios (Figure 1). Ideally to measure η reliably, a wide frequency range between about 0.1 and a few Hz is desirable (Xie et al., 2004). Unfortunately, many spectral ratios used in this study are only available in relatively narrow frequency ranges between about 0.1 and 1 Hz owing to the rapid loss of high frequency signals at the more distant stations. We are, therefore, less confident at the measured η values for many individual paths. Figure 4 shows the histogram of the 594 η measurements, which allows us to examine their gross range. The mean and standard deviation of these η measurements are of 0.17 and 0.3, respectively, meaning the range of η is roughly between -0.1 and 0.5. The mean η of 0.17 is much lower than the mean η values of 0.4-0.5 obtained using Lg coda (Mitchell et al., 1997) or using a simultaneous inversion of source spectra and Lg Q (Xie et al., 1996). This discrepancy in measured η values may result from some systematic bias in the different measurement methods that are based on various assumptions. The coda Q method assumes a single, frequency independent scattering process. The simultaneous inversion of source spectra Q assumes an idealized, omega-squared source model. The two-station method assumes nothing about Lg scattering or source, but has a strict requirement of recording geometry which often leads to a large epicentral distances (> 1500 km) of the more distant stations. The assumptions of Lg scattering or omega-source model may not be perfectly valid, or η could tend to decrease with recording distance in addition to varying laterally (Xie et al., 1996). Assuming that the latter is not the case and η values measured in this study are not grossly biased, we may map the lateral variation of η spatially. Future research with more data should enable us to explore the cause of the η discrepancy.

CONCLUSIONS AND RECOMMENDATION

Thousands of Lg spectral ratios are collected from eastern Eurasia that includes China and surrounding regions. These ratios repeatedly sample Lg attenuation, or Q, over 594 two-station paths. Lateral variations of Lg Q are mapped using a tomographic inversion. The 1 Hz Lg Q (Q_0) varies between about 100 and 900. There is a general correlation between values of Lg Q_0 and the time length measured from the last major tectonic event that modified the crustal structure. The lowest Q_0 is found in the Tibetan plateau. Values of Q_0 increase to moderate numbers toward east and north. The highest Q_0 is found in broad regions that coincide with the Siberia and Eastern Europe Cratons. Values of Lg Q_0 are grossly compatible to those of Lg coda Q_0, measured using data, assumption and method that are different from those in this study. The power-law frequency dependence (η) values obtained in this study are systematically lower then those obtained previously using Lg coda. Resolving this discrepancy is important because path-corrections at high frequencies are critically dependent on accurately estimated η values. Future research with more data should enable us to explore the cause of the η discrepancy.

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REFERENCES

Chun, K. Y., G. F. West, R.J. Kokoski and C. Samson (1987). A novel technique for measuring Lg attenuation - Results from eastern Canada between 1-Hz to 10-Hz, *Bull. Seism. Soc. Am*. 77: 398-419.

Hearn T. M., S. Y. Wang, J.F. Ni,, Z.H. Xu, Y.X. Yu and Zhang X.D. (2004). Uppermost mantle velocities beneath China and surrounding regions, *J. Geophys. Res*., 109: Art. No. B11301, doi:10.1029/2003JB002874.

Liang, C., X. Song, and J. Huang (2004). Tomographic inversion of Pn travel times in China, *J. Geophys. Res.* 109: B11304, doi:10.1029/2003JB002789.

Mitchell, B. J., Y. Pan, J. Xie and L. Cong, (1997). Lg coda Q variation across Eurasia and its relation to crustal evolution, *J. Geophys. Res*. 102: 22767-22780.

Phillips, W. S., Hartse H. E., Taylor S.R. and G.E. Randall (2000). 1 Hz Lg Q tomography in Central Asia, *Geophys. Res. Lett.* 27: 3425-3428.

Phillips, W. S. and H. E. Hartse (2002). Regional path calibration using multiple-station amplitude tomography. *Seism. Res. Lett.* 73: 228.

Wu F. T., A. L. Levshin and V.M. Kozhevnikov (1997). Rayleigh wave group velocity tomography of Siberia, China and the vicinity, *PAGEOPH* 149: 447-473.

Xie, J. and B. J. Mitchell (1990). A back projection method for imaging large scale lateral variation in Lg coda Q with application to continental Africa, *Geophys. J.* 100: 161-181.

Xie, J., L. Cong, and B. J. Mitchell, (1996). Spectral characteristics of the excitation and propagation of Lg from underground nuclear explosions in Central Asia, *J. Geophys. Res.* 101: 5813-5822.

Xie, J., R. Gok, J. Ni, and Y. Aoki (2004). Lateral variations of crustal seismic attenuation along the INDEPTH Profiles in Tibet from Lg Q inversion, *J. Geophys. Res.* 109: B10308, doi:10.1029/2004JB002988.