EXCITATION AND PROPAGATION OF Lg IN CENTRAL EURASIA

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Abstract

Lg spectra from 20 underground nuclear explosions and 52 shallow earthquakes in central Eurasia have been collected at 21 broad band IRIS, CDSN and KNET stations. Using the non-linear method of Xie (1993), we simultaneously invert for Lg source spectral parameters and path-variable Lg Q_0 and η values (Lg Q at 1 Hz and its power-law frequency dependence, respectively). The inversions yield Lg seismic moments (M_0), corner frequencies (f_c) for the events, as well as Lg Q_0 and η values for numerous paths in central Eurasia.

Grossly speaking, Lg Q and Lg coda Q are similar in central Eurasia, although minor discrepancies exist between (a) Lg η and Lg coda η at large (> about 2700 km) distances, and (b) Lg Q_0 and Lg coda Q_0 values in a subregion northeast of the Lop Nor test site. For both explosions and earthquakes Lg M_0 values correlate linearly with the ISC M_b values, both having slopes slightly greater than 1.0. For the same Lg M_0 values, M_b values from explosions tend to be larger than those from earthquakes. Lg M_0 tend to scale with $f_c^{-\alpha}$, with α closer to 4 than to 3. Regression analysis over M_0 and f_c values suggest that for the same M_0 values, explosions tend to have higher f_c values. This may form a basis of an explosion discriminant, but the fact the there is a slight overlap among M_0 and f_c values from explosions and those from earthquakes suggests that the use of this discriminant should be used with caution.

Applications of the methodology used in this study to other regional phases, such as Pn, may contribute to our understanding of regional wave excitation/propagation by various types of seismic source, and to the evaluation of various discriminants using regional waves.

Key words: Lg, Q, source spectral parameters, explosion discrimination.

Research Accomplished

Over the past two years we have collected Lg spectra from 20 underground nuclear explosions in the Balapan and Lop Nor test sites, recorded by 17 broad-band IRIS, CDSN and KNET stations (Figures 1, 4, also *cf.* Xie *et al.*, 1995). We have also collected Lg spectra from 52 shallow earthquakes (5-33 km) that occurred in the areas of the central Asian Republics of the F.S.U. and southern Xinjiang, China, recorded by 11 broad band stations (Figures 1, 5). These spectra are used to invert for Lg source spectral parameters (M_0, f_c) and path variable Lg Q_0 and η values (Lg Q at 1 Hz and its power-law frequency dependence, respectively), with the non-linear inverse method of Xie (1993). Figures 2 and 3 show examples of the fit of the optimal source/path parameters to the observed Lg spectra, where the inverted Q_0, η values for multiple stations that recorded an explosion (Figure 2) and earthquake (Figure 3) are used to remove path effects, resulting in reduced Lg spectra at the source. It appears that the fit for the explosion event (Figure 2) is better than for the earthquake event (Figure 3), particularly for the station averages (lower right panels). The main findings of this study are:

(1) *Importance of the number of stations recording Lg*: During the spectral inversions using Lg, we found that when the number of stations recording the same event is less than 3, the available Lg spectra is typically not sufficient for a simultaneous inversion of source M_0, f_c and path Q_0, η values. Accordingly, *a priori* information on the Q_0, η values obtained in previous simultaneous inversions must be used. It also appears that the M_0 and f_c values obtained with Lg spectra from only one or two stations are less reliable than those obtained with Lg spectra from more stations. Much of the scatter in Figure 9 is due to the M_0, f_c values obtained using only 1 or 2 stations.

(2) *Effects of radiation pattern by earthquake sources*: For paths connecting the Lop Nor test site and stations AAK, GAR and ARU, there are two sets of Lg Q_0 values obtained, one using earthquake data and the other using explosion data (Figures 5 an 6). These Lg Q_0 values are very similar, suggesting that the radiation patterns for the earthquake sources are insignificant.

(3) *Comparison between Lg Q_0 and and Lg coda Q_0*: For most of the paths used in this study, the Lg Q_0 obtained in this study are highly consistent with the Lg coda Q_0 map of Xie & Mitchell (1991) and Pan *et al.* (1992) (see Figures 4, 5, 6). For three paths that run from the earthquake in Xinjiang northeastward to stations MDJ, HIA and TLY (Figure 6(a)), the Lg Q_0 values are somewhat higher than the Lg coda Q_0 values (Figure 4). The most likely cause of this discrepancy is that the direct Lg phase and Lg coda are affected by 3D structural complexities in different manners in the area, causing the two Q_0 values differ.

(4) *Comparison between Lg η and and Lg coda η*: When the epicentral distance (Δ) is less than about 2700 km, the frequency dependence of Lg Q, η, obtained in this study agrees (within an uncertainty level of about 0.1 to 0.2) with the Lg coda η. At larger distances ($\Delta > 2700$ km), the η values obtained in this study tend to be low (often down to ~ 0.0). This discrepancy is most likely due to imprecisely estimated Lg η in this study due to narrower frequency bands, or effects of the earth's curvature at large Δ.

(5) *Scaling of Lg* M_0 *with ISC* M_b: For both explosions and earthquakes, the Lg M_0 values correlate linearly with ISC M_b (Figure 7). Linear regression over the points in Figure 7 yield

$$\log M_0 = 1.19(\pm 0.11)\, M_b + 8.85(\pm 0.64) \tag{1}$$

for explosions, and

$$\log M_0 = 1.04(\pm 0.09)\, M_b + 10.66(\pm 0.51) \tag{2}$$

for earthquakes. These are straight lines that parallel each other (Figure 7), but are offset such that for the same M_0 values, M_b values tend to be systematically higher for explosions.

(6) *Scaling of Lg* M_0 *with* f_c *for explosions*: Figure 8 shows Lg M_0 versus f_c obtained in this study obtained for the 20 underground nuclear explosions studied, with the explosion source model [*i.e.*,, the model with an overshoot effect; see equation (2) of Sereno *et al.* (1988) or equation (10) of Xie, (1993)]. Lg M_0 values correlate linearly with ISC M_b and a linear regression yields

$$\log M_0 = 15.12(\pm 0.22) - 3.98(\pm 0.43) \log f_c \quad . \tag{3}$$

This suggests that Lg M_0 scales with f_c^{-4}, instead of with f_c^{-3} (*i.e.*, constant stress drop scaling).

(7) *Scaling of Lg* M_0 *with* f_c *for earthquakes*: Figure 9 shows Lg M_0 versus f_c obtained for the 53 earthquakes obtained in this study, using an earthquake source model (*i.e.*, the ω^2 model without overshoot). A linear regression over the points in Figure 9 yields

$$\log M_0 = 14.85(\pm 0.29) - 3.56(\pm 0.29) \log f_c \quad . \tag{4}$$

(8) *Difference between the* M_0, f_c *scaling for earthquakes and explosions*: Equation (3) is obtained for Lg M_0 and f_c values of explosion sources, obtained in inversions using the *explosion* source model. On the other hand, equation (4) is obtained for Lg M_0 and f_c values of earthquakes using the *earthquake* source model. For the purpose of discriminating explosions from earthquakes, it is desirable to obtain M_0 and f_c for explosions using the earthquake source model, thus simulating a situation where we do not know that the explosions under study are explosions. The resulting Lg M_0 and f_c values for the explosions, obtained using the earthquake source model, are plotted in Figure 9, and a linear regression over these values yields

$$\log M_0 = 15.69(\pm 0.23) - 3.83(\pm 0.45) \log f_c \quad . \qquad (5)$$

The straight lines represented by equations (4) and (5) are subparallel, both being closer to $M_0 \sim f_c^{-4}$ scaling than to $M_0 \sim f_c^{-3}$ scaling. However, the two lines are offset and for a given M_0, the explosions tend to have higher f_c values. This suggests greater high-frequency content of Lg from explosions, as compared to that from earthquakes of similar moments. The M_0 and f_c values may therefore be used to discriminate explosions from earthquakes. However, Figure 9 shows that there is some slight overlap of the M_0 and f_c values for the two groups of events at smaller moments, indicating that this discriminant should be used with caution.

Conclusions and Recommendations

Grossly speaking, Lg Q and Lg coda Q are similar in central Eurasia, although minor discrepancies exist between (a) Lg η and Lg coda η at large (> about 2700 km) distances, and (b) Lg Q_0 and Lg coda Q_0 values in a subregion northeast of the Lop Nor test site. For both earthquake and explosion sources, Lg M_0 values correlate linearly with the ISC M_b values, both having slopes that are slightly greater than 1.0. Lg M_0 tends to scale with $f_c^{-\alpha}$, with α being closer to 4 than to 3. Regression analysis over M_0 and f_c values suggests that for the same M_0 values, explosions tend to have higher f_c values. This may form a basis of a explosion discriminant, but the fact the there is a slight overlap among M_0 and f_c values from explosions and those from earthquakes suggests that the use of this discriminant should be used with caution.

Future research is recommended in the following areas:

(1) Establish more precise, perhaps distance and frequency dependent geometrical spreading for the Lg phase and other regional phases based on synthetics using realistic velocity structures.

(2) Conduct experiments to see if the ω^2 source model needs to be modified for Lg excitation by earthquake sources.

(3) Apply the same methodology in this study to the spectral characteristics of excitation and propagation of other regional phases, particularly the Pn phase, and systematically evaluate the Pn/Lg spectral ratio discriminant. Also, test to see if the Pn/Lg discriminant is more reliable than the Lg discriminant.

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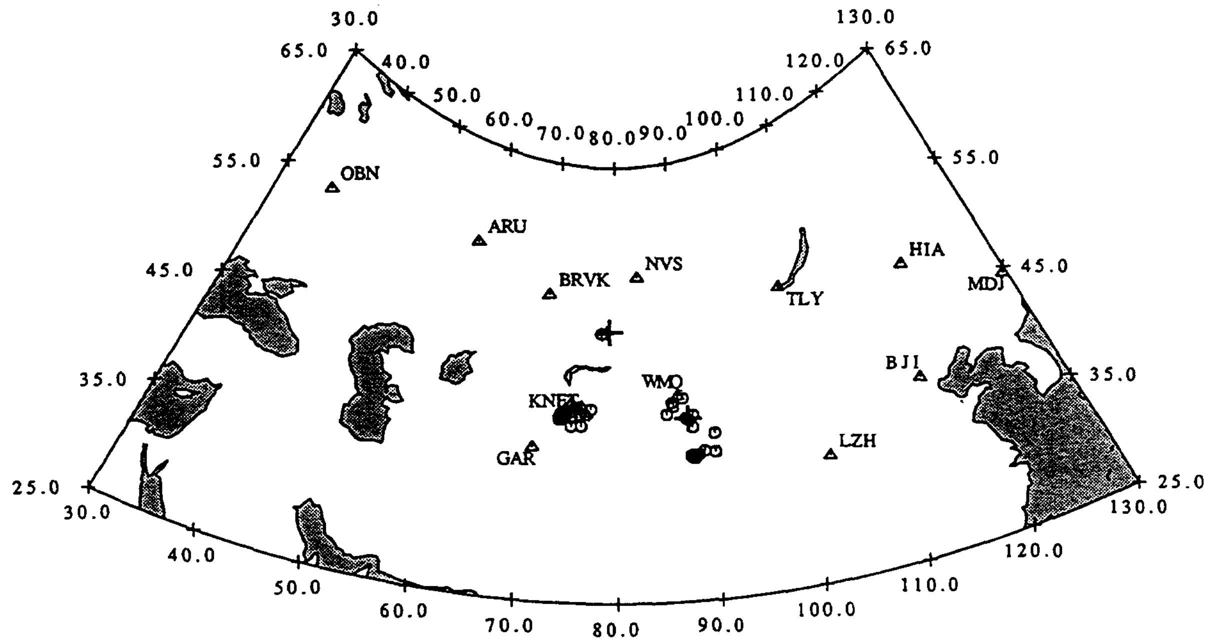

Fig. 1. Locations of the 20 underground nuclear explosions (crosses), 52 earthquakes (circles) and 21 seismic stations (triangles) used in this study. The numbers of stations providing Lg records are 17 for the explosions, and 11 for the earthquakes.

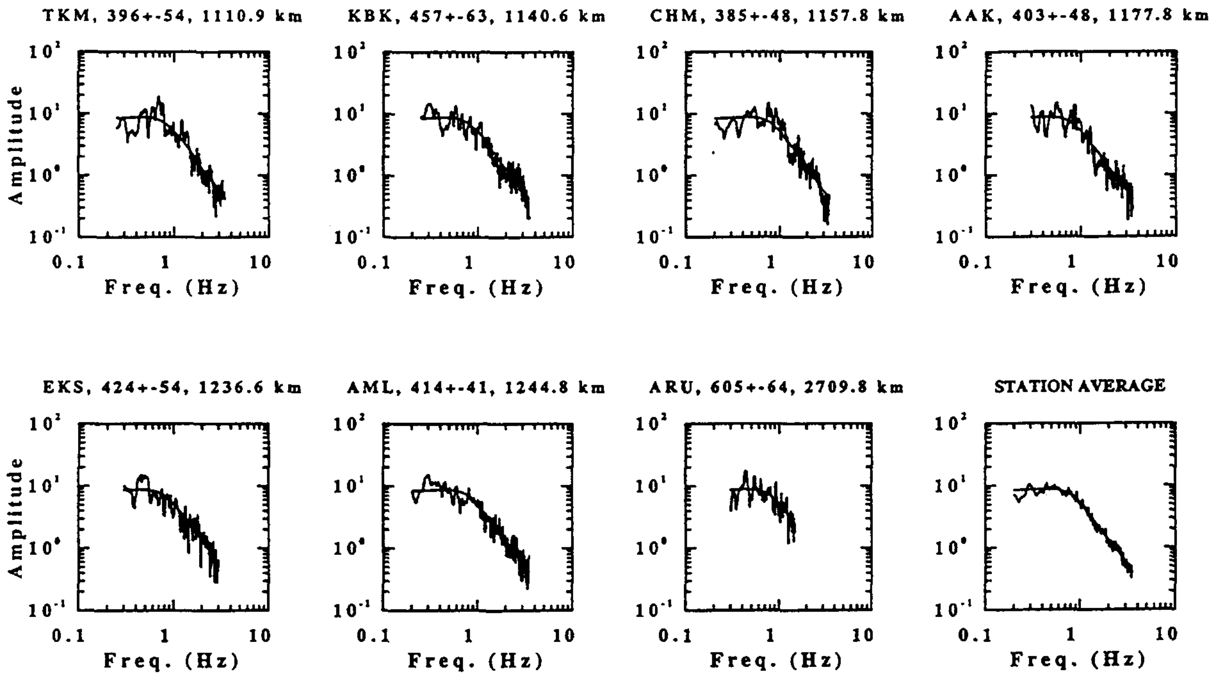

Fig. 2. Synthetic Lg source spectra for seven KNET and IRIS stations recording the October 5, 1993, Lop Nor explosion, versus the observed Lg spectra that are reduced to source by removing path effects. The lower right panel is the average for all of the seven stations. The synthetic spectra are calculated using optimal source spectral parameters (M_0 = 8.3×10^{15} Nm, f_c=0.68 Hz) obtained in the inversion. Path Q_0 values obtained in the inversion are written on the top of the panels, together with the epicentral distances.

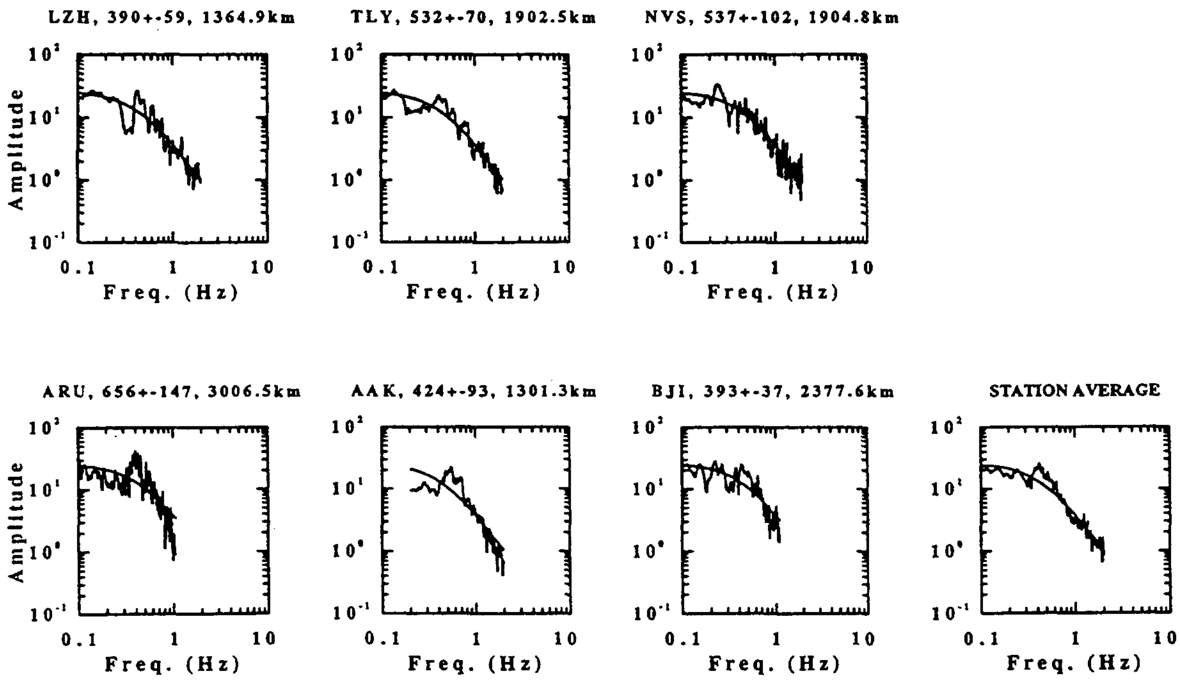

Fig. 3. Synthetic Lg source spectra for six IRIS and CDSN stations recording the October 2, 1993, southern Xinjiang earthquake (Mb = 5.6), versus the observed. The synthetic spectra are calculated using optimal source spectral parameters (M_0=2.6×10^{16} Nm, f_c=0.41 Hz) obtained in the inversion.

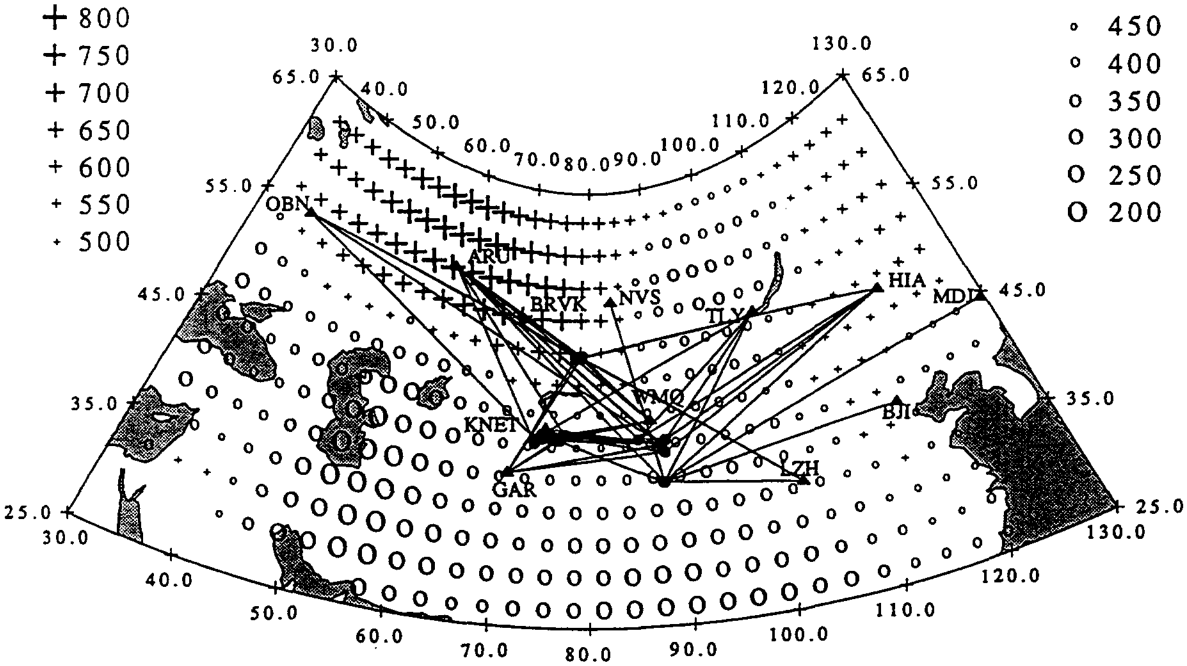

Fig. 4. The Lg paths for which Q values are measured in this study, plotted with the Lg coda Q_0 values from the tomographic inversion by Xie and Mitchell (1991). Solid dots and triangles are sources and stations, respectively.

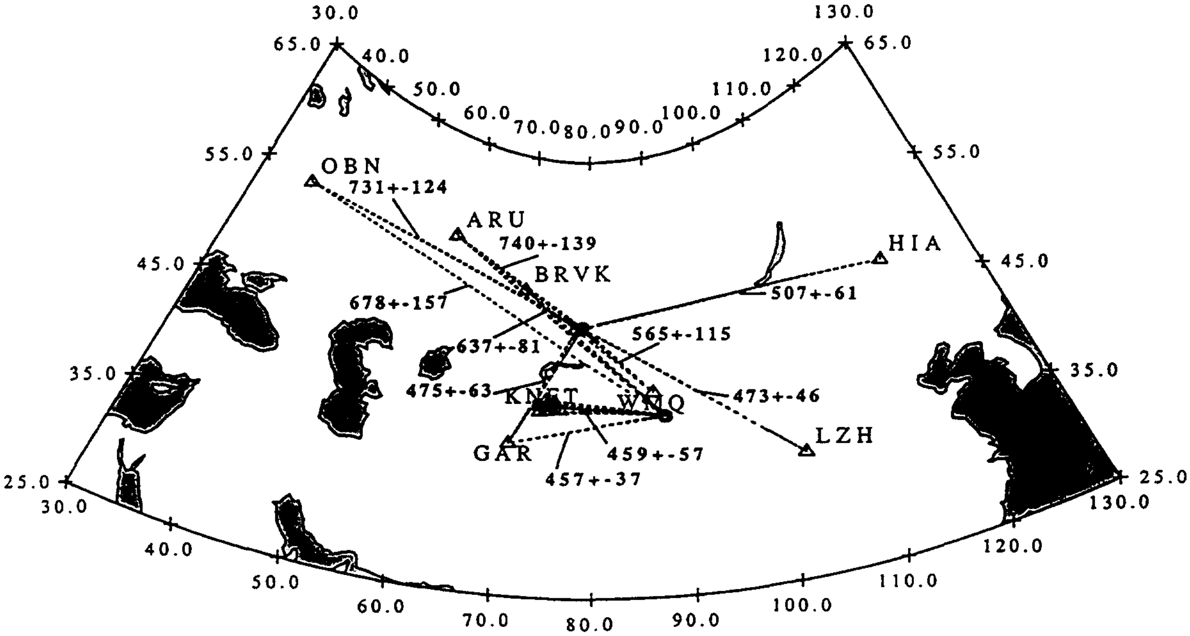

Fig. 5 Lg Q_0 values obtained for the great circle paths from the Lop Nor and Balapan test sites to the 17 IRIS, CDSN and KNET stations. Water-covered areas are shaded.

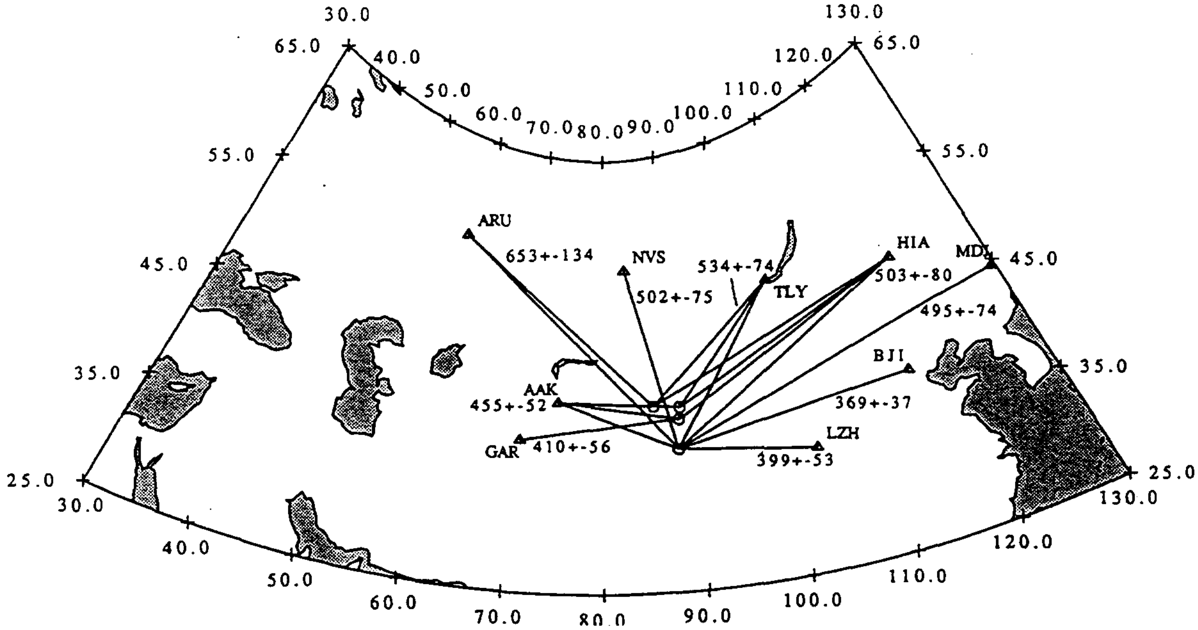

Fig. 6(a) Lg Q_0 values obtained for the great circle paths from the Xinjiang earthquakes to IRIS and CDSN stations.

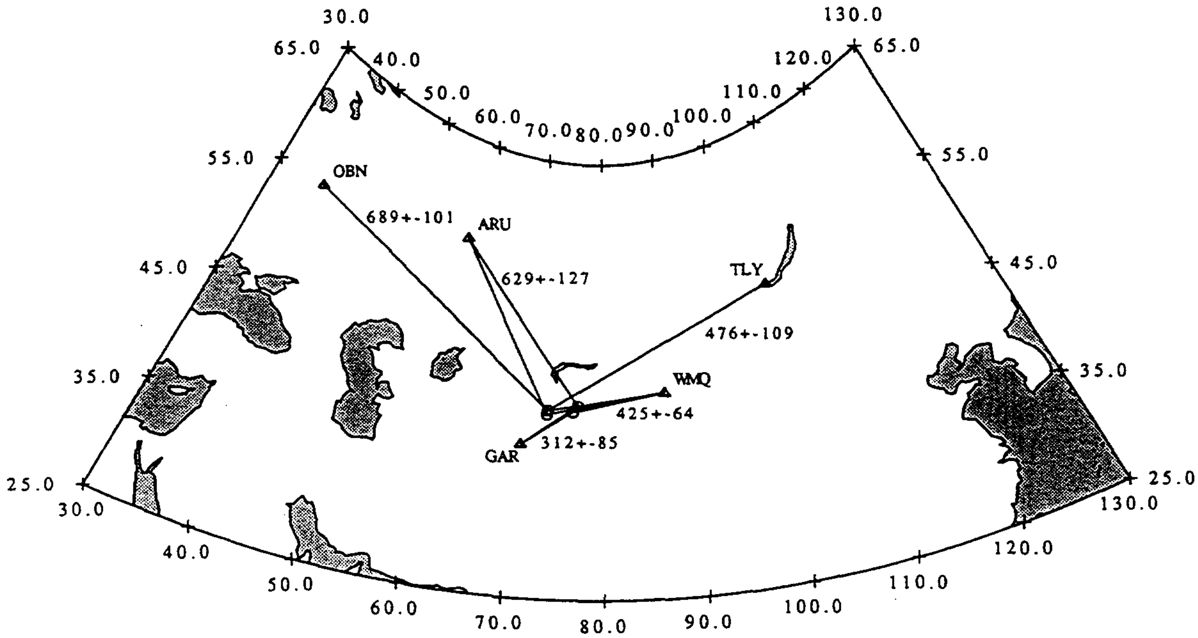

Fig. 6(b) Lg Q_0 values obtained for the great circle paths from earthquakes in the central Asian Republics of the F.S.U. to IRIS and CDSN stations.

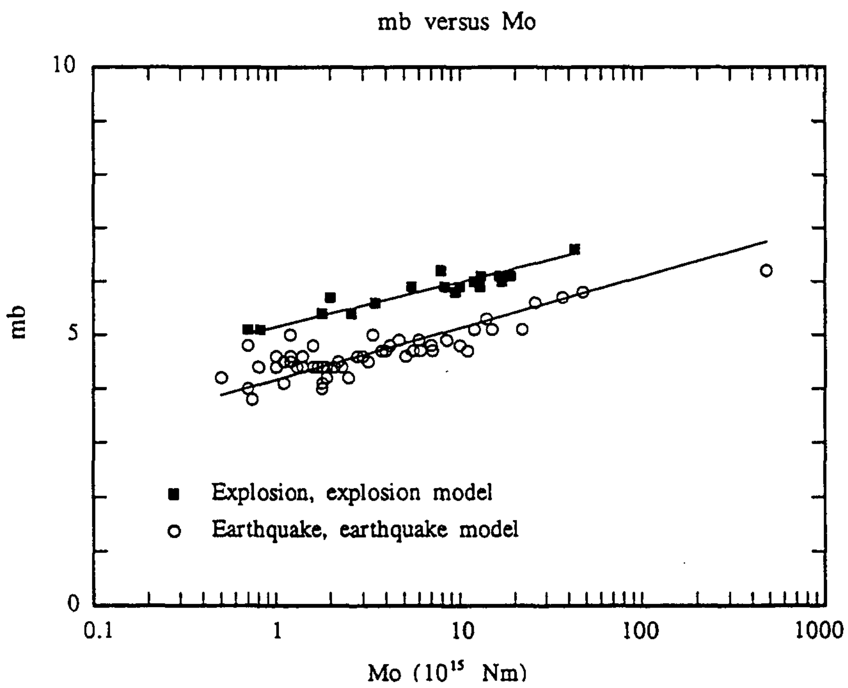

Fig. 7. M_b values versus logarithm of M_0 values (in 10^{15} Nm) obtained for explosions and earthquakes. Straight lines represent the linear regression fitting.

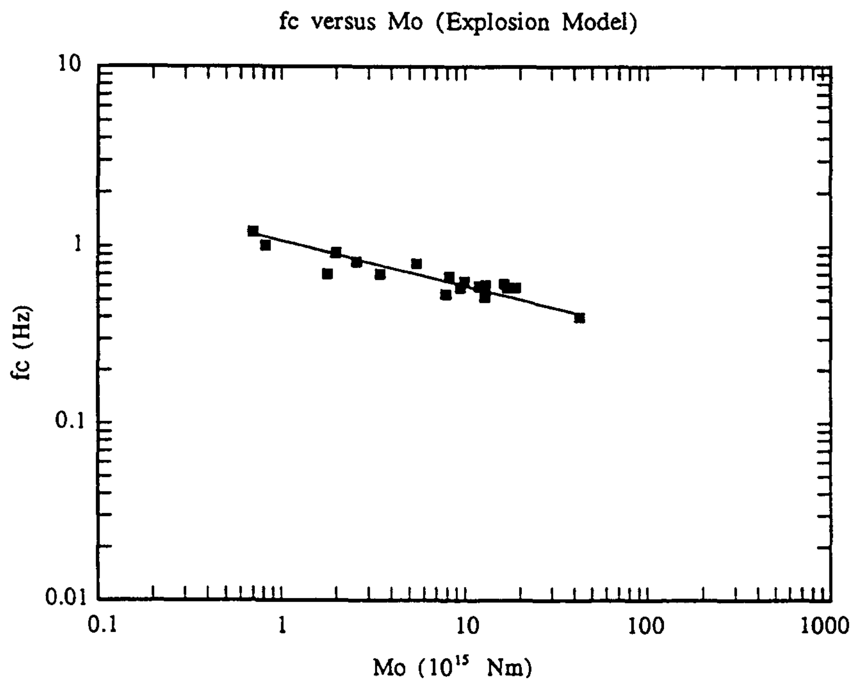

Fig. 8. Logarithm of M_0 (in 10^{15} Nm) versus logarithm of f_c values for the explosions studied, obtained by inverting the Lg spectra using the explosion source model. Straight line represents the linear regression fitting.

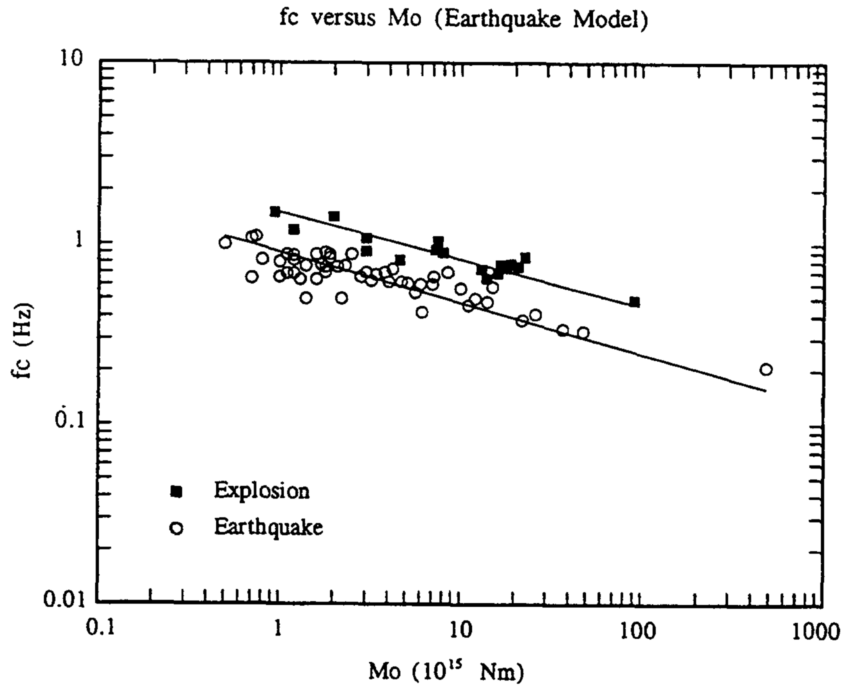

Fig. 9. Logarithm of M_0 (in 10^{15} Nm) versus logarithm of f_c values for the earthquakes and explosions studied, both obtained by inverting the Lg spectra using the earthquake source model. Straight lines represent the linear regression fitting.