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VII. SUMMARY OF TECHNICAL REPORTS / PAPERS PUBLISHED

VII.1 Spectral analysis of Shagan River explosions recorded at NORSAR and NORESS

As shown by Ringdal and Hokland (1987), NORSAR recordings of Lg and P coda can provide very stable estimates of the magnitudes of underground nuclear explosions at the Shagan River test site. These data thus hold considerable promise in relation to obtaining accurate yield estimates for the purpose of verifying a threshold test ban treaty.

To investigate the observational basis for estimation of magnitudes based on P-coda and Lg measurements, we have calculated power spectra from NORSAR recordings of about twenty Shagan River explosions.

The mean spectrum of the NORSAR short-period channels and the curves representing plus/minus two standard deviations are estimated for noise preceding the P-phase, for P-coda and for Lg. The time windows are equal to those applied by Ringdal and Hokland (1987) for estimating RMS based magnitudes. We will not go into detail on their procedure, but point out that the RMS of noise, P-coda and Lg were calculated from traces bandpass-filtered between 0.6 and 3.0 Hz. Fig. VII.1.1(a-c) give the spectra from the Joint Verification Experiment (JVE) explosion in the Shagan River region of September 14, 1988. The plots show the mean spectrum across NORSAR as well as curves corresponding to plus/minus two standard deviations. In the range 0.6-3.0 Hz, we find that the variations across the NORSAR array are of comparable size for both noise, P coda and Lg, and the same variation characteristics also apply to the other events investigated in this study.

A procedure to compensate for the background noise level forms part of the RMS magnitude measurements. This procedure can be simulated on the power spectra by subtracting the pre-P noise from the P-coda or Lg spectra. In Fig. VII.1.2 we illustrate the background noise compensation by showing the spectra of the noise, of Lg and of Lg minus noise.

We note that in this case the effect of the noise compensation is small in the frequency band with the maximum power (around 0.8 Hz). In fact, the noise compensation only becomes important for the lower magnitude events. In the following, references will be made to noise-corrected Lg spectra only.

Note that the Lg spectrum of Fig. VII.1.2 exhibits a peak between 0.7 and 0.8 Hz. From the NORSAR short-period response given in Fig. VII.1.3, we can see that in the frequency range 0.6 to 3.0 Hz the amplification is varying by a factor of ten. If the dominant frequency of the Lg phase were to vary significantly from event to event, the RMS-based magnitude estimates could be influenced by the varying amplification. To investigate this problem further, Fig. VII.1.4a shows expanded Lg spectra of eleven events from the southwestern part of the Shagan River test region. The RMS Lg magnitudes range from 5.67 to 6.19. Although there is a trend of lower dominant frequencies for the highest peaks, the actual variation is small. In Fig. VII.1.4b we show similar spectra for seven events from the northeastern part of the Shagan River test region. The RMS Lg magnitudes for these events vary from 5.87 to 6.11.

Ringdal and Hokland (1987) found in their study of Lg and P-coda magnitudes from the Shagan River test site that there was a significant regional anomaly within that site. In the northeastern part, the P-coda and ISC magnitudes were consistently low compared to Lg, whereas in the southwestern part they were consistently high. To investigate whether this anomaly is reflected in the Lg spectra, we have plotted in Fig. VII.1.5 the peak frequencies for the events investigated as a function of RMS Lg magnitude, with different symbol types for the two subregions. Although there are a couple of outliers, both the events from the NE part (crosses) and the SE part (filled rectangles) follow the same trend of lower dominant frequencies for higher magnitudes. From the results given in Fig. VII.1.5 we can infer that the Lg peak frequency characteristics do not differ significantly from the NE to the SW part of the Shagan River test site. The overall variation of the dominant frequency among the events of different magnitude is less than 0.15 Hz. We therefore find that amplification differences, see Fig. VII.1.3, will not influence the variation of the magnitude estimates significantly.

In Fig. VII.1.6a and VII.1.6b we have calculated P-coda and Lg spectra for two Shagan River events with comparable RMS Lg magnitudes. The event represented in Fig. VII.1.6a is located in the SW region and has an RMS Lg magnitude of 5.96, whereas the event given in Fig. VII.1.6b is located in the NE region and has a magnitude of 5.87. The feature we want to emphasize from these figures is that the P-coda spectrum of the SW event is well above that from the NE event in the entire frequency range 0.6 to 3.0 Hz. On the other hand, the differences in the Lg spectra are small and are confined to the frequency range 0.6 to 1.0 Hz.

For events below a certain magnitude, the SNR of Lg at NORSAR is too low for application of Lg-based magnitude measurements. In theory, the SNR could be improved through beamforming, but in practice the Lg phase has too low coherency across NORSAR for this to be meaningful. On the other hand, the NORESS array has shown an excellent capability of improving the SNR. In Fig. VII.1.7a we show the mean NORESS spectra for noise preceding the P-phase and for Lg. The event considered is the JVE explosion of September 14, 1988. At 0.8 Hz, the SNR is about 11 decibels. By forming a beam from the center instrument and the D-ring of the NORESS array with steering delays corresponding to an apparent velocity of 4.3 km/s and the azimuth to the Shagan River test site (80 degrees), the SNR can be significantly improved. In Fig. VII.1.7b, we show the beam spectra of noise and Lg and find and SNR of 17 decibels at 0.8 Hz, implying that NORESS Lg measurements of Shagan River explosions may be done for event of 6 dB (0.3 m_b units) lower than for NORSAR. However, in the low-SNR cases where we have to apply the beamforming technique on NORESS array recordings to obtain an Lg magnitude estimate, the variance in the estimate will be larger than for the high SNR cases where we can average over the full NORSAR array.

To illustrate how NORESS beamforming works for the Lg phase, we have applied the wide-band slowness estimation techinque to NORESS short-period recordings of a 16 min long wavetrain comprising all phases from the JVE explosion. The center instrument and the C- and D-rings were analyzed in the frequency band 0.6 to 3.0 Hz. Each time window was three seconds long and the separation between the windows was one second. The results are given in Fig. VII.1.8 and show the following: In the upper panel, the intermediate period vertical channel, bandpass filtered between 0.6 and 3.0 Hz is displayed. In order to more clearly visualize the PP phase, occurring after about 120 seconds and the Lg phase arriving between 750 and 870 seconds, we have clipped the amplitude of the P-phase in the plot. In the second panel, the azimuth from the slowness analysis is given. The size of the rings represent a coherency measure of the slowness solution. Although there is a relatively large scatter in azimuth around the theoretical value of about 80 degrees, the time intervals around P, the early P-coda, PP and Lg show a more uniform pattern than the rest. The slowness or apparent velocity estimates, given in the lower panel, show that between P and PP the apparent velocity is consistently above 10 km/s. It then drops to below 5 km/s after about 6 minutes, and then stays at about this level throughout the wavetrain. The relatively consistent azimuth and apparent velocity estimates within the Lg wavetrain explain why the beamforming works well for this phase.

Conclusions

In this study we have presented some results illustrating some of the features related to magnitude estimation based on RMS Lg and RMS P-coda measurements. The Lg spectra from both the NE and the SW part of the Shagan River region show little variation in spectral shape and dominant frequency. Even though the RMS Lg magnitudes are computed from traces filtered in the 0.6-3.0 Hz band, the spectra show that the signal energy level between 0.6 and 1.0 Hz essentially determines the Lg magnitudes.

For events from SW Shagan, the spectral difference between P-coda and Lg is larger than for events from the NE part. This applies to the entire frequency range 0.6 to 3.0 Hz . It also follows that the spectral level of the entire frequency band analyzed (0.6 to 3.0 Hz) contributes to the RMS P-coda magnitude estimates.

In cases where the single station SNR of the Lg is too low for Lg magnitude estimation, we can employ the beamforming capability of the NORESS array to improve the SNR. About 6 decibels SNR improvement can be achieved, i.e., about 0.3 magnitude units. The applicability of beamforming of the Lg phases has been demonstated by running moving time window slowness analysis on a 16 minutes long window covering all phases from a Shagan River nuclear explosion.

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References

Ringdal, F. and B.Kr. Hokland (1987): Magnitudes of Semipalatinsk explosions using P coda and Lg measurements at NORSAR. Semiannual Technical Summary 1 April - 30 September 1987, No.1-87/88.

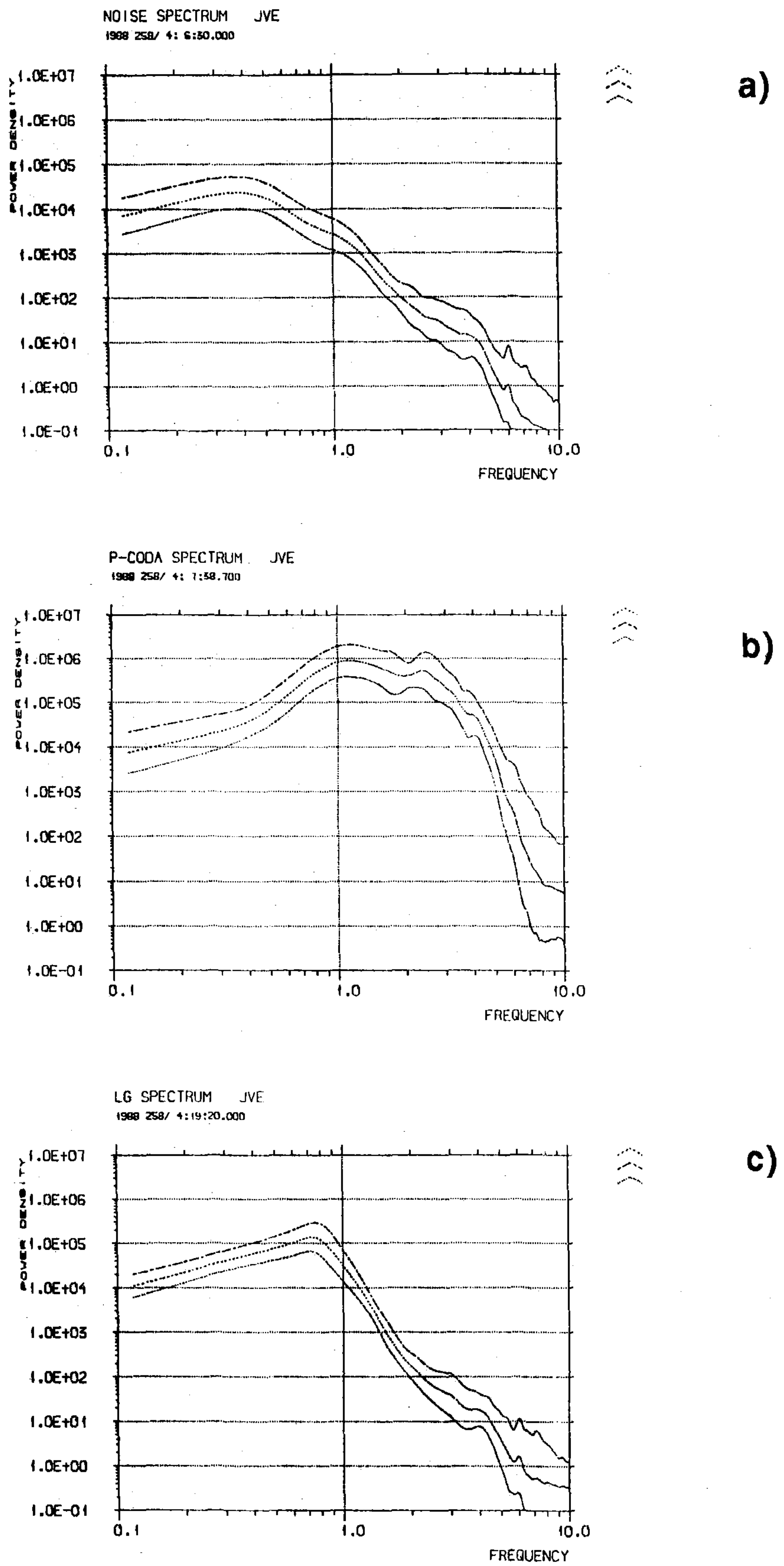


Fig. VII.1.1. Mean uncorrected NORSAR power spectra of noise preceding the P-phase (a), P-coda (b) and Lg (c). The upper and lower curves indicate plus/minus two standard deviations. The event analyzed is the Joint Verification Experiment (JVE) explosion at the Shagan River test site on September 14, 1988.

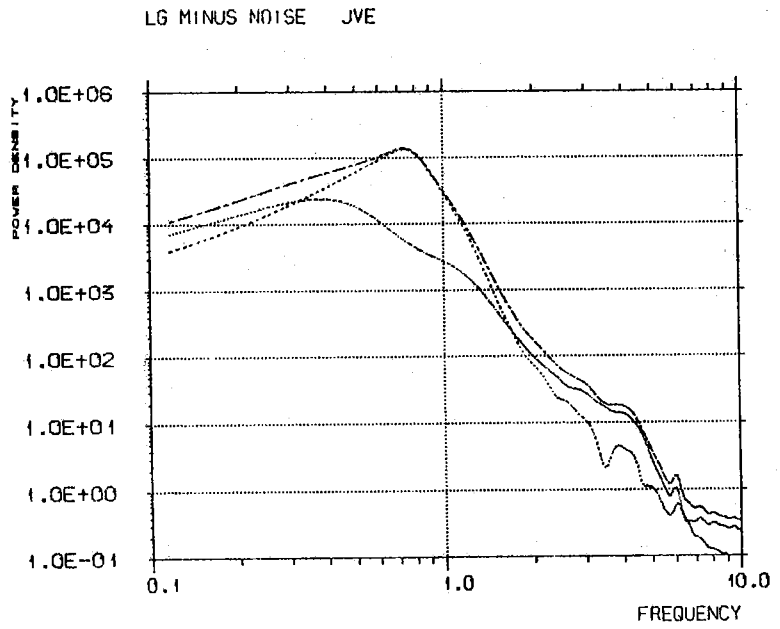


Fig. VII.1.2. The noise compensation procedure is illustrated in this figure. The upper spectrum represents the Lg phase from the JVE, the lower spectrum represents noise preceding the P-phase and the difference is given in the middle. Note that the frequency range around the spectral peak of Lg is marginally influenced by the noise compensation.

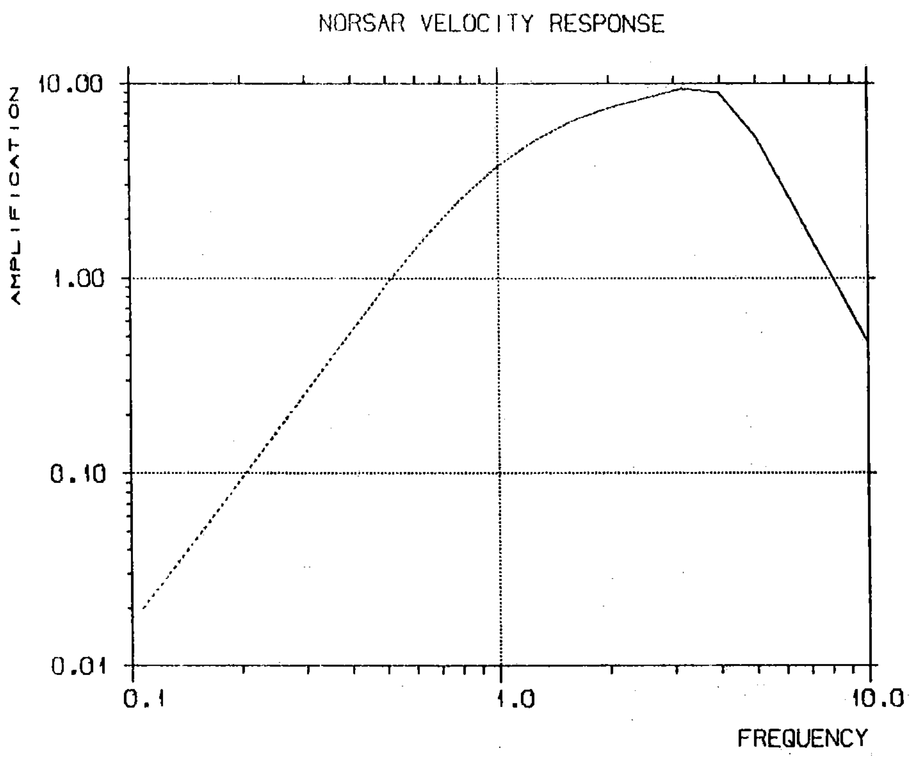


Fig. VII.1.3. NORSAR short-period velocity response function.

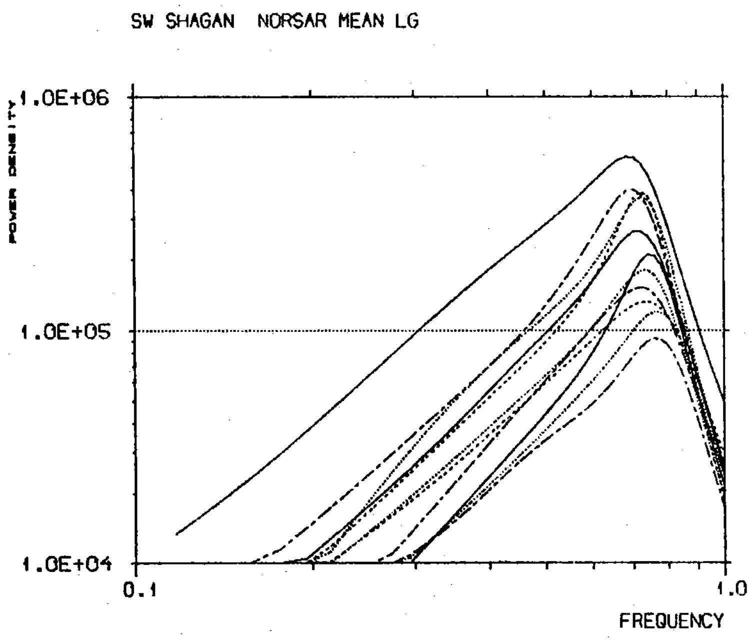


Fig. VII.1.4a Expanded plot of Lg spectra calculated from NORSAR recordings of eleven explosions from the southwestern part of the Shagan river test site.

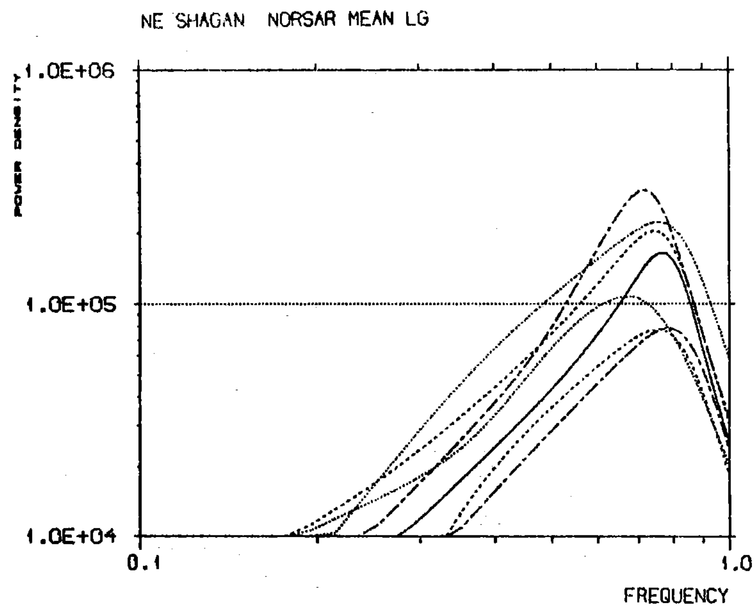


Fig. VII.1.4b. Expanded plot of Lg spectra calculated from NORSAR recordings of seven explosions from the northeastern part of the Shagan river test site.

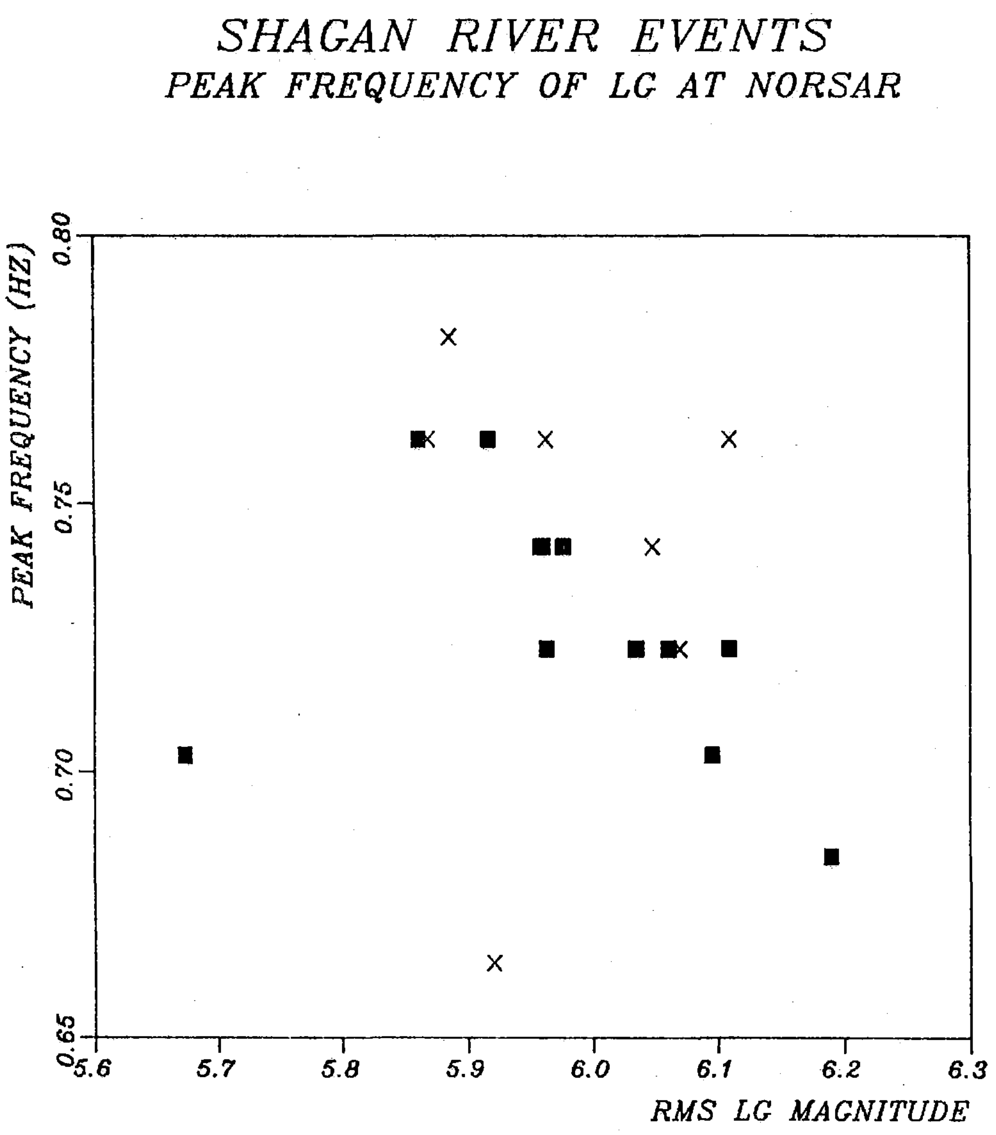


Fig. VII.1.5. Peak frequency versus RMS Lg magnitude for the events given in Fig. VII.1.4a and 4b. Crosses represent events from the NE part of the Shagan River test site, whereas filled rectangles represent events from the SW part.

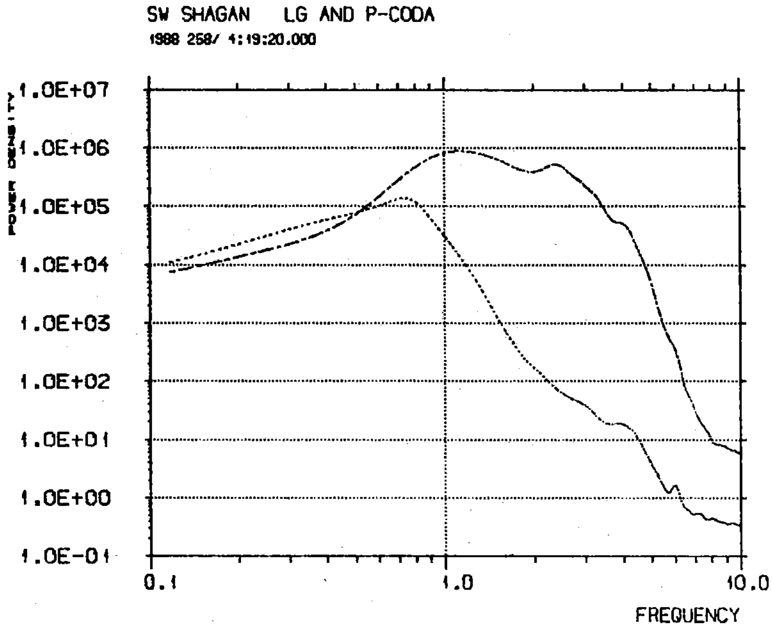


Fig. VII.1.6a. P-coda and Lg spectra from the JVE explosion of September 14, 1988. This event is located in the SW part of the Shagan River test site. The RMS Lg magnitude is estimated at 5.96.

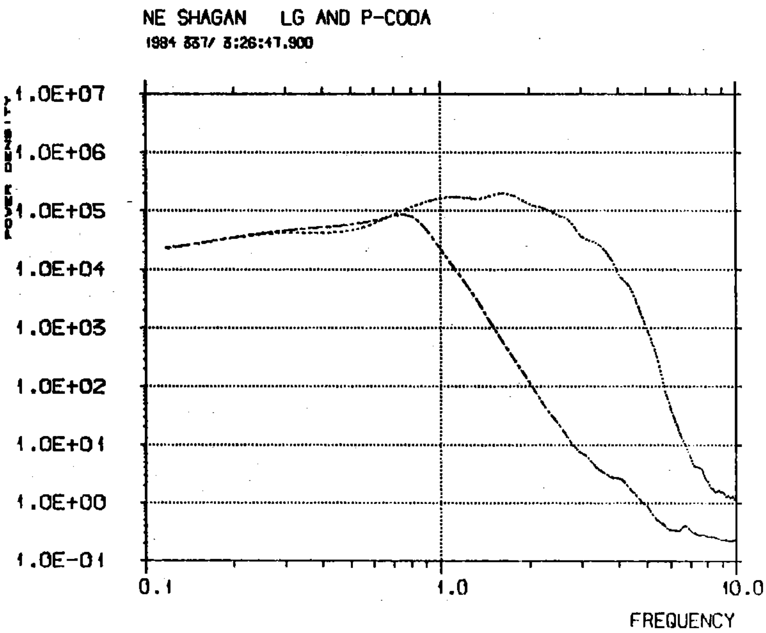
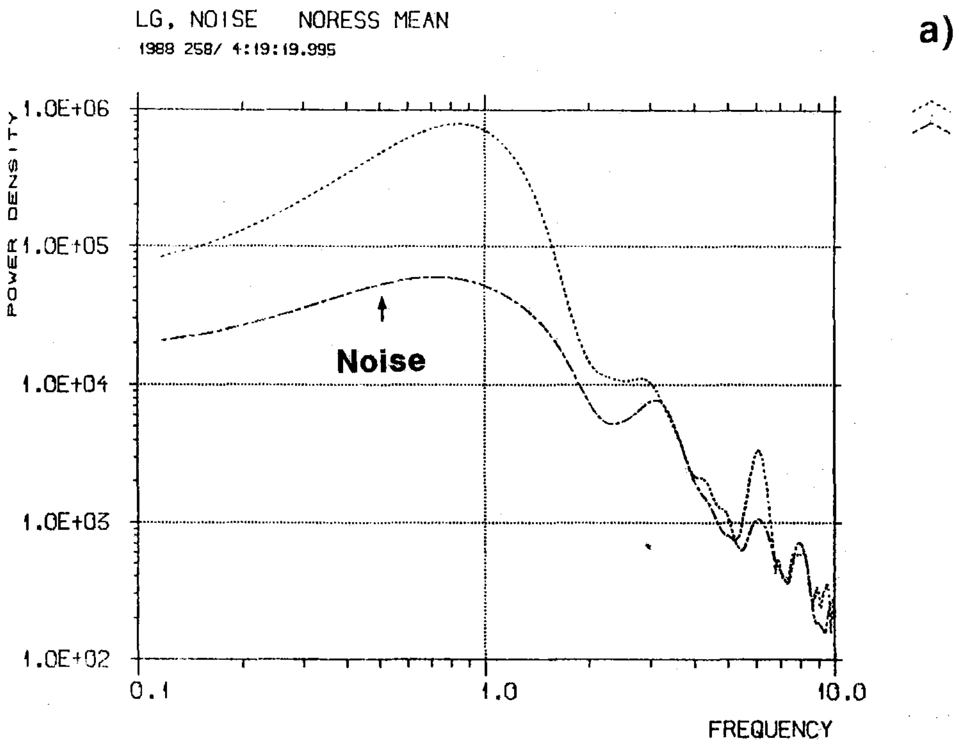


Fig. VII.1.6b. P-coda and Lg spectra from an event of 12 December 1984. This event is located in the NE part of the Shagan River test site and the RMS Lg magnitude is estimated at 5.87.



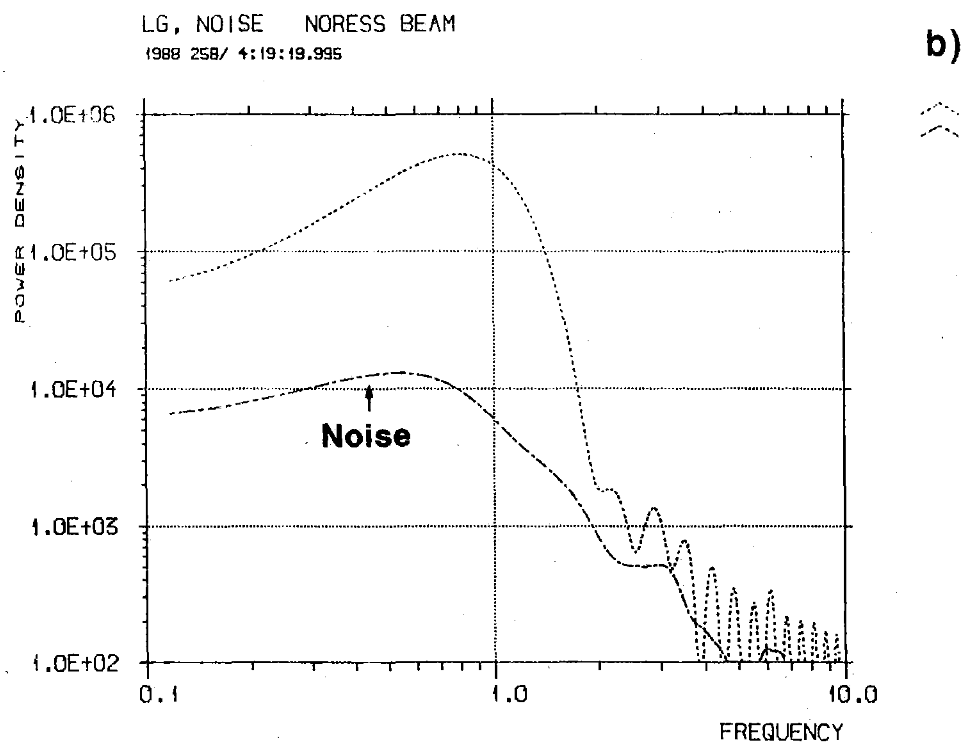


Fig. VII.1.7. Illustration of SNR gain for Lg by beamforming using NORESS data from the JVE explosion. Panel a) shows uncorrected NORESS power spectra for Lg and noise averaged over all individual seismometers. Panel b) is based on a beam formed from the center instrument and the D-ring, using steering delays typical of Lg phases from Semipalatinsk (phase velocity 4.3 km/s, azimuth 80 deg). Note the considerably greater SNR for the NORESS beam.

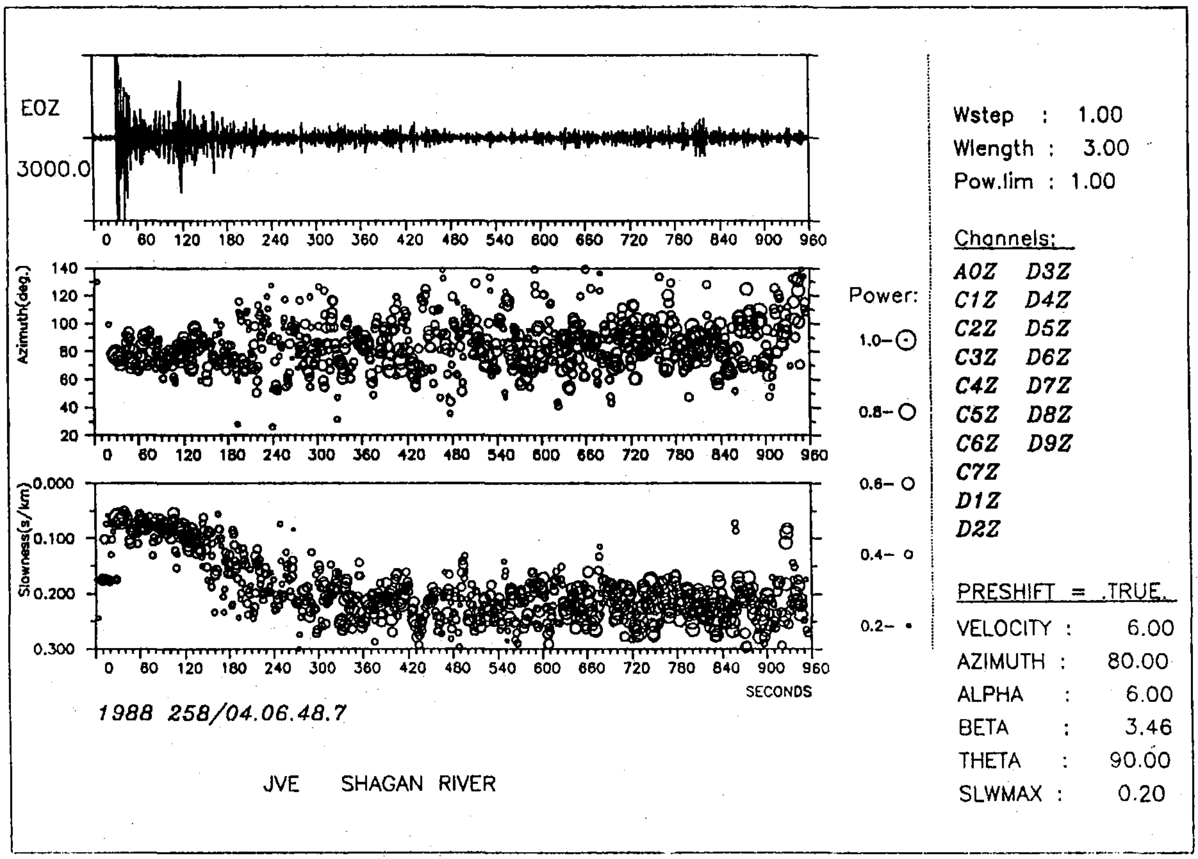


Fig. VII.1.8. Results from slowness analysis of NORESS recordings of the JVE explosion. The upper panel shows the intermediate period vertical component bandpass filtered between 0.6 and 3.0 Hz. The middle panel gives the azimuth solutions and the lower panel the absolute slowness (inverse of apparent velocity) solutions. The size of the circles represents a coherency measure of the individual estimates.