APPLICATION OF SOVIET PNE DATA TO THE IMPROVEMENT OF SEISMIC MONITORING CAPABILITY

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ABSTRACT

In order to discriminate the regional seismic signals produced by underground nuclear explosions from those produced by earthquakes, rockbursts, and conventional mining explosions of comparable magnitude, it is necessary to know the ranges of signal variations that can be expected as a function of source type and propagation path conditions over the entire ranges of these conditions which may be encountered in global test monitoring of the Comprehensive Nuclear-Test-Ban Treaty. For this reason, Maxwell Technologies and the Russian Institute for Dynamics of the Geospheres (IDG) have been working on a joint research program to improve regional discrimination capability through analyses of seismic data recorded from Soviet Peaceful Nuclear Explosion (PNE) events. During the past year this effort has focused on the compilation of a seismic source summary for Soviet PNE tests and on discrimination analyses of regional seismic data recorded from Soviet PNE tests and nearby events reported in the Reviewed Event Bulletin (REB). A seismic source summary has now been completed which contains all currently available information regarding the source parameters for 122 Soviet PNE tests conducted during the 1965 to 1988 time period. The data presented include detonation times, locations, explosion yields and depths of burial, as well as summary information regarding the explosion configurations and source emplacement media. The discrimination analysis has focused on regional seismic data recorded at the Borovoye station from 28 Soviet PNE tests and 24 prototype International Data Centre REB events located at comparable distances from Borovoye. These selected events sample a magnitude range extending from 3.7 to 5.7 and a distance range extending from 5.2 to 19.1 degrees. The Borovoye data have now been processed for estimates of the RMS spectral amplitude levels in the group velocity windows corresponding to the P_n, P_g, S_n, and L_g phases. Associated spectral ratios L_g/P_n, S_n/P_n, L_g/P_g, S_n/P_g, have been computed and averaged over the 2- to 5-Hz frequency band for each event. In addition, L_g spectral ratio discriminant values based on the average spectral amplitude levels in the 0.50- to 1.25-Hz and 2.00- to 5.00-Hz passbands have been estimated for each event. Following normalization for observed effects of event magnitude and epicentral distance, the effectiveness of each of these five potential discriminants has been evaluated. It has been found that, though the traditional S/P type spectral ratio discriminants provide some average separation of source type for this sample of events, there is significant overlap of the values from the two populations for each of these four discriminants. Better separation of source type is provided by the L_g spectral ratio discriminant. However, for this sample of events, L_g shows larger low- to high-frequency spectral ratio values for earthquakes than for explosions, which is inconsistent with prior western U.S. experience. These results indicate that the various proposed regional discriminants will have to be carefully calibrated on a station-by-station basis.

Key Words: seismic, discrimination, regional, Soviet PNE, Borovoye

OBJECTIVES

Under this research program, scientists from Maxwell Technologies, Inc. and the Russian Institute for Dynamics of the Geospheres (IDG) are using seismic data recorded from Soviet Peaceful Nuclear Explosions (PNE) and nearby Central Asian earthquakes and chemical explosions to better define the limitations of existing operational capabilities with respect to the global seismic monitoring required by the Comprehensive Test Ban Treaty (CTBT). The objectives of this program are to expand our recently completed analysis of regional seismic data recorded from Soviet PNE events to incorporate seismic data from nearby earthquakes and large chemical explosions, and to use these data to directly test the utility of different regional discriminants over the widest possible ranges of source and propagation path conditions.

RESEARCH ACCOMPLISHMENTS

During the past year, work has focused on the finalization of a seismic source summary for Soviet PNE events and on a detailed discrimination analysis of broadband seismic data recorded at the Borovoye Observatory in Central Asia from samples of Soviet PNE and PIDC REB events located at regional distances from that station. With regard to the PNE source summary, a paper has now been published (Sultanov et al, 1999) listing the best currently available source parameters for 122 Soviet PNE experiments conducted between 1965 and 1988. The data presented include detonation times, locations, explosion yields and depths of burial, as well as summary information regarding the explosion configurations and source emplacement media. Exact origin times and locations are currently available for 69 of these 122 explosions. Exact locations and seismically determined origin times with estimated accuracy's of ±0.5 sec are available for an additional 8 explosions. Thus, the paper lists source parameters for some 77 widely dispersed Soviet PNE tests that are accurate enough for highly detailed seismological investigations. Hopefully, future studies encompassing analyses of satellite imagery and regional seismic data, perhaps supplemented by GPS determinations from visits to selected sites, will eventually provide accurate locations for all the other explosions in this unique data set.

The discrimination analysis of the Borovoye regional seismic data recorded from Soviet PNE tests and other source types has focused on comparisons with PIDC REB events located within 20 degrees of the Borovoye station. Data recorded at the IRIS station at Borovoye from a selected sample of such REB events were recovered from the IRIS database and previewed for signal quality, resulting in a sample of 28 REB events (including 2 Chinese Lop Nor underground nuclear explosions) with good signals at Borovoye for the time interval extending from 1/1/95 to 4/1/98. The map locations of these events are shown in Figure 1, together with the locations of previously analyzed Soviet PNE events. It can be seen that, although there is some overlap in location between the two sets of events, the majority of the Soviet PNE tests are located to the north of the Borovoye station, where few REB events have been detected. Therefore, even though the data to be analyzed were recorded at a common station, the regional propagation paths are generally not common for the different source types. This, of course, is representative of the general CTBT monitoring problem in that there will be many IMS stations for which there will be no regional recordings of previous underground nuclear explosions which can be used as a calibration reference.

Data recorded at Borovoye from these selected REB events have been processed through a series of narrowband filters to obtain estimates of the spectral composition of the signals in the group arrival windows associated with the P_n, P_g, S_n and L_g phases, using exactly the same procedures which were previously applied to the corresponding Borovoye PNE data (Murphy et al, 1997). The regional phase spectral ratios L_g/P_n, Lg/P_g, S_n/P_n, S_n/P_g were then computed from these narrowband filter amplitudes and averaged over the frequency band extending from 2-5 Hz, for which the signal-to-noise ratios are generally good for all these Borovoye data. In addition to these interphase spectral ratios, an Lg spectral ratio of the average amplitude level in the 0.50-1.25 Hz band to that in the 2.00-5.00 Hz band was also computed. Review of these various spectral ratio data revealed that they all showed some trends with epicentral distance (Δ) and magnitude (m_b). Consequently, for each ratio type, the PNE and REB spectral ratio values were separately analyzed in multivariate regression analyses in which the data for each phase ratio type *p* were fit to a functional relation of the form.

$$R_p = K_p \cdot 10^{n_p m_b} \cdot \Delta^{m_p}$$

The regression analysis results for the L_g/P_n spectral ratio data are shown in Figure 2 for the PNE and REB data sets. It can be seen that the variations with both distance and magnitude are quite similar for the two event groups in this case. This was found to be true for all the other phase spectral ratios as well and, consequently, the statistically derived n_p and m_p scaling exponents for the PNE and REB samples were averaged for each spectral ratio type and these average exponents were used to scale all the observed spectral ratio values to the sample mean distance and magnitude levels (i.e. $\Delta = 12.5°$, $m_b = 4.6$). Note that since the PNE and REB data are normalized in exactly the same way for each phase ratio type, no average bias between event groups is introduced by this scaling procedure.

The resulting normalized discriminant values for the L_g/P_n and L_g/P_g spectral ratios are shown in Figure 3, where it can be seen that, while there is some average separation between the underground nuclear and other source types, there is also considerable intermixing of the spectral ratio values for the different source types. In particular, as has been noted previously, although the L_g/P_n discriminant generally provides the best separation of source types along common propagation paths, the P_n amplitudes show much greater variability as a function of propagation path differences than do the corresponding P_g amplitudes and, consequently, the L_g/P_n spectral ratios show considerably more scatter than do the L_g/P_g spectral ratios. Note also from Figure 3 that, while the Lop Nor explosions are very consistent with the Soviet PNE population with respect to their L_g/P_n ratio values, the corresponding Lop Nor L_g/P_g ratio values fall closer to the mean of the REB population. This suggests that a multvariate discriminant will provide better resolving power than any single spectral ratio discriminant.

Results of some preliminary analyses of the Borovoye PNE data indicate that the intermingling of the 2-5 Hz band L_g/P_n spectral ratio discriminant values shown in Figure 3 persists at higher frequencies as well. Thus, for example, Figure 4 shows a comparison of the 6-8 Hz band P_n/L_g ratio values estimated for that subset of the Borovoye PNE data having usable signal-to-noise ratios in that band with comparable ratios computed for a large sample of REB events and explosions at other test sites using the prototype PIDC P_n/L_g discriminant (personal communication, Mark Fisk, 1999). It can be seen from this figure that a number of the Borovoye PNE values fall within the population of REB values and that, in fact, they contribute several of the lowest explosion values observed with respect to the corresponding REB mean values at those distances. It appears most likely that these anomalously low explosion values are due primarily to propagation path effects, although it is possible that the unusual source environments of the PNE tests may be contributing to some extent. That is, as was noted previously, these PNE tests were predominately low-yield, overburied explosions in hardrock, quite unlike the typical nuclear weapons tests represented by the other explosion values on Figure 4. In any case, these results indicate that the L_g/P_n spectral ratio discriminant will have to be carefully calibrated for applications at previously untested sites.

Somewhat surprisingly, it was found that the best separation of Borovoye PNE and REB events was provided by the L_g spectral ratio discriminant. This robustness is documented in Figure 5 where it can be seen that the mean values of this discriminant for the two event groups are separated by nearly a full order of magnitude, with very little intermingling of the two populations. Unfortunately, the sense of the observed difference is opposite to that found by Murphy and Bennett (1982) for NTS explosions, which indicates that the performance of this discriminant can be expected to vary significantly as a function of source and propagation path conditions. It follows that, in the absence of a quantitative theoretical model which can be used to predict this variability, it will be necessary to empirically calibrate any such L_g spectral ratio discriminant on a station by station and region by region basis. However, it may well be worth such an effort in regions where the separation of source types is as powerful as that shown in Figure 5.

CONCLUSIONS AND RECOMMENDATIONS

A seismic source summary for Soviet PNE events has now been published (Sultanov et al, 1999) which lists the best currently available source parameters for 122 Soviet PNE experiments conducted between 1965 and 1988. These data represent a unique resource for seismic calibration studies of the vast territories of the former Soviet Union. The discrimination analysis of regional seismic data recorded at the Borovoye station in Central Asia from Soviet PNE events and PIDC REB events located within 20° of that station has revealed important new information regarding the variability of regional phase spectral ratio discriminants. In particular, it has been shown that some of the Soviet PNE tests can't be reliably identified as nuclear explosions using the nominal L_g/P_n spectral ratio disciminant, at least with the currently available calibration information. An alternate L_g spectral ratio discriminant was found to work

well to separate the different source types at Borovoye, but a quantitative theoretical understanding of this discriminant is currently lacking, and more research will be required to determine whether it can be calibrated well enough to be generally applicable at the wide variety of IMS stations.

REFERENCES

Murphy, J. R. and T. J. Bennett (1982), "A Discrimination Analysis of Short-Period Regional Seismic Data Recorded at Tonto Forest Observatory," *Bull. Seism. Soc. Am.*, *72*, pp. 1351-1366.

Murphy, J. R., D. D. Sultanov, B. W. Barker, I. O. Kitov and M. E. Marshall (1997), "Further Analyses of Regional Seismic Data Recorded From the Soviet PNE Program: Implications With Respect to CTBT Monitoring," PL-TR-97-2141.

Sultanov, D. D., J. R. Murphy and Kh. D. Rubinstein (1999), "A Seismic Source Summary For Soviet Peaceful Nuclear Explosions," *Bull. Seism. Soc. Am., 89*, pp. 640-647.

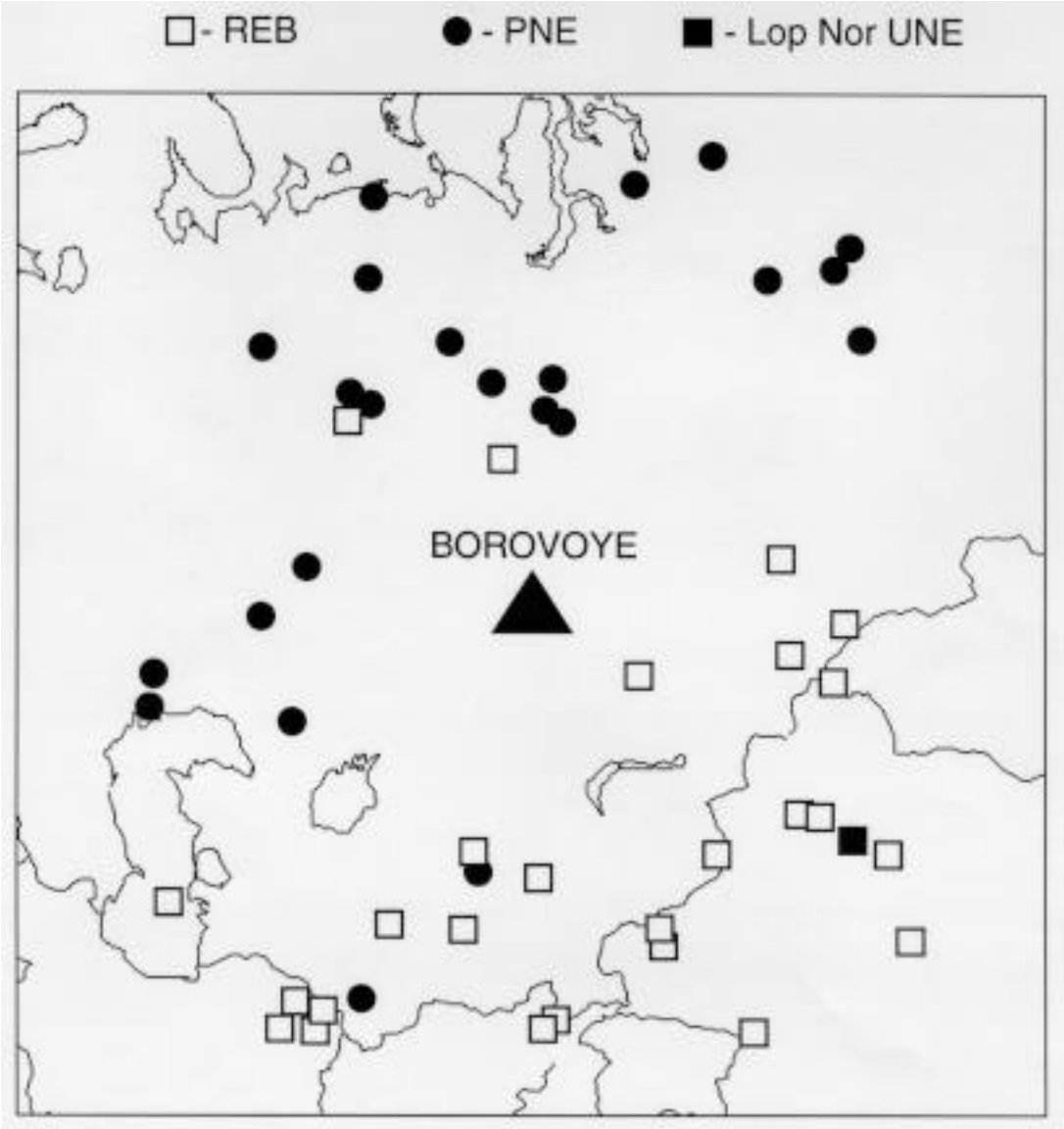

Figure 1. Map locations of Soviet PNE tests and selected REB events located within 20° of the Borovoye station in Kazakhstan.

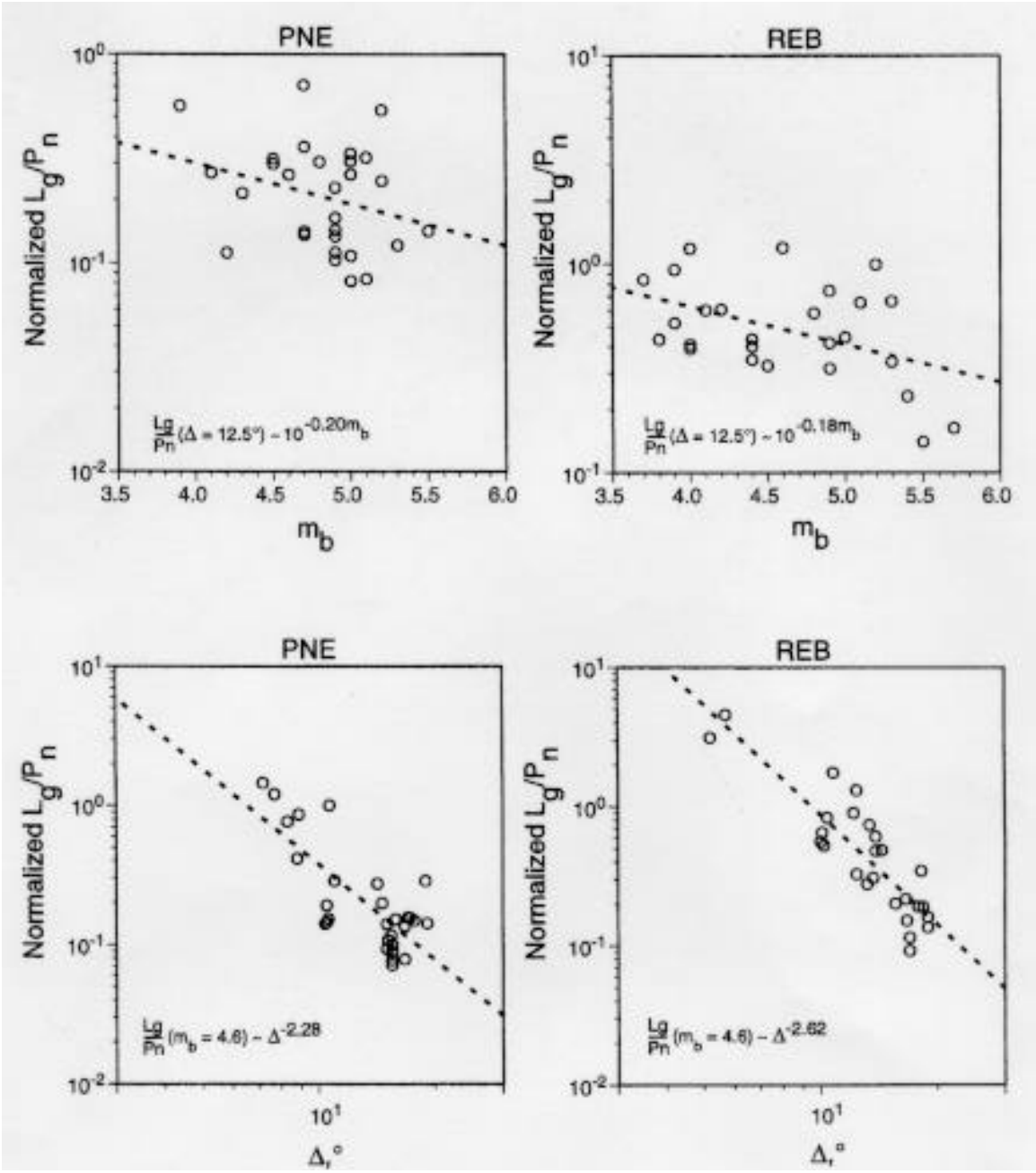

Figure 2. Comparison of estimated magnitude dependence (top) and distance dependence (bottom) for the Borovoye PNE and REB Lg/Pn spectral ration data.

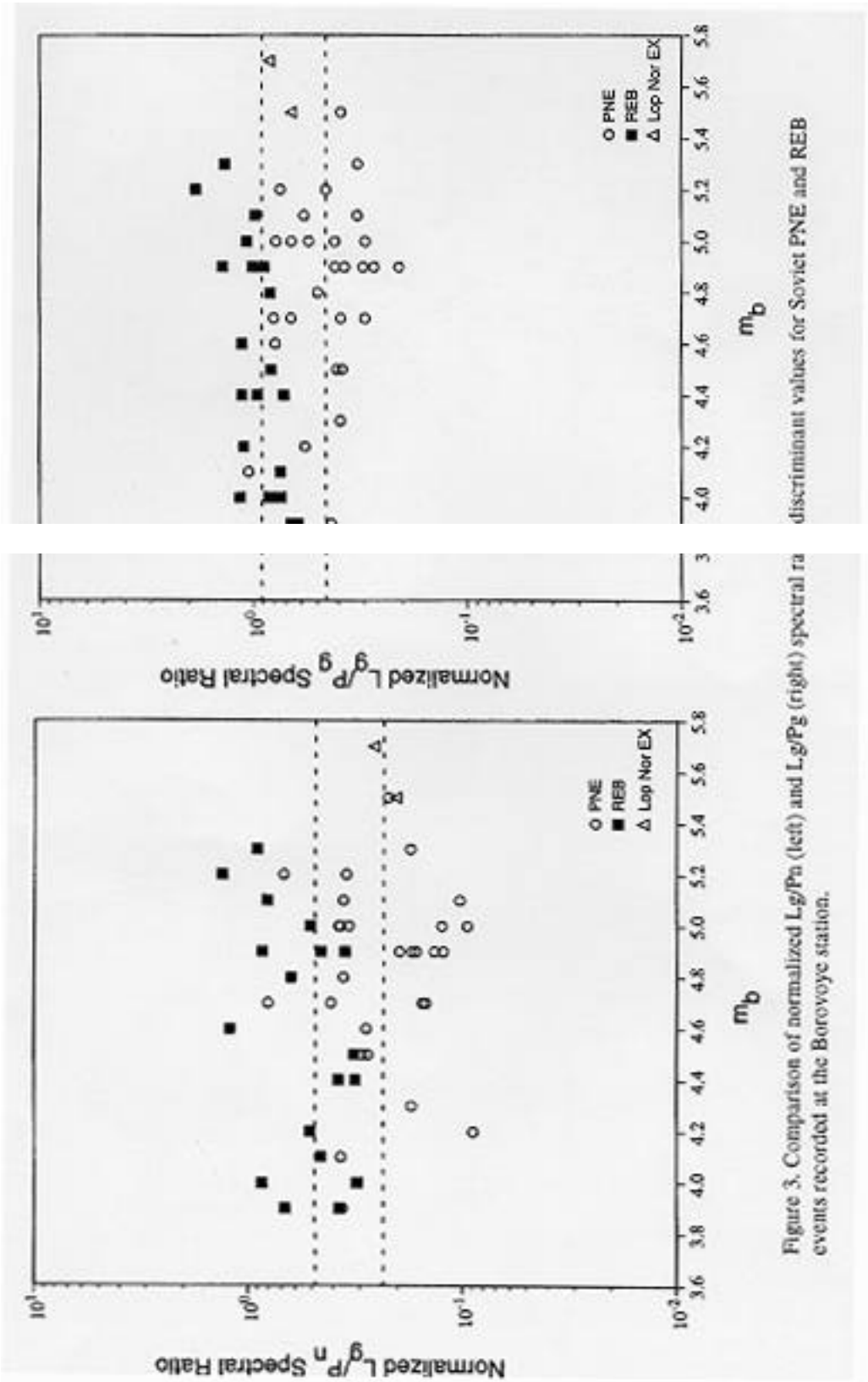

Figure 3. Comparison of normalized Lg/Pn (left) and Lg/Pg (right) spectral ra
events recorded at the Borovoye station.

discriminant values for Soviet PNE and REB

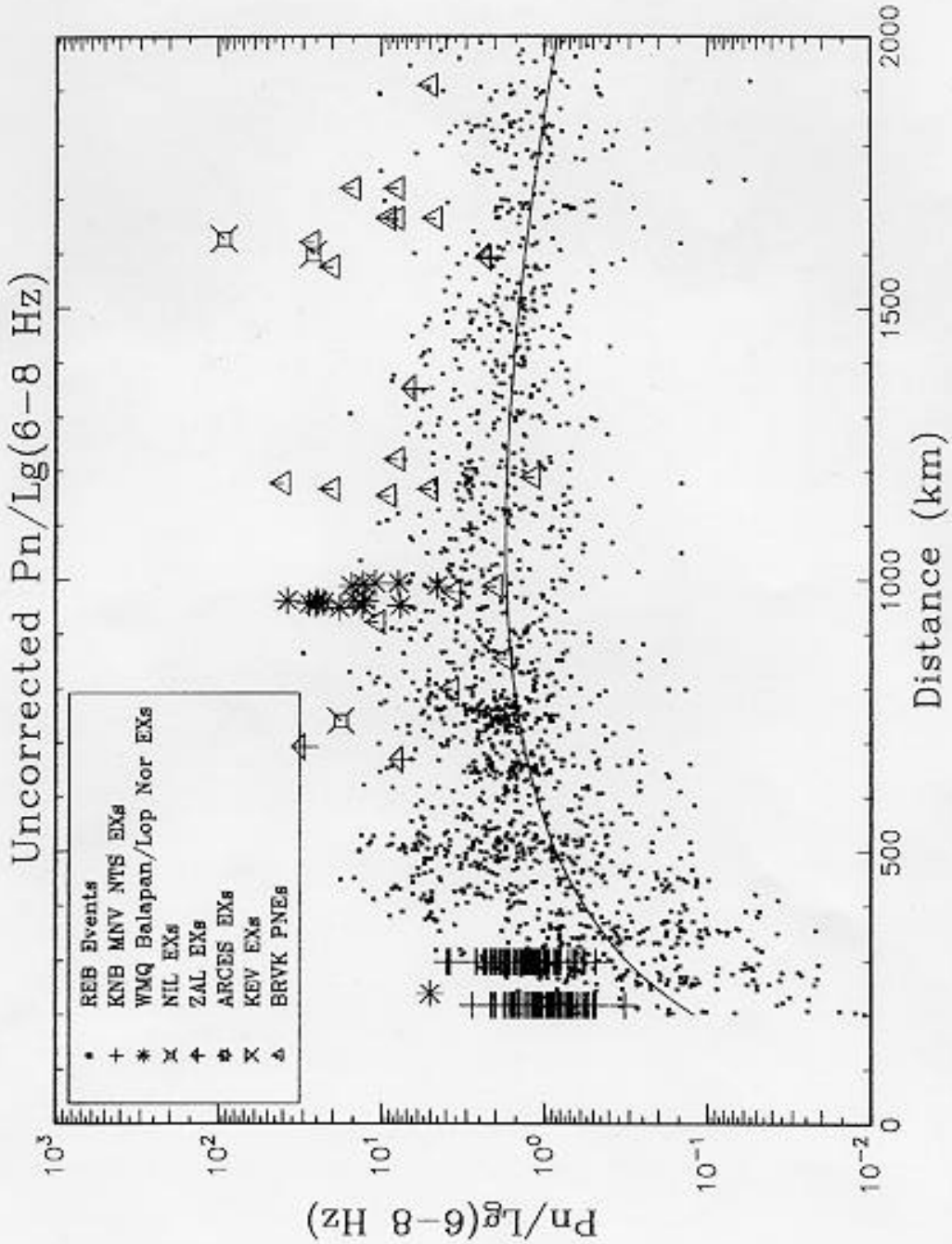

Figure 4. Comparison of 6-8 Hz band Pn/Lg ratio values estimated from Borovoye PNE recordings with corresponding ratios computed for a large sample of REB events and explosions at other test sites (Fisk, 1999).