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7.2 NORSAR P-wave detection and yield estimation of selected Semipalatinsk explosions

In the most recent NORSAR Semiannual Technical Summary (NORSAR Scientific Report No. 2-88/89) results are presented showing that the Lg phase provides very stable measurements of magnitudes of Semipalatinsk underground nuclear explosions, thereby showing considerable promise with regard to explosion yield estimation (Ringdal and Marshall, 1989). A possibility to compare Lg and P magnitudes to published yields for Semipalatinsk explosions has now emerged with the recent publication by Soviet scientists quoting yield estimates for a number of such explosions (Bocharov *et al*, 1989, Vergino, 1989). This paper presents preliminary results from a study comparing NORSAR measurements to these yield data.

Yield estimation based on NORSAR Lg data

We have made an effort to conduct detailed analysis of available NORSAR Lg data for the largest explosions in the data set given by Bocharov *et al* (1989) (Table 7.2.1). The results are as follows:

The Shagan River event of 11/02/72: This event was included in the data base of Ringdal and Marshall (1989), with an M(Lg) value of 6.118.

The Shagan River event of 12/10/72: This event was likewise in the above data base, with M(Lg) = 6.116. However, a factor not compensated for in this estimate was the occurrence of a smaller (M_b = 5.6) explosion at Degelen Mountains with origin time a few seconds before the Shagan River event (Fig. 7.2.1). The quoted M(Lg) value includes a contribution from Lg waves from this smaller event, and is therefore slightly high. Making the reasonable assumption that the Lg signals from the two events add up incoherently, i.e., that the signal power adds up, it is possible to compensate for this interference in the same way as the noise compensation is performed. To do this, we need an estimate of M(Lg) for the smaller event, and a range of 5.5–5.7 seems reasonable. The corresponding bias values are found to range from 0.013 to 0.030 units, with a mean of 0.021. Thus a revised M(Lg) estimate of 6.116-0.021 = 6.095 is obtained, with an uncertainty of about ± 0.01 units resulting from this compensation procedure.

The Shagan River event of 11/30/69: We have been able to recover initial NORSAR data from this explosion. At the time, only 13 NORSAR SP channels (out of 132) were in operation, and 5 of these were among the 42 channels used in the previous analysis. Based on these 5 channels, we have estimated M(Lg) = 6.043 ± 0.021 for this event.

The Degelen Mountains event of 4/25/71: We have processed this event, using exactly the same procedure as for the Shagan River explosions, with the same time windows, filter setting and channel corrections. The resulting estimate is M(Lg) = 5.862 ± 0.013, based on 42 NORSAR channels.

Fig. 7.2.2 shows a plot of M(Lg) versus published yields (Bocharov *et al*, 1989) for these four explosions. We note that the correspondence is excellent, although there are of course far too few data points to draw any firm conclusion. Nevertheless, it is interesting to note that the Degelen event appears to give consistent observations with the Shagan River explosions, which also would be expected from the earlier observed stability of the M(Lg) estimates.

For comparison, Fig. 7.2.3 shows a plot of world-wide m_b versus these yield values for the same four events. The scatter is far greater than for the Lg data. Looking at the differences m_b-log Y, it is interesting to note that the two explosions in the SW and NE Shagan River area show a relative bias of 0.13 units, which is very close to the m_b-M(Lg) anomaly of 0.15 magnitude units found by Ringdal and Marshall (1989) between these two subregions.

Detection of low-yield explosions

The cited Soviet publication also lists a number of low-yield nuclear explosions conducted at Semipalatinsk. We have analyzed available NORSAR data for these explosions, for the purpose of assessing the detection thresholds of the NORSAR/NORESS system in terms of explosion yields. Fig. 7.2.4 shows NORSAR single instrument P-wave recordings of the three smallest explosions with NORSAR data available: 2 Sep 72 (2 kt), 28 Mar 72 (6 kt) and 16 Aug 72 (8 kt). We have chosen to display the instrument 06C02, which is co-located with the center seismometer of the NORESS array (Note that NORESS data have only been available since 1984). The traces have been filtered in the band 2.0-4.0 Hz, and the signal-to-noise ratios (STA/LTA) are given for each trace. Note that an STA/LTA treshold of 4.0 is generally sufficient to confidently declare a signal detection.

It is clear from this figure that the NORSAR detection threshold, at the single seismometer level, is well below the yields of the three events shown. By a reasonable extrapolation, it can be inferred that, given similar coupling conditions and noise levels as in these three examples, Semipalatinsk explosions of yields as low as 0.5 kt would be expected to produce detectable signals at NORSAR, even at the single sensor level.

While the available data are not sufficient to draw any firm conclusions regarding the NORSAR/NORESS array thresholds, some preliminary observations may nevertheless be made. Thus, it has been established in earlier studies that the SNR gains of NORESS in the filter band shown are at least 14 dB (Kværna, 1989), which corresponds to a factor of 5 in signal amplitude. This indicates a detection threshold of 0.1 kt or lower for the NORESS array for fully coupled Semipalatinsk explosions, assuming normal noise conditions. Such an assertion is also consistent with earlier studies indicating that NORESS has a detection threshold, in terms of m_b, of about 3.0 or lower for the Semipalatinsk region.

Conclusions

Studies of NORSAR recordings of Semipalatinsk explosions for which Soviet yield estimates are available confirm that NORSAR Lg magnitudes have a potential for providing very accurate yield estimates in the magnitude range where there is sufficient signal-to-noise ratio. Notably, the P-Lg bias earlier observed between the NE and SW parts of the Shagan River test site is reflected in a similar bias between m_b and log (Yield).

Furthermore, the excellent signal detectability of the NORSAR/NORESS system has been confirmed. The detection threshold for fully coupled Semipalatinsk explosions, assuming normal noise conditions, appears to be below 1 kt, even at the single sensor level. Additional significant improvement would be obtainable through array processing. Clearly, this detection level will not be achieved in cases where the noise level is abnormally high (e.g., in the coda of a large earthquake) or if coupling conditions are not optimal (e.g., in case of full or partial cavity decoupling). It must also be noted that the event identification threshold is necessarily higher than the signal detection threshold, and that there are currently no seismic methods available to distinguish reliably between small underground nuclear explosions and chemical explosions of similar yields.

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References

Bocharov, V.S., S.A. Zelentsov and V.I. Mikhailov (1989): Characteristics of 96 underground nuclear explosions at the Semipalatinsk test facility, *Atomic Energy*, 67, 3, 210-214 (in Russian).

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Ringdal, F., and P.D. Marshall (1989): Yield determination of Soviet underground nuclear explosions at the Shagan River Test Site. *NORSAR Semiannual Technical Summary, 1 Oct 1988 - 31 Mar 1989*, NORSAR Sci. Rep. 2-88/89.

Vergino, E.S. (1989): Soviet Test Yields, EOS, Nov 28, 1989, 1511-1525.

Date	Region	m_b	NORSAR M(Lg)	Yield kt
11/30/69	Shagan (TZ)	6.02	6.043	125
04/25/71	Degelen	5.94	5.862	90
11/02/72	Shagan (SW)	6.16	6.118	165
12/10/72	Shagan (NE)	5.96	6.095*)	140

*) Adjusted for interfering explosion

Table 7.2.1 Parameters of four explosions analyzed in this study. Yield estimates are from Bocharov *et al* (1989).

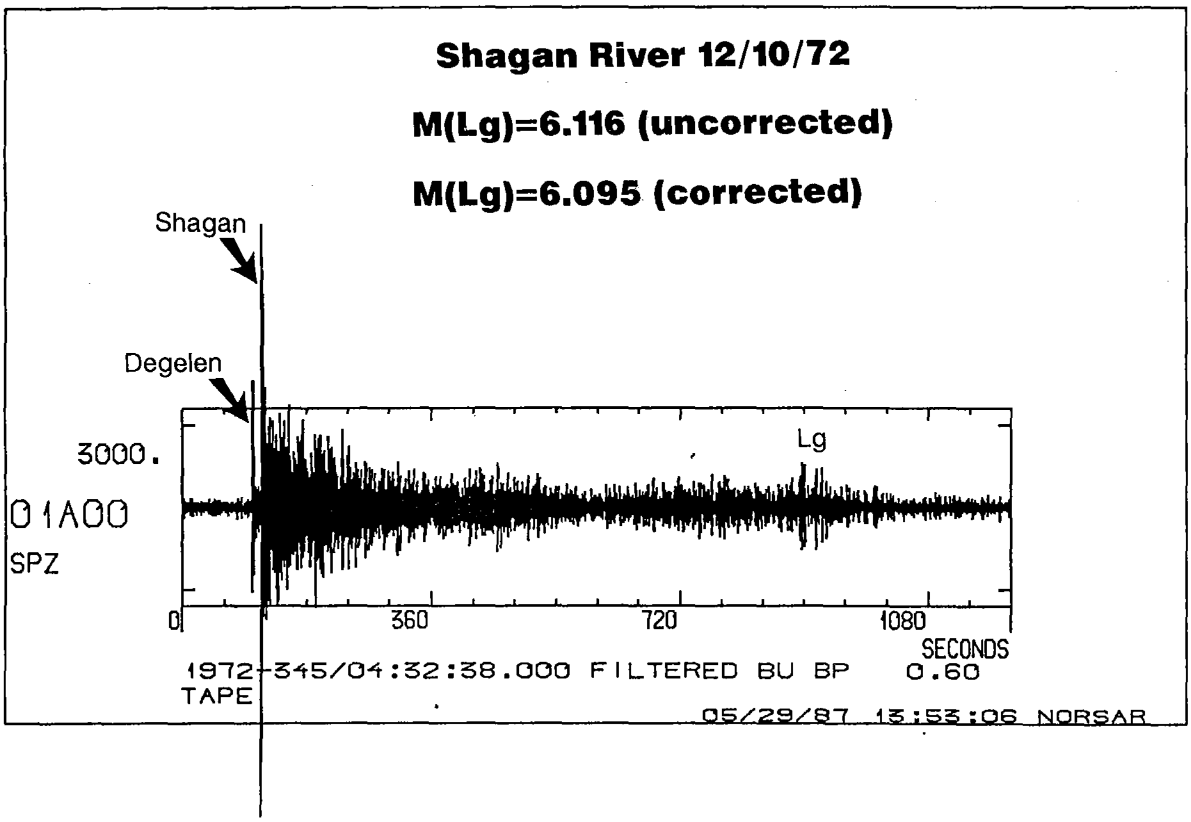

Fig. 7.2.1 NORSAR recordings (instrument 01A00) of the double explosion on Dec 12, 1972. Note that the Lg phase is a superposition of signals from both sources, although the contribution from the smaller explosion (Degelen) is relatively modest. By estimating a confidence interval of the M(Lg) for the Degelen event, it is possible to compensate for the effects on the M(Lg) for the Shagan River event, as described in the text.

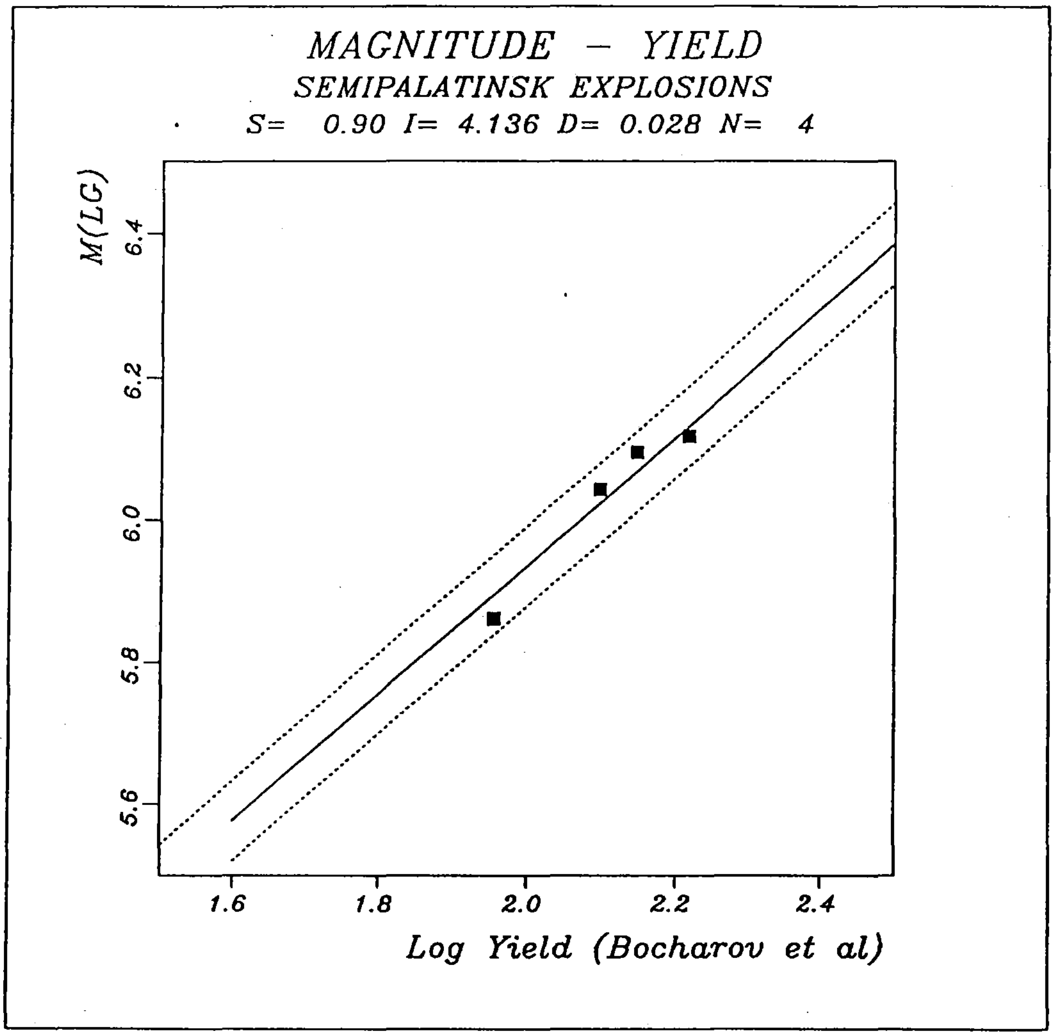

Fig. 7.2.2 Comparison of M(Lg) and log(yield), of the four explosions in Table 7.2.1, with the yield values taken from Bocharov *et al* (1989). The slope of the straight lines has been restricted to 0.9. Note the excellent correspondence.

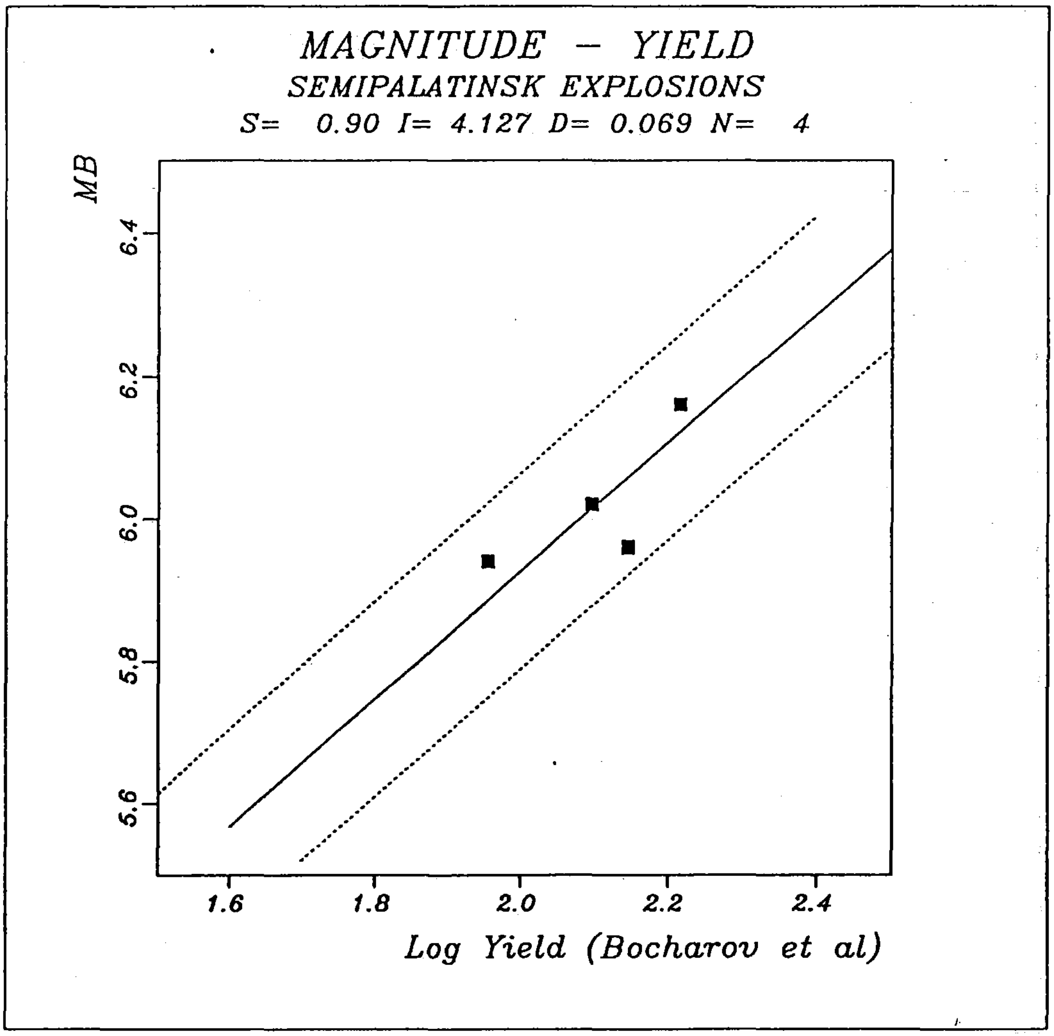

Fig. 7.2.3 Same as Fig. 7.2.2, but using m_b instead of M(Lg). Note the much greater scatter in this plot.

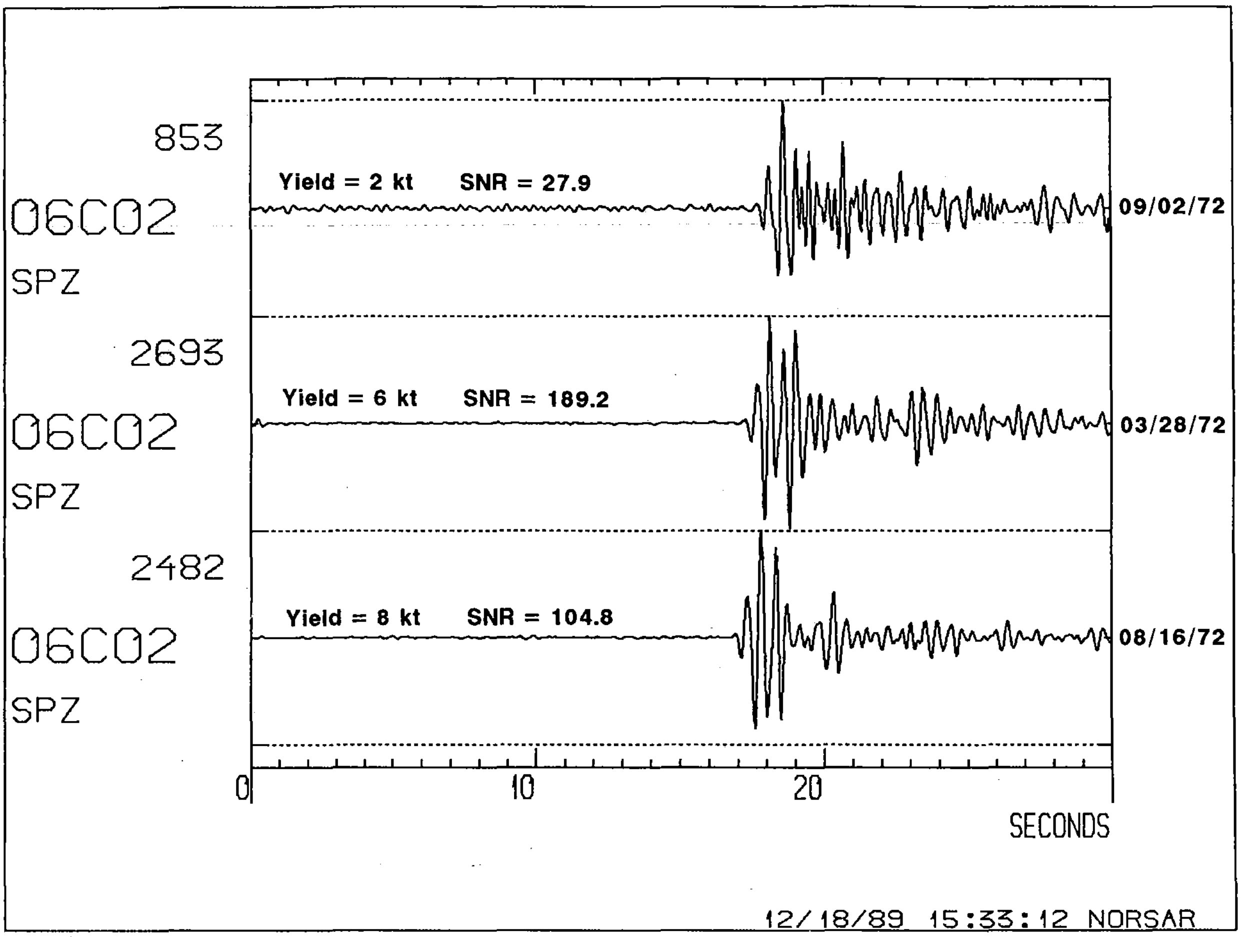

Fig. 7.2.4 NORSAR single seismometer recordings (instrument 06C02) of three low-yield Semipalatinsk nuclear explosions. The traces have been filtered in the band 2.0-4.0 Hz, and the signal-to-noise ratio is shown for each trace. Note the very high SNR observed even at the single sensor level. Significant additional SNR gain would be obtained through array processing of the NORSAR data.