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7.1 Detection and yield estimation studies

1. Yield estimation using Lg recordings

Over the past several years, extensive research has taken place at NORSAR to develop and evaluate the RMS Lg estimation technique for underground nuclear explosions. Some of the most recent results have been documented by Ringdal and Marshall (1989) and Hansen, Ringdal and Richards (1990).

These studies have so far concentrated on the Shagan River (Semipalatinsk) test site, using data from stations in Norway, Germany, USSR and China (Fig. 7.1.1). By using NORSAR as a reference system, and plotting observed RMS Lg for other stations against NORSAR values, it has been found that the standard deviations of the residuals are consistently as low as 0.03 magnitude units, as shown for selected stations in Fig. 7.1.2. Furthermore, comparing two of the stations with lowest Lg detection threshold (GAM and ARU in the Soviet Union), we have found that this consistency appears to span two full orders of event magnitude, down to approximately m_b = 4.0 (Hansen *et al*, 1990).

A possibility to compare the RMS Lg 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; see also Vergino, 1989a,b). We have made an effort to conduct detailed analysis of available NORSAR Lg data for the explosions in this data set. Since NORSAR is located at more than 4000 km distance from Semipalatinsk, only explosions of more than 10 kt yield will usually provide sufficient SNR for Lg measurements at this station, and even so, it must be noted that at these lower yields, the estimated RMS Lg is less precise than at yields exceeding 50 kt.

Table 7.1.1 gives the NORSAR Lg magnitudes obtained in these analyses. The table comprises altogether 8 explosions from both the Shagan River (Balapan), Degelen Mountains and Konystan (Murzhik) subareas. The NORSAR data for the four largest of these explosions have been previously presented in Ringdal (1989).

Fig. 7.1.3 (top part) shows a plot of NORSAR M(Lg) versus published yields for these 8 explosions. For comparison, the bottom part of Fig. 7.1.3 shows world-wide m_b (UK values as quoted by Vergino, 1989a) versus yield for the same 8 events. The slope in each plot has been restricted to 0.75, and the standard deviation in the vertical direction is 0.043 for M(Lg) and 0.081 for m_b versus log yield. We note that this data set is too small to allow any confident estimate of the accuracy in estimating yield from M(Lg), especially in view of the aforementioned uncertainty in M(Lg) values for the smaller explosions. Nevertheless, the figure would appear to confirm the potential of RMS Lg as a stable estimator of yields for fully coupled explosions from this region, and indicates that even single station M(Lg) is better correlated to log(yield) than is world-wide m_b.

2. P-wave detectability studies

Ringdal (1990) has conducted a study of the NORESS array detection capability for Semipalatinsk explosions, both in terms of m_b and yield (Bocharov *et al*, 1989). In terms of NORESS m_b, the 50 per cent detection threshold is estimated at $m_b = 3.7 \pm 0.1$. A noteworthy feature, illustrated in Fig. 7.1.4, is the large difference in NORSAR m_b bias (S) for the subregions Shagan River ($S \approx 1.0$) and Degelen/Konystan ($S \approx 0.4$). In terms of world-wide m_b, the estimated NORESS detection threshold, at the 50 per cent level, thus becomes $m_b = 2.7$ and $m_b = 3.3$ for these subareas, respectively.

Fig. 7.1.5 shows NORESS m_b values (measured at the NORSAR seismometer 06C02 which is co-located with the present NORESS center site) versus log yield for 6 low-yield nuclear explosions (the only ones in Bocharov *et al* (1989) with available data that did not exceed NORSAR's dynamic range). As before, we have used a restricted slope of 0.75 in the magnitude-log yield relationship, and fitted a straight line with this slope to the observed data. The NORESS beam threshold range (plus/minus two standard deviations) is shown as dotted horizontal lines.

Fig. 7.1.5 indicates that, given similar coupling conditions and noise levels as in our data base of 6 explosions, Semipalatinsk explosions of yields at 0.1 kt would be expected to produce detectable signals at NORESS. We note that the 6 reference explosions are all from Degelen or Konystan. In view of the previous discussions, the detectability for Shagan River explosions would be expected to be even better.

In Fig. 7.1.6, we plot NORESS, ARCESS, FINESA and GERESS recordings of an $m_b = 5.7$ nuclear explosion at Novaya Zemlya. The figure shows an unfiltered, single sensor trace for each array, and the signal-to-noise rato on the best array beam (STA/LTA as computed by the online detector) is given in the figure caption. ARCESS has a strong S-phase detection, and there is some S-wave energy visible also for the three other arrays. The Lg phase is not visible on these unfiltered recordings, but in the best filter band, the energy in the Lg window still exceeds significantly the pre-P noise.

From Fig. 7.1.6 it is seen that the P-wave detection capability for Novaya Zemlya explosions is excellent for NORESS, FINESA and ARCESS, in particular the latter. Thus, ARCESS SNR for the event shown was 8383 on the array beam in the filter band 3–5 Hz. This is more than 3 orders of magnitude above the operational threshold, and we note that similar SNR has been observed for the other Novaya Zemlya explosions of similar size recorded at ARCESS (only 4 such events have been recorded since the array came into operation). While this is too limited a data base to give a reliable threshold estimate, a straight extrapolation would indicate that the ARCESS threshold at this site is well below $m_b = 3.0$. NORESS and FINESA also appear to have thresholds close to $m_b = 3.0$, whereas GERESS has a lower detectability for this test site.

3. Conclusions and Recommendations

Our studies confirm that Lg magnitude estimates of Semipalatinsk explosions are remarkably consistent between stations widely distributed in epicentral distance and azimuth. It thus appears that a single station with good signal-to-noise ratio can provide M(Lg) measurements with an accuracy (one standard deviation) of about 0.03 magnitude unit. It is noteworthy that this accuracy is consistently obtained for a variety of stations at very different azimuths and distances, even though the basic parameters remain exactly as originally proposed by Ringdal for NORSAR recordings (0.6–3.0 Hz bandpass filter, RMS window length of 2 minutes, centered at a time corresponding to a group velocity of 3.5 km/s). Moreover, the Lg phase shows considerable promise for use in yield determination, although more data will be needed before the accuracy of Lg-estimated yields can be firmly established.

The excellent detection capability of the regional arrays in northern Europe have been confirmed by case studies, comprising a detailed evaluation of the NORESS capability for Semipalatinsk explosions, and preliminary observations of ARCESS detection of Novaya Zemlya explosions.

Further work will be directed toward additional expansion of these studies, in particular analyzing new data as they become available, and pursuing our analysis of Novaya Zemlya recordings at regional arrays as well as other available stations.

F. Ringdal

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Date	Region	m_b	NORSAR M(Lg)	Yield (kt)
11/30/69	Shagan (TZ)	6.048	6.043	125
04/25/71	Degelen	6.076	5.862	90
06/06/71	Konystan	5.526	5.44	16
10/09/71	Konystan	5.371	5.25*)	12
10/21/71	Konystan	5.580	5.54	23
02/10/72	Shagan (NE)	5.370	5.37	16
11/02/72	Shagan (SW)	6.224	6.118	165
12/10/72	Shagan (NE)	5.996	6.095**)	140

*) Low precision due to low SNR

**) Adjusted for interfering explosion

Table 7.1.1. Parameters of eight explosions analyzed in this study. Yield estimates are from Bocharov *et al* (1989), and the m_b values are the "UK m_b" listed in Vergino (1989a).

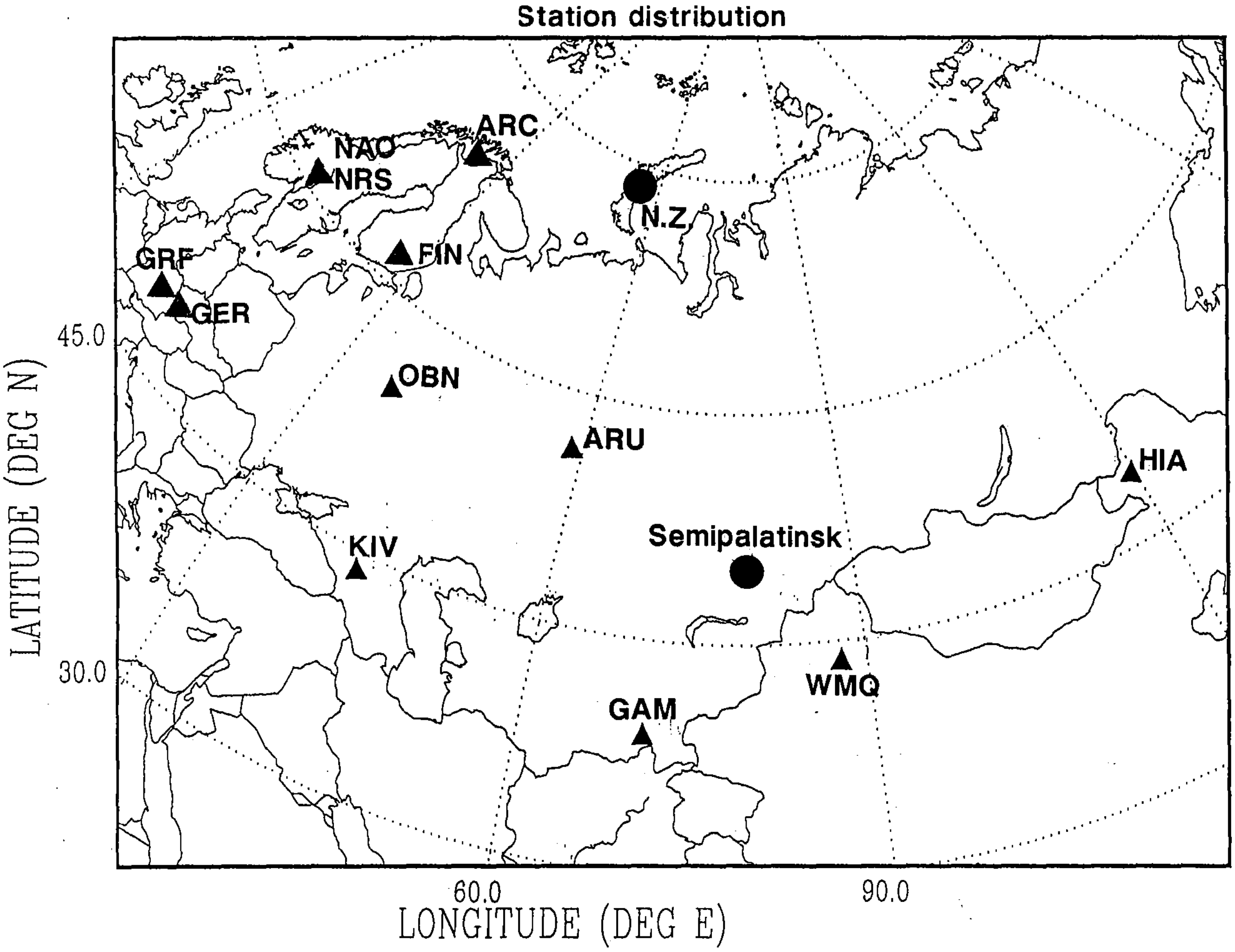

Fig. 7.1.1. Map showing the location of stations analyzed in this study (triangles). The two main USSR test sites (Novaya Zemlya and Semipalatinsk) are marked as filled circles.

RMS Lg comparison

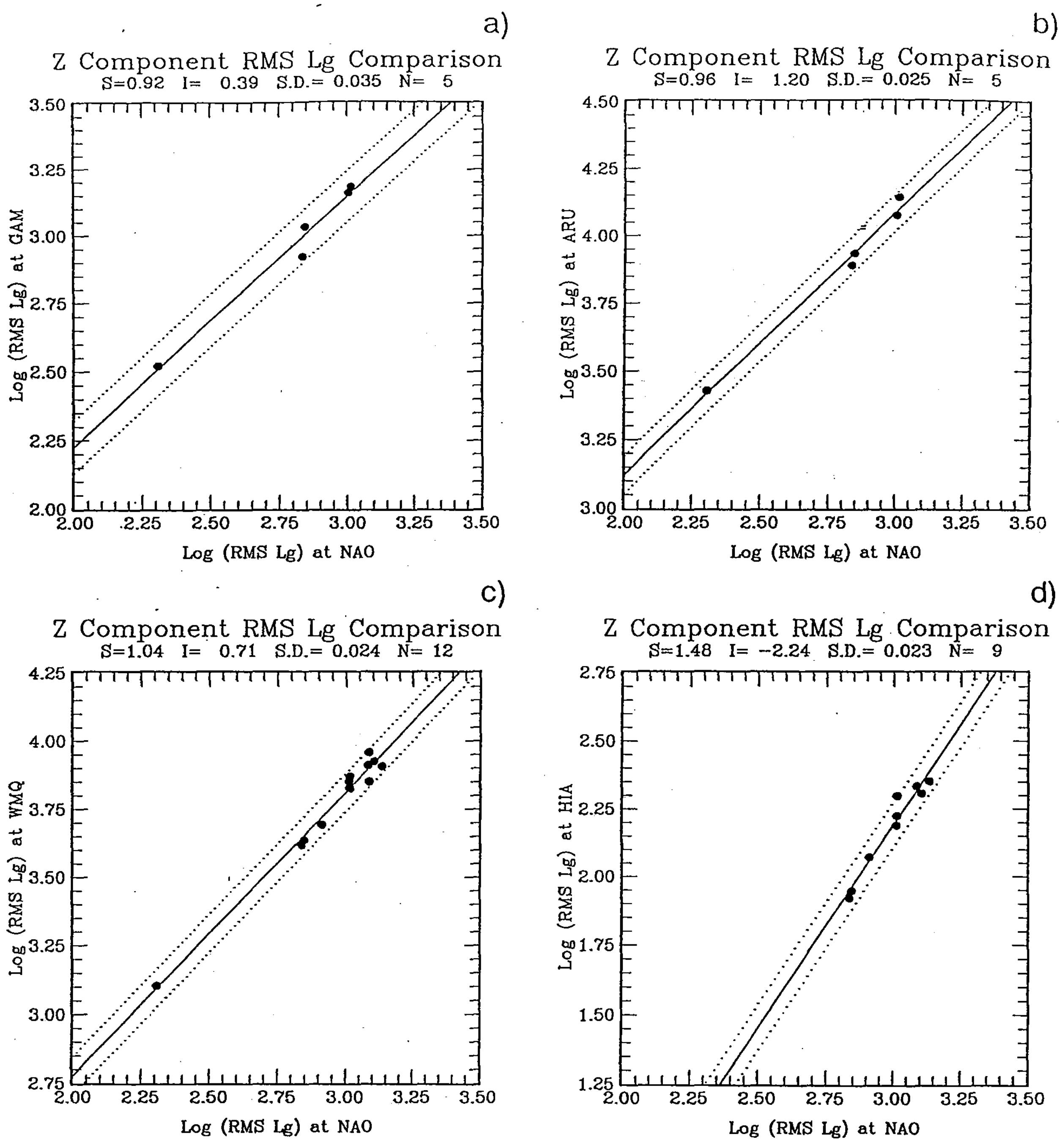

Fig. 7.1.2. Examples of observed correlations between RMS Lg at NORSAR and selected stations in the USSR and China. Note the excellent consistency in all of the plots.

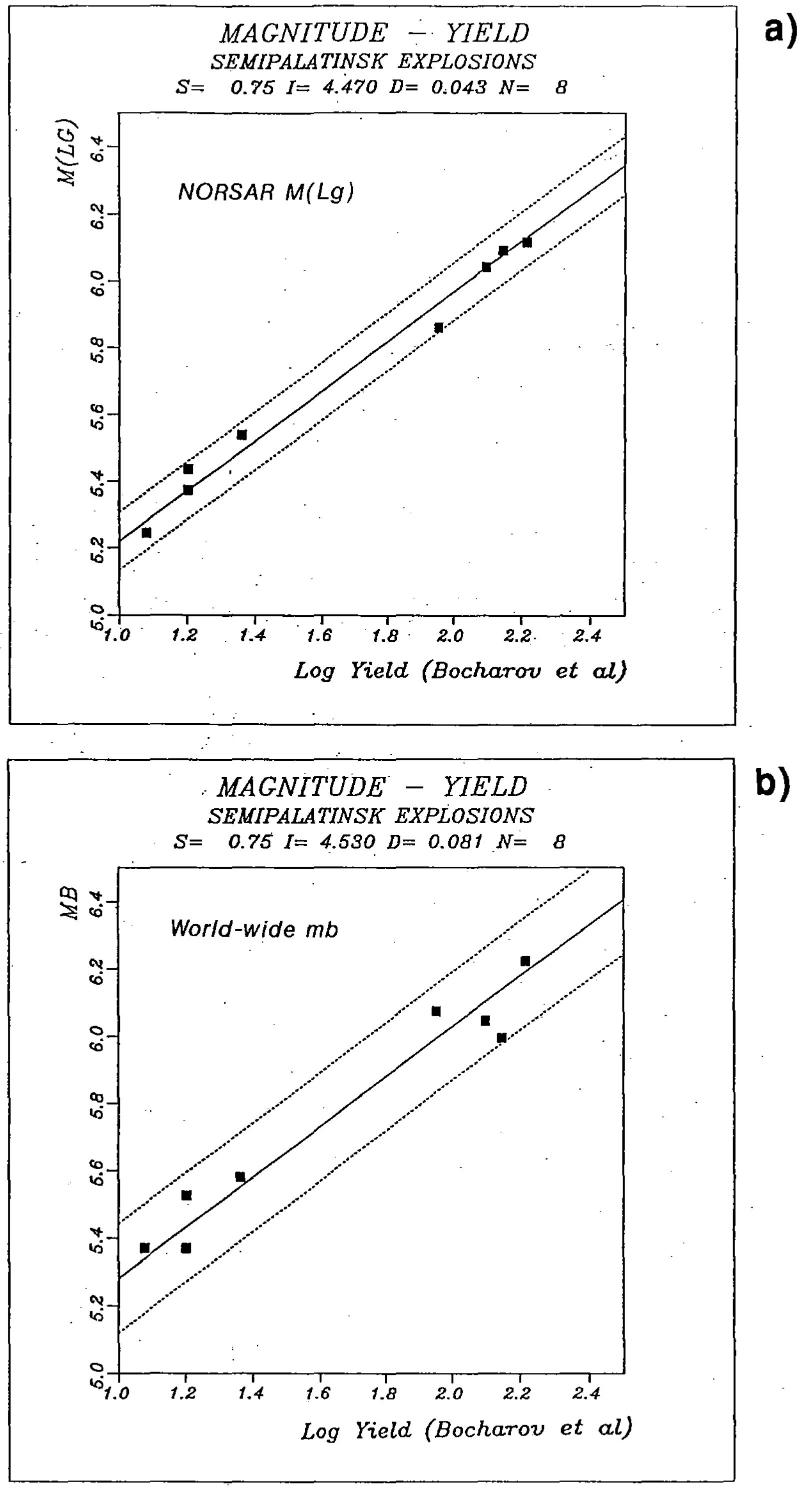

Fig. 7.1.3. Magnitude-yield relationships for 8 nuclear explosions at Semipalatinsk, with yields provided by Bocharov *et al* (1989): a) NORSAR M(Lg) versus log(yield) and b) world-wide m_b versus log(yield). The slopes of the straight lines have been restricted to 0.75. Note that the NORSAR values show significantly less scatter.

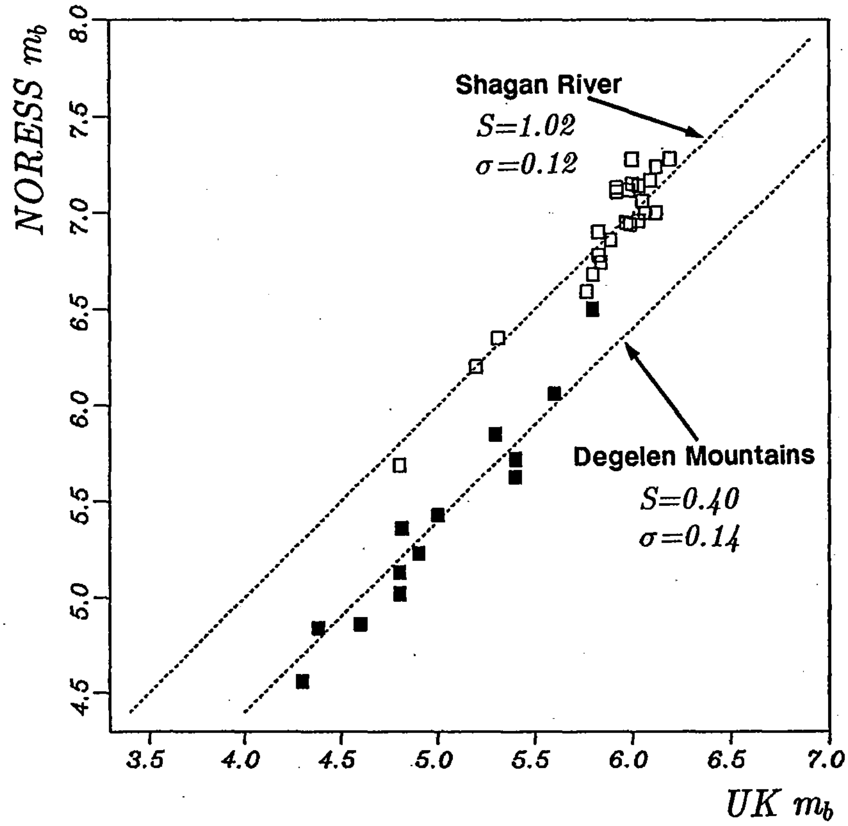

Fig. 7.1.4. Comparison of NORESS and world-wide m_b (as calculated at Blacknest, United Kingdom) for Semipalatinsk explosions. Note the difference in average m_b bias between events from Shagan River (1.0 m_b units) and Degelen Mountains (0.4 m_b units). The straight lines on the plot have a restricted slope of 1.00.

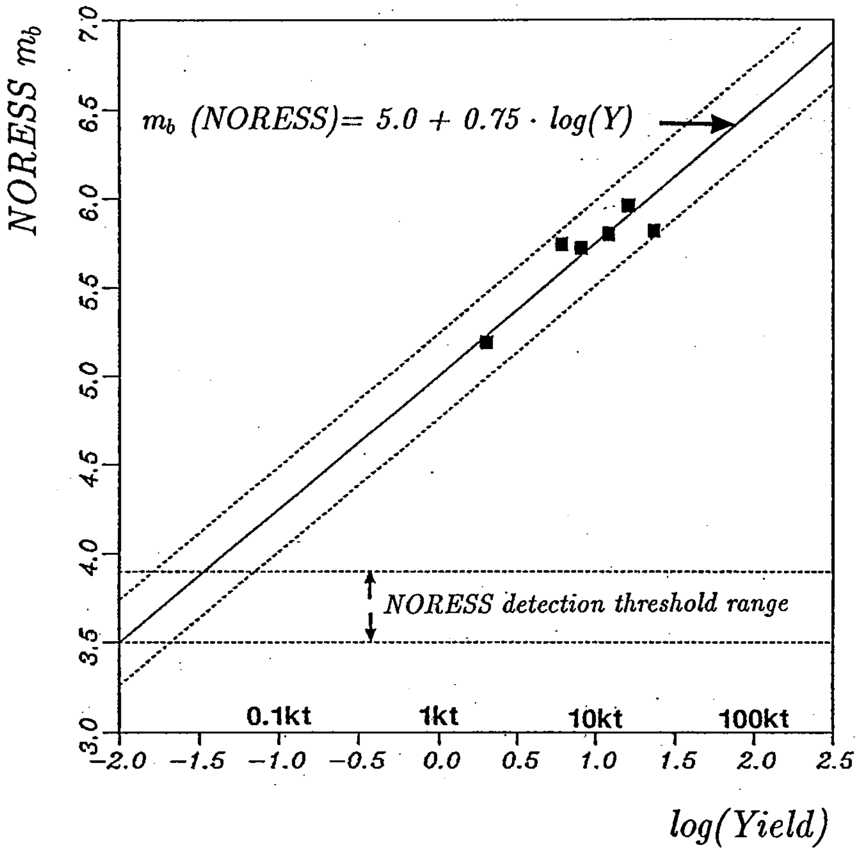

Fig. 7.1.5. Observed m_b versus yield (Bocharov *et al*, 1989) for six Semipalatinsk nuclear explosions listed in Table 7.1.1. The straight line has been fitted using a restricted slope of 0.75. The m_b values are based on NORSAR seismometer 06C02, located at the present NORESS center site. The estimated range of the NORESS m_b detection threshold is indicated (see text for details).

Novaya Zemlya nuclear explosion 24 October 1990 - Regional array recordings

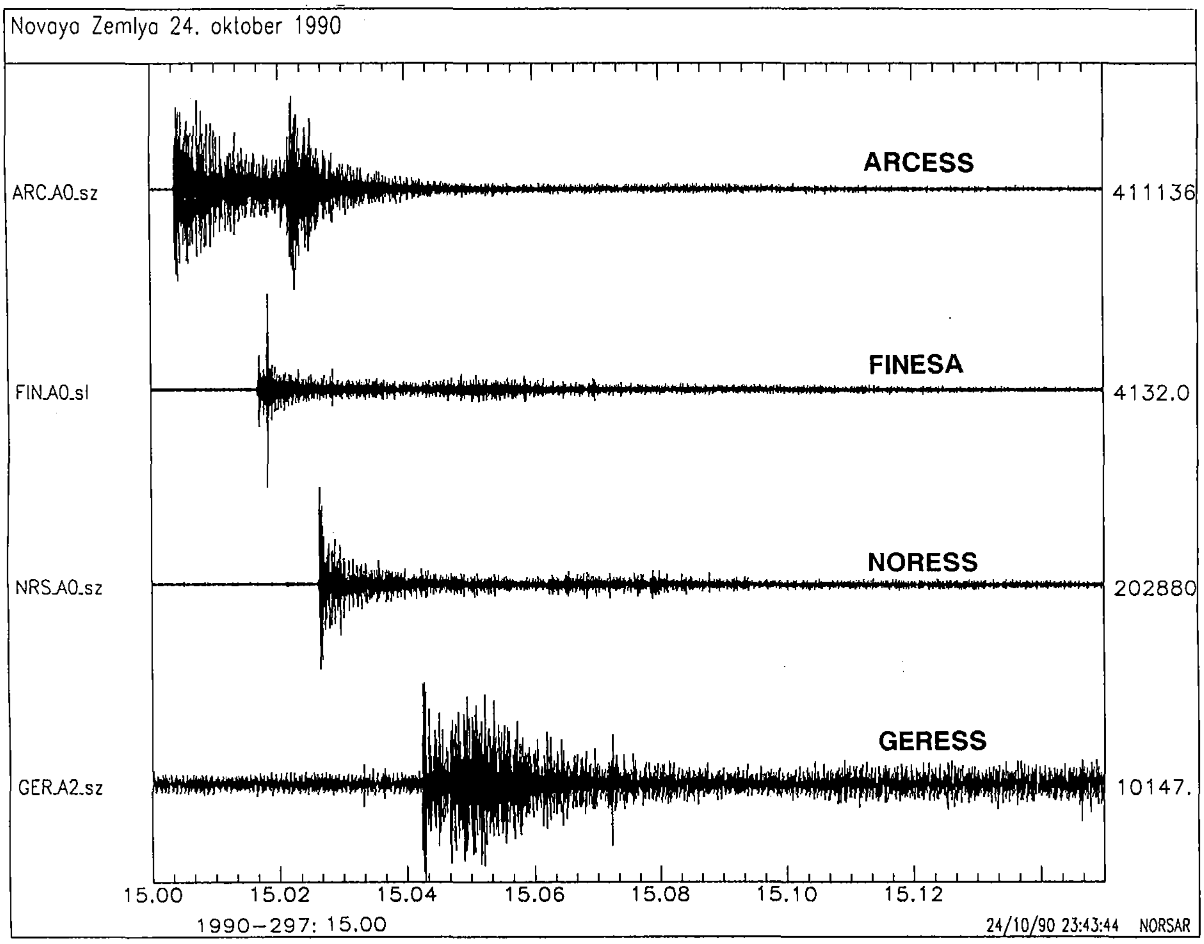

Fig. 7.1.6. Selected single seismometer SPZ recordings from the four regional arrays in northern Europe for the $m_b = 5.7$ nuclear explosion at Novaya Zemlya on 24 October 1990. Epicentral distances and maximum P-phase signal-to-noise ratios on the array beam are as follows:

ARCESS 1110 km, SNR = 8383; FINESA 1780 km, SNR = 2189
NORESS 2270 km, SNR = 2478; GERESS 3380 km, SNR = 105