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7.6 P/S ratios for seismic events near Novaya Zemlya

Introduction

The seismic event near Novaya Zemlya on 16 August 1997 at 02.11 GMT has been the subject of extensive analysis in order to locate it reliably and classify the source type. Because it was detected with high signal-to-noise ratio only by stations in Fennoscandia, NW Russia and Spitsbergen, the azimuthal coverage of the recordings is insufficient to obtain a good picture of the seismic field. Nevertheless, there has been suggestions that the recorded signals at some stations show characteristics similar to those that could be expected from an explosion. On the other hand, there has also been arguments forwarded to the extent that this event could be confidently classified as an earthquake, especially based on observed P/S ratios. In this paper we consider some of this evidence in light of previous recordings of nuclear explosions.

The NORSAR large array has an extensive database of recordings from events near Novaya Zemlya, including some nuclear explosions of magnitudes similar to those of the 16 August event and the nearby earthquake of 1 August 1986 (Ringdal, 1997). It is therefore of interest to compare the P/S ratios for these events, as recorded by individual sensors in the array. In this paper, we give some comments on these observations as well as observations from other available stations at regional distances.

Before going into detail on this analysis, we note that the IDC processing of this low-magnitude event was remarkably accurate and in full accordance with the procedures envisaged for the future International Monitoring System. Even though one of the key arrays (ARCESS) was out of operation due to repairs, the IDC successfully provided an automatic location and magnitude estimate that turned out to be quite close to the solution obtained through more extensive analysis at a later processing stage.

The earthquake of 1 August 86 and the nuclear explosion of 9 October 77

Figs. 7.6.1 and 7.6.2 show recordings at five NORSAR subarrays (center sensors) for the earthquake of 1 August 1986 and the nuclear explosion of 9 October 1977. These events have similar magnitudes (4.3 and 4.5) and are also at similar epicentral distance (~20 degrees) and azimuth.The data has been filtered in the band 1.0-3.0 Hz. The following observations can be made:

- The P/S ratios show very large variability across the array for both events.
- For each sensor pair, the P/S ratios are quite similar, although P/S is slightly smaller on average for the earthquake
- The variability in the P/S ratios are dominated by strong P-wave focusing effects across NORSAR

While it is seen that the P/S for the earthquake is generally slightly smaller than for the explosion (as might be expected), it is in fact *larger* for one of the sensors (NBO00).

It must be concluded from these two figures that P/S in this frequency band is not a very powerful discriminant when using data recorded at a single array or station. Clearly, a better performance might be expected if data from a large range of azimuths are available, but the overall performance of this discriminant is still questionable. Recent studies for Central Asia (Hartse et al, 1997), has shown that the P/S discriminant for that region appears effective at frequencies above 4 Hz, but has a poor performance for frequencies below 4 Hz. At NORSAR, there is almost no significant S-wave energy above 4 Hz, so we are confined to consider the lower frequencies.

Comparison of recordings at the same NORSAR seismometer sites

Figs. 7.6.3 and 7.6.4 show recordings of 4 events near Novaya Zemlya at NORSAR sites 02B00 and 04C00 respectively. These two sites are representative in the sense that one has a fairly large P/S ratio and the other has a fairly weak such ratio. The four events are (shown from top to bottom on the figures):

- 16 August 1997 (m_b 3.5)
- 1 August 1986 (earthquake, m_b 4.3)
- 26 August 1984 (nuclear explosion, m_b 3.8)
- 9 October 1977 (nuclear explosion, m_b 4.5)

The data has been filtered in the band 1.5-3.0 Hz, in order to maximize the SNR.

In both figures, it is very difficult to see any appreciable S-wave energy for the 16 Aug 97 event, because the noise preceding the P-phase is of the same order as the signal recorded in the S-phase window. In fact, we have been unable to find a filter band in which the S-wave of the 16 Aug 97 event is clearly defined. This of course means that the amplitude of the S-wave for this event as seen on the plots must be considered an “upper limit”, making any firm conclusion rather difficult.

Nevertheless, it seems fair to state that the S-wave of the 16 August 1997 event (relative to P) is probably weaker than for the earthquake on 1 August 1986. On the other hand, the difference between the 1 August 1986 earthquake and the two nuclear explosions is not large, which is consistent with the general statements made above. Thus, the data are rather inconclusive as far as source classification of the 16 August 1997 event is concerned.

Kevo and Finess P/S ratios for NZ events

We have looked at recent data from Kevo and Finess, and compared the 16 August 1997 event to the nuclear explosion at Novaya Zemlya on 24 October 1990. The two figures that follow are descriptive of the situation:

Fig. 7.6.5 shows Kevo data (BBZ) for the two events. The data have been filtered in the band 3-5 Hz, which should be one of the more useful bands for source identification. It is obvious that theP/S ratio for the 16 August 1997 event is much smaller than for the nuclear explosion Similar results have been obtained when comparing to other nuclear explosions in the magnitude range 5.5-6.0 (Richards and Kim, 1997).

Fig. 7.6.6 shows a similar plot (1.5-3.0 Hz) for the Finess center sensor (SPZ). At the time of the 1990 explosion, we had only the temporary Finesa configuration deployed, and the figure shows the low-gain channel from that configuration for the 1990 event. (All the other channels were severly clipped). The seismometer (Geotech S-13) and the instrument location are, however, identical for the 1990 and 1997 events, so in spite of the change of digitizer, the filtered channels should be quite comparable.

The S-phase at Finess for the 1997 event is not very distinct, but does appear to exceed the background noise. The P/S ratio in this filter band seems to be close to 1.0. For the 1990 explosion, the S phase is likewise difficult to see, but because of the strong P-phase, it is clear that the P/S ratio is well above 1. Thus, the P/S criterion as applied to Finess gives a similar result as for Kevo.

Unfortunately, we do not have data for Kevo or Finess for nuclear explosions of a magnitude similar to the 16 August 1997 event. The comparison of this event with past nuclear explosions which are two orders of magnitude larger cannot be considered conclusive, without taking into account the possibility of source scaling differences. This is discussed in more detail below.

Source scaling of the P/S ratio

To our knowledge, only one station at a regional distance, the NORSAR array, has available digital recordings of both large and small nuclear explosions from Novaya Zemlya. It may be instructive to study the P/S pattern of these explosions as a function of the event size.

In order to accomplish this, we have used the one NORSAR sensor (01A01) that has dual gain recording (the usual high-gain channel and a channel that is attenuated by 30dB). The attenuated channel has been available since 1976, and therefore provides a good data base of unclipped short period recordings of Novaya Zemlya explosions.

Fig. 7.6.7 shows a selection of nuclear explosions recorded at 01A01, with magnitudes ranging from 3.8 (26 August 1984) to 6.0 (10 August 1978). The data have been filtered in the band 1.0-3.0 Hz. There is a remarkable and systematic increase in the P/S ratio with increasing magnitude. This demonstrates that comparing the P/S ratios of large and small events could easily give misleading conclusions.

An illustration, in an expanded scale, for two of these explosions is shown in Fig. 7.6.8. The difference between these two explosions is in fact rather similar to the differences seen for the Kevo recordings shown earlier, which likewise compares a large and a small seismic event. Admittedly, the Kevo recordings are in a higher frequency band, but there is clearly reason for caution in interpreting the Kevo plots based on the results discussed above.

Because of the large epicentral distance of NORSAR from the test site, there is no appreciable high-frequency energy in the NORSAR recordings. Consequently, we have not been able to assess the possible source scaling of the P/S ratio for frequencies of 3 Hz and above. It would seem reasonable that such a source scaling might in fact be present also at these higher frequencies, but this needs to be further studied.

Conclusions

The P/S ratio as recorded by NORSAR and other available stations does not give sufficient evidence to provide a confident classification of the 16 Aug 97 event. This is mainly due to the lack of recordings of earthquakes and explosions in the Kara Sea of magnitudes similar to this event. It would be very desirable to carry out a chemical calibration explosion (in water) near the epicenter of the event. Besides contributing to improved seismic velocity models for the Barents region, such a calibration explosion would also help providing more confident classification of the 16 August 97 event, including constraints on the source depth.

The 16 August 97 event is certainly a very interesting case study for defining the potentials and limitations in classifying a low-magnitude seismic event, especially taking into account that it occurred near a known nuclear test site for which at least some calibration data exists. We will continue our analysis of this event as more data becomes available.

F. Ringdal

References:

Hartse, H.E., S.R. Taylor, W.S. Phillips and G.E. Randall (1997). A preliminary study of regional seismic discrimination in Central Asia with emphasis on western China, *Bull. Seism. Soc. Am.* 87, 551-568

Richards, P.G. and Won-Young Kim (1997). Test-ban Treaty monitoring tested, *Nature*, 23 Oct. 1997

Ringdal, F. (1997): Study of low-magnitude seismic events near the Novaya Zemlya nuclear test site, *Bull. Seism. Soc. Am.* (in press)

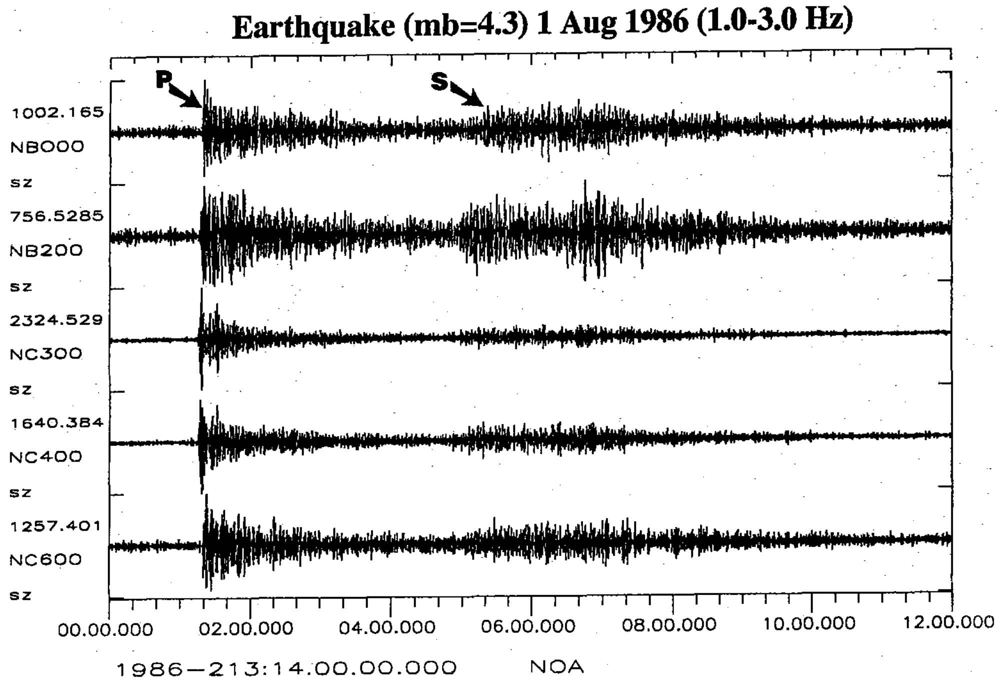

Fig. 7.6.1. Selected NORSAR SP seismometer recordings for the Novaya Zemlya earthquake of 1 August 1986. Note the strong variation in relative strength of the P and S phases across the array.

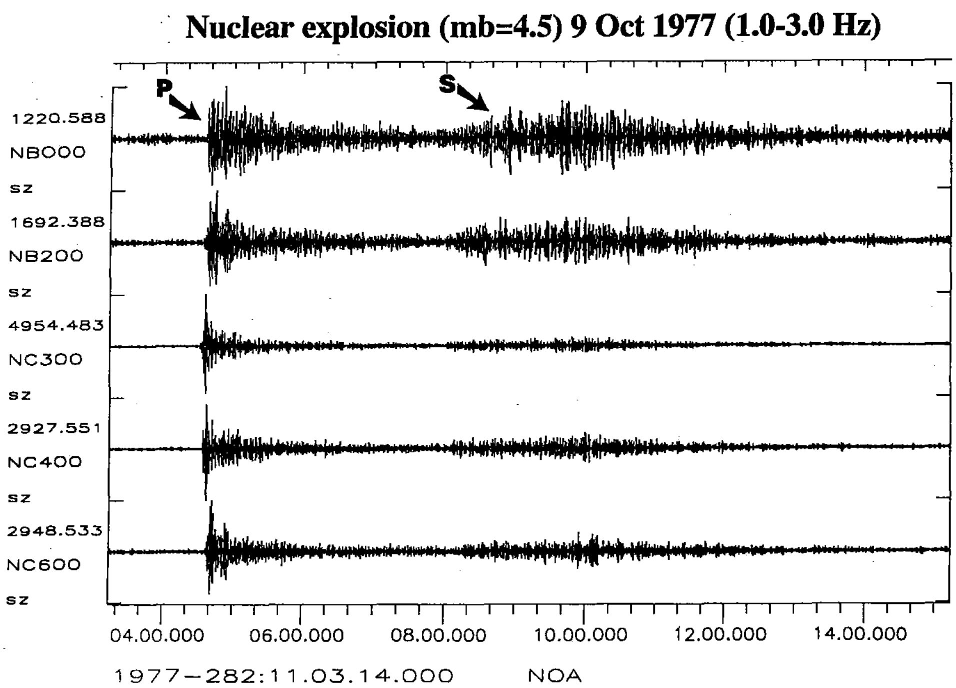

Fig. 7.6.2. Selected NORSAR SP seismometer recordings for the Novaya Zemlya nuclear explosion of 9 October 1977. Note the similarity to Fig. 7.6.1 as to the relative strength of P and S phases pairwise for the same instruments, as well as the similarity in variation across the array.

NORSAR 02B00

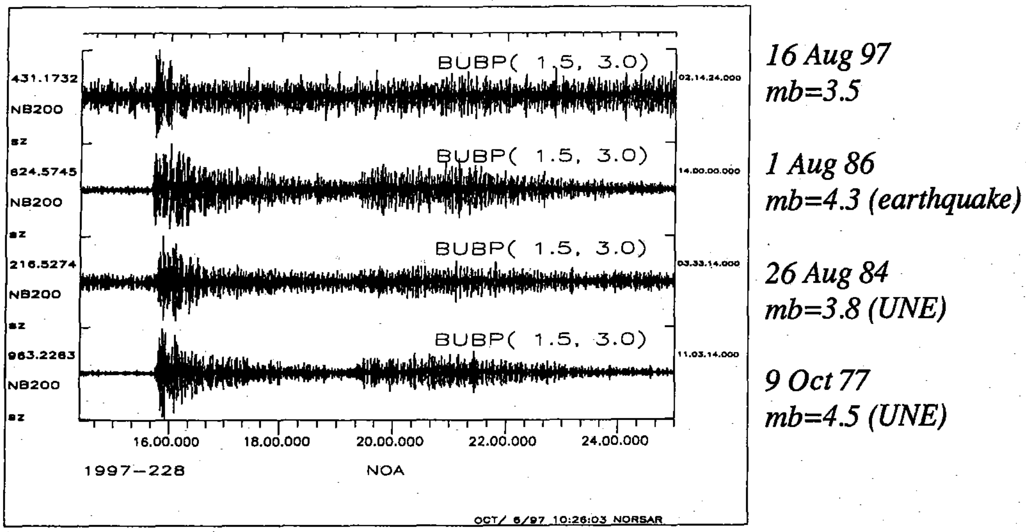

Fig. 7.6.3. Comparison of P and S recordings for four seismic events near Novaya Zemlya, as recorded by seismometer 02B00 of the NORSAR array.

NORSAR 04C00

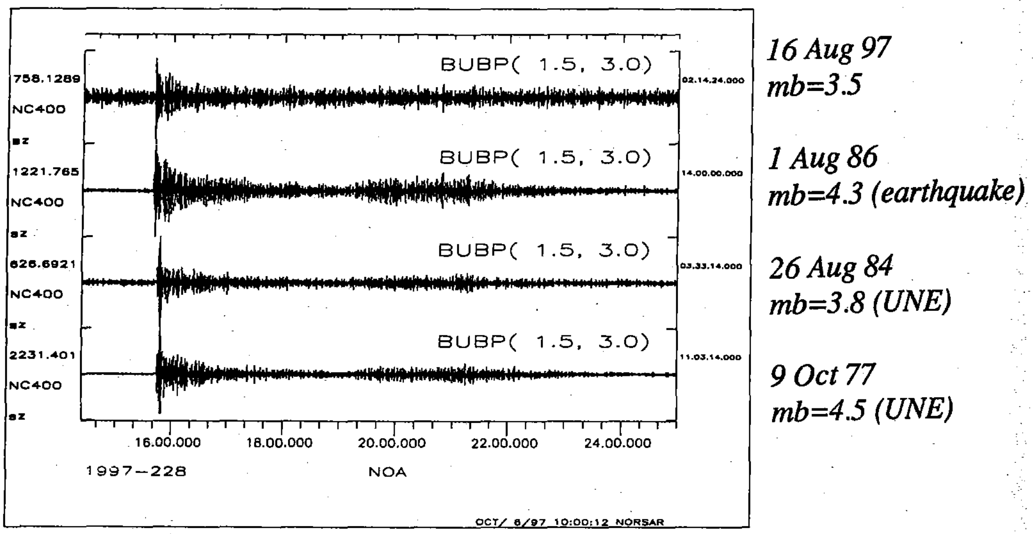

Fig. 7.6.4. Comparison of P and S recordings for four seismic events near Novaya Zemlya, as recorded by seismometer 04C00 of the NORSAR array.

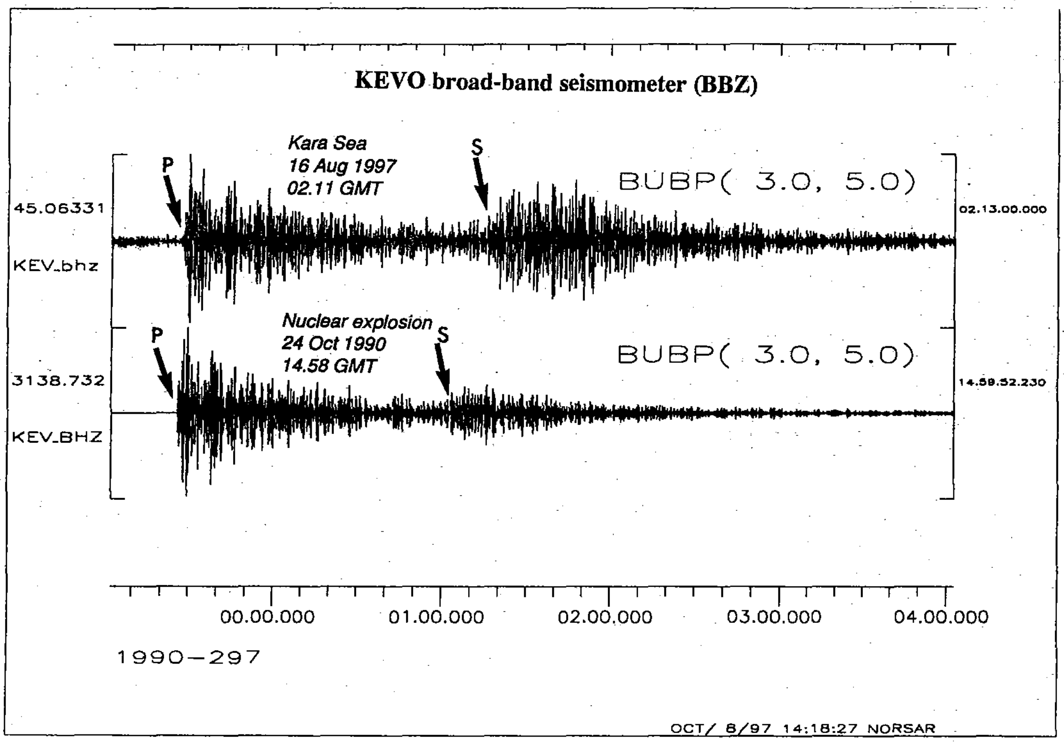

Fig. 7.6.5. Waveforms recorded by the Kevo station in Finland for the 16 August 1997 event and the nuclear explosion of 24 October 1990. Note the relatively much stronger S-phase for the first event, but also note that these two events differ in size by two magnitude units.

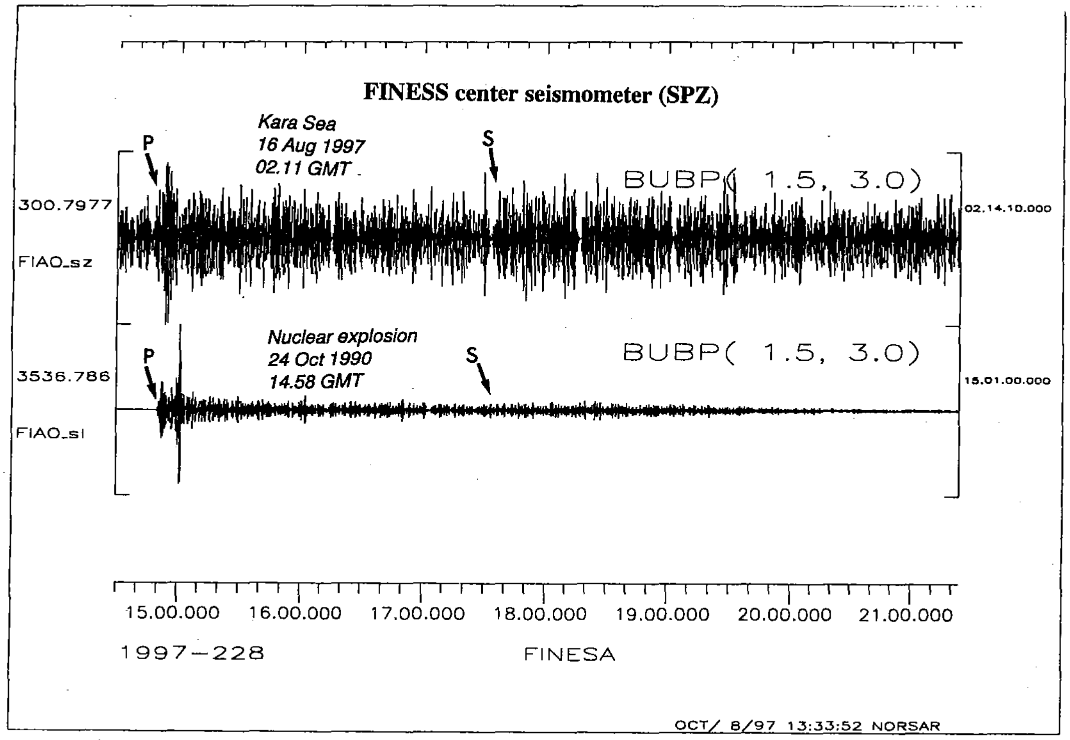

Fig. 7.6.6. Waveforms recorded by the center sensor of the Finess array in Finland for the 16 August 1997 event and the nuclear explosion of 24 October 1990. In this case, the S-phases are barely above the noise level, tbut it appears that the data are consistent with the picture for Kevo.

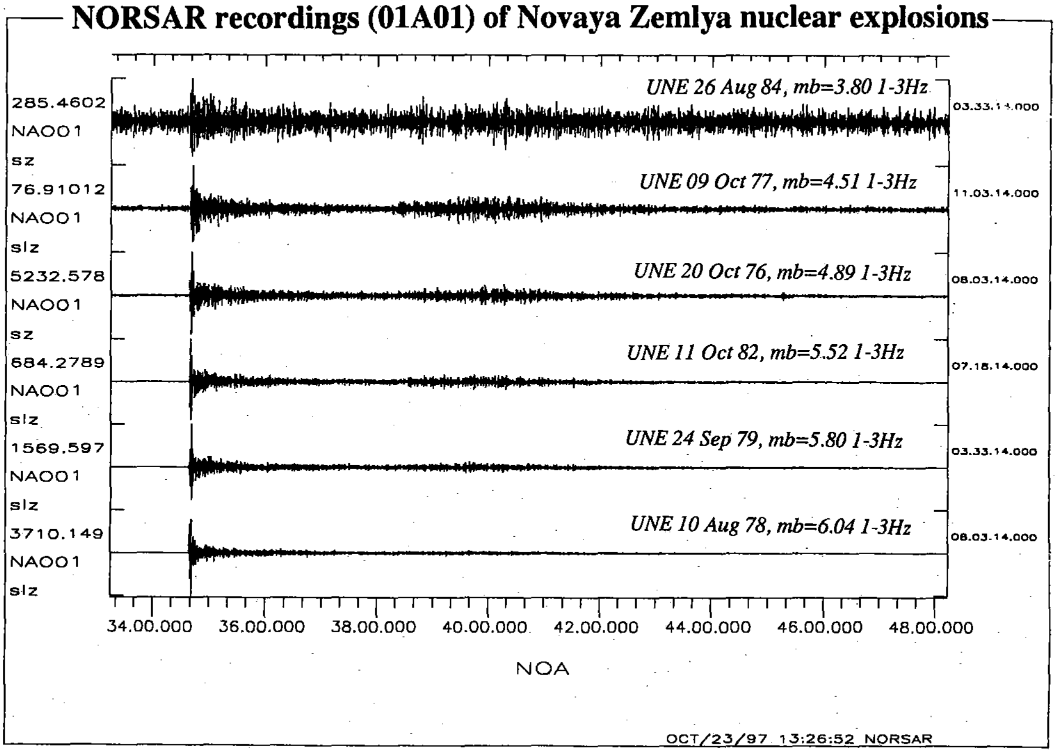

Fig. 7.6.7. NORSAR recordings (seismometer 01A01) of six Novaya Zemlya nuclear explosions of varying magnitudes. The data have been filtered in the 1-3 Hz band. Note the systematic increase in P/S ratio with increasing magnitude.

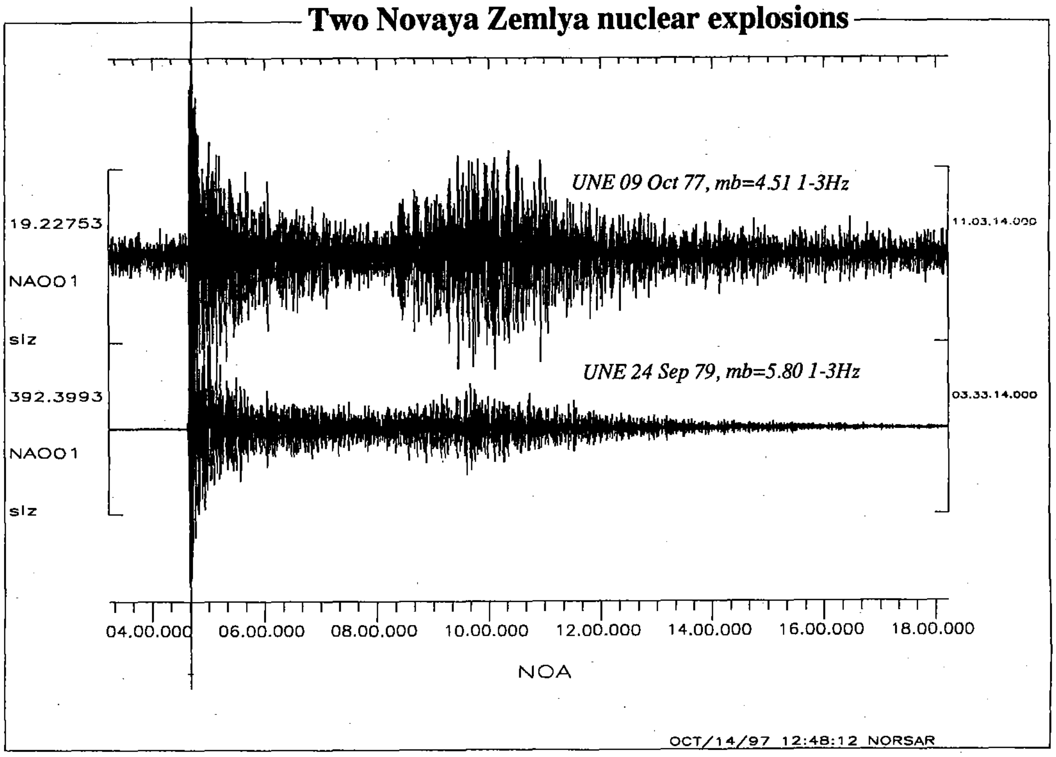

Fig. 7.6.8. NORSAR recordings (seismometer 01A01) of two of the Novaya Zemlya nuclear explosions shown in Fig. 7.6.7. The top trace shows a small explosion (m_b=4.5), whereas the bottom trace shows a large explosion (m_b=5.8). The vertical scale has been amplified to highlight the difference in P/S ratio between the two events.