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7.5 The seismic event near Novaya Zemlya on 16 August 1997

Introduction

On 16 August 1997, the CTBT prototype International Data Center in Arlington, Va. reported a small seismic disturbance located near the Russian nuclear test site on Novaya Zemlya. Initial IDC analysis indicated that this event could have taken place on land, and that the seismic signals had characteristics similar to those of an explosion.

The event caused significant concern in the United States and several other countries, because it was seen as a possible violation of the treaty that was signed in September 1996. Russian authorities claimed that it was a small earthquake, and not an explosion.

The 16 August 1997 event provides a very useful case study of what might happen if an unusual seismic event is detected after a CTBT enters into force. In this paper, we briefly recollect the sequence of analysis carried out at the Norwegian National Data Center for this event, including our interaction with the IDC and other countries in this analysis.

Data analysis at the prototype IDC

The PIDC located this event very well already in their Automatic Event List (AEL), which was published only hours after the event occurred. The AEL location was 72.79N, 57.37E, which turned out to be only a few tens of kilometers away from the best location that we eventually were able to calculate. Furthermore, the automatic algorithm to retrieve auxiliary data worked according to the specifications, so that Spitsbergen array data was retrieved and included in the subsequent automatic processing.

The excellent IDC performance is particularly noteworthy since only three primary stations (NORES, FINES and NRI) detected the 16 August 1997 event. Unfortunately, the key primary station for this region (ARCES) was not available due to repair work at that site. The processing and subsequent interactive analysis of the event clearly suffered from this absence, but the redundancy of seismological stations in the Fennoscandian region nevertheless contributed to alleviate this situation to some extent.

The Reviewed Event Bulletin (REB) location was published a few days later, in general accordance with the IDC time schedule. This location (72.6484N, 57.3517E) was again quite good, and did not differ much from the initial automatic location. However, the IDC used only P-phases as defining phases, due to the well-known problem of IASPEI91 vs Fennoscandian model travel times. Thus, the need to include regionally calibrated travel-time curves was accentuated by this experience.

Data analysis at the Norwegian NDC

In cooperation with colleagues in the United States, Scandinavia, Finland and Russia, NORSAR scientists carried out a detailed analysis of the 16 August 1997 event, even before the REB solution became available. To assist in this analysis, we collected considerable additional data from stations not forming part of the IMS. In particular, the entire Finnish network was made available to us, as well as data from the Apatity array in the Kola Peninsula. Station KEV in Finland had particularly high SNR, and provided a good replacement for ARCES. Some of the stations in the Northern European Network are shown in Figure 7.5.1.

Although most of these additional data were in principle available in near real-time, it took some time to collect it, because the appropriate mechanisms for on-line retrieval had not been implemented. This is clearly an area in which improved procedures are required for the future.

NORSAR and Kola Regional Seismological Centre (KRSC) worked together on locating this event, each carrying out independent analysis. Since some phase onsets were very difficult to read, this was quite useful, and the results were very consistent. We were very quickly able to confirm beyond doubt that the 16 August 1997 event was located in the Kara Sea, at least 100 km from the Novaya Zemlya nuclear test site.

Subsequent analysis resulted in only minor adjustment of the location. Our "best" result so far, using all available P and S phases and applying the Fennoscandian travel-time model, is as follows:

72.51N, 57.55E Depth = 0 km (fixed)

The error ellipse is about 10km (major semi-axis), but it is of course uncertain how well it represents the actual error. Figure 7.5.2 shows the estimated location and error ellipse, and also shows for comparison Marshall et al's (1989) location of the 1 August 1986 earthquake, which is the only confirmed eartquake previously recorded near Novaya Zemlya.

The depth of the 16 August 1997 event can, in our opinion, not be resolved on the basis of the available data. While it is true that the RMS residuals are smaller if a greater than zero depth is assumed, the available travel-time calibration and the accuracy of the phase readings are insufficient to give a confident depth estimate (See also the discussion in Section 7.3 of this report).

As is well known, epicentral location using P-phases only is less sensitive to possible errors in the regional travel-time model than locations using both P and S phases. If the SNR is sufficient, the P-phase readings can also be made with much higher accuracy than those of later phases. For illustration purposes, we have located the epicenter using the P-phases from three stations with very high SNR. These stations (Spitsbergen, Kevo and Amderma) have well separated azimuths to the epicenter. The result is shown in Figure 7.5.3, and is in fact quite consistent with our "best" estimate, although slightly to the southwest.

The size of the 16 August 1997 event is about two orders of magnitude smaller than e.g. the underground nuclear explosion of 24 October 1990 (which was close to 50 kilotons), and is also considerably less than the nearby earthquake of 1 August 1986. The Richter magnitude is estimated to 3.5.

We have no evidence, based on our recordings, that would classify this event as an explosion. We have not been able to find Rayleigh waves corresponding to this event, and have therefore been unable to apply the Ms:mb discriminant. The P/S ratio is in our opinion inconclusive, as detailed in Section 7.6 of this report. The offshore location suggests that is was a natural earthquake. Other explanations could be forwarded, but the data does not enable us to reach a firm conclusion.

Searching for aftershocks

Perhaps the best indication of an earthquake source would be the presence of several aftershocks, if such could be found. We have carried out a detailed search for aftershocks of the 16 August 1997 event, using both Spitsbergen array data and data that later have become available at KRSC from the Amderma station south of Novaya Zemlya.

Our search of Spitsbergen data, which was conducted by detailed visual inspection of the array beam, enabled us to find a second (smaller) event from the same site a little more than 4 hours after the main event. This second event had Richter magnitude 2.6, and could be quite clearly seen to originate from the same source area (Figure 7.5.4).

This conclusion was supported when Amderma data became available at KRSC some weeks later. Figures 7.5.5 and 7.5.6 show Amderma 3-component recordings of the two events. The recordings are very similar, but as can be seen by the scaling factor in front of the traces, they differ in size by about an order of magnitude. Note the high SNR even for the smallest of the two events. The P-wave spectrum of the largest event (Fig. 7.5.7) shows that there is signifcant signal energy from 1 Hz up to the Nyquist frequency of 20 Hz, with maximum SNR at frequencies above 5 Hz.

In spite of very careful analysis of both Spitsbergen and Amderma data, we have not been able to identify additional aftershocks during the two weeks following the main event.

Although we were confined to carry out the search for aftershocks by visual inspection, the development currently in progress at NORSAR on establishing a method for optimized site-specific threshold monitoring (Kværna & Ringdal, 1997) holds promise to provide a simple interactive tool to aid the analyst in such searches in the future.

Conclusions

The 16 August 1997 event provides a particularly interesting case study for the Novaya Zemlya region. It highlights the fact that even for this well-calibrated region, where numerous well-recorded underground nuclear explosions have been conducted, it is a difficult process to reliably locate and classify a seismic event of approximate m_b 3.5. It is also shown that supplementary data from national networks can provide useful constraints on event location, especially if the azimuthal coverage of the monitoring network is inadequate. It thus serves to confirm the conclusions of Ringdal (1997) in this regard.

It is clear from this study that more research is needed on regional travel-time calibration, regional signal characteristics and application of M_s:m_b and other discriminants at regional distances. In applying the latter criterion, it would be particularly useful to estimate an upper confidence limit on M_s for events with marginal or non-detected surface waves.

It would be a particularly useful exercise to carry out a small chemical calibration explosion in the Kara Sea, in order to improve the travel-time tables for this region. Such an explosion, even if not recorded teleseismically, would provide valuable additional information for future studies. It is well worth noting that even though many nuclear explosions have been conducted at Novaya Zemlya in the past, the value of these for such calibration is limited, since very few of the IMS stations were in operation during that time.

While the IDC processing functioned very well for this event, it should be taken due note of the fact that a second (smaller) event, not satisfying the current IDC event definition criteria, could be clearly singled out by detailed analysis of the IMS station at Spitsbergen. It might be useful to consider, for future processing, the possibility of the IDC carrying out routine searches for aftershocks in such cases of events of special interest. The optimized threshold monitoring technique could provide a useful tool to help the analyst undertake such searches efficiently and easily.

Another lesson learned from this event is the need to organize rapid retrieval of supplementary data from available national seismic stations. Such data, although not being part of the IMS, could nevertheless provide increased confidence in the IMS solutions, and thus be valuable in national CTBT monitoring.

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References

Kværna, T. & F. Ringdal (1997): Threshold Monitoring of the Novaya Zemlya Test Site, Manuscript in preparation, NORSAR, Kjeller.

Marshall, P.D., R.C. Stewart and R.C. Lilwall (1989): The seismic disturbance on 1986 August 1 near Novaya Zemlya: a source of concern? *Geophys. J.*, 98, 565-573.

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

Station network

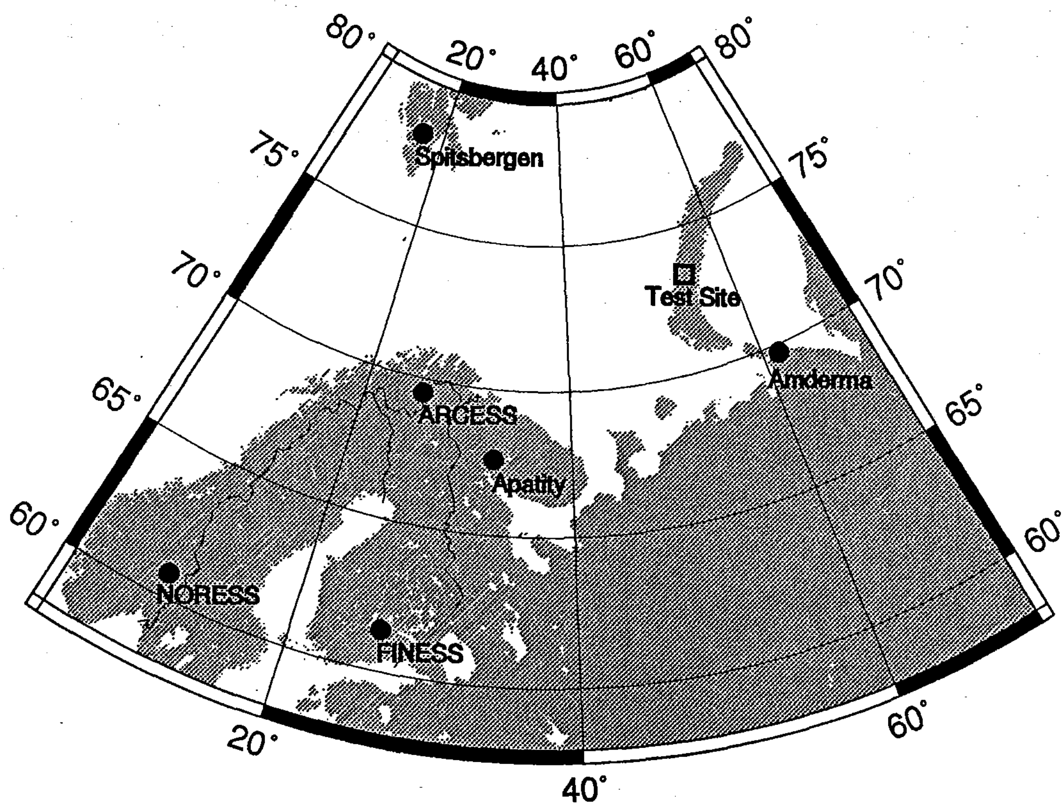

Fig 7.5.1. Map showing the locations of regional arrays in Northern Europe. The location of the northern Novaya Zemlya nuclear test site is also shown.

Location of 16 August 1997 event

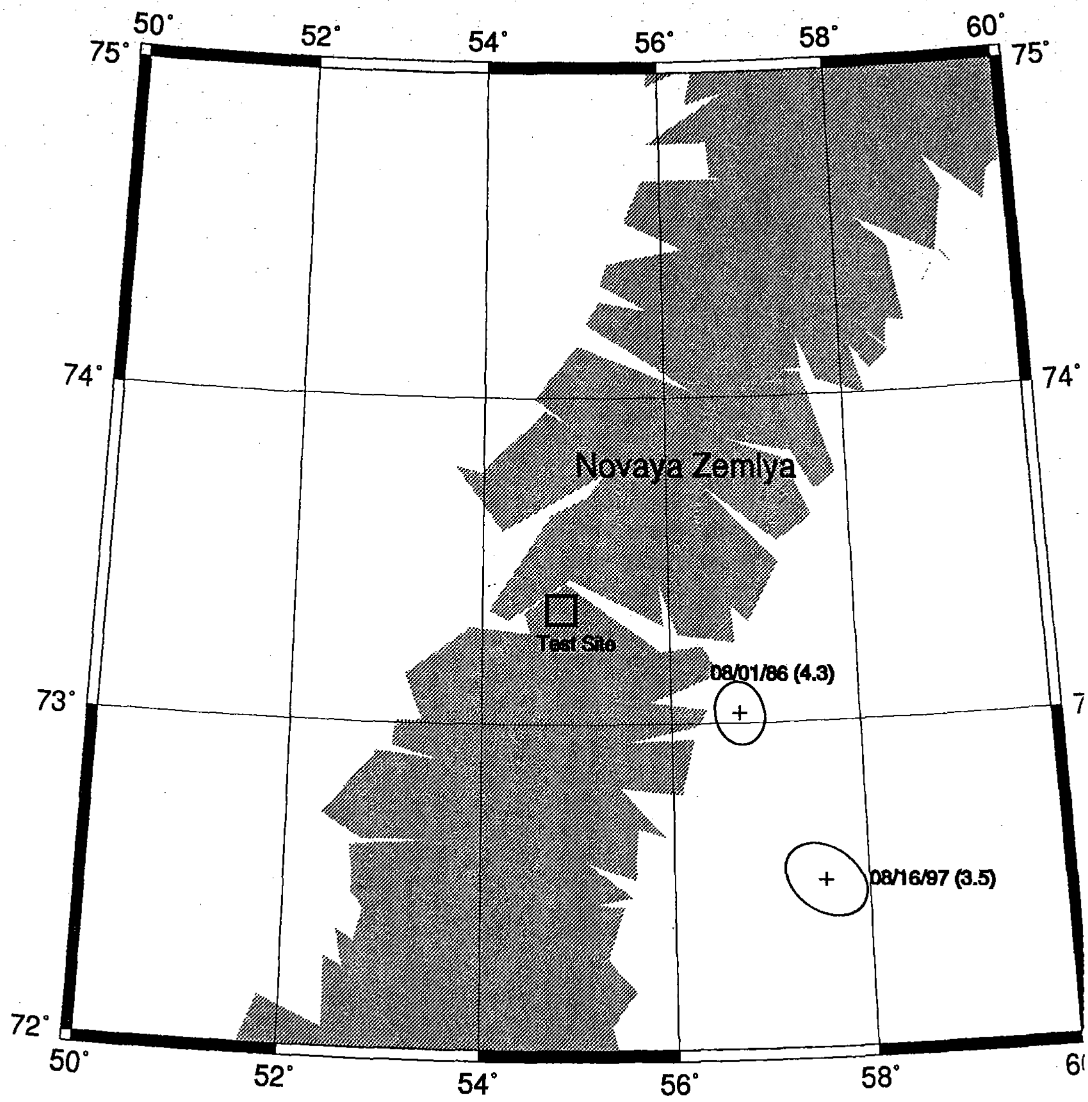

Fig 7.5.2. NORSAR's location estimates of the 16 August 1997 seismic event, together with the estimated location of the 1 August 1986 earthquake (Marshall et al, 1989). The error ellipses (90% confidence) are based on assumed prior uncertainties in the regional travel-time tables and onset time readings, and must be taken as only a tentative indication of the actual epicentral accuracy.

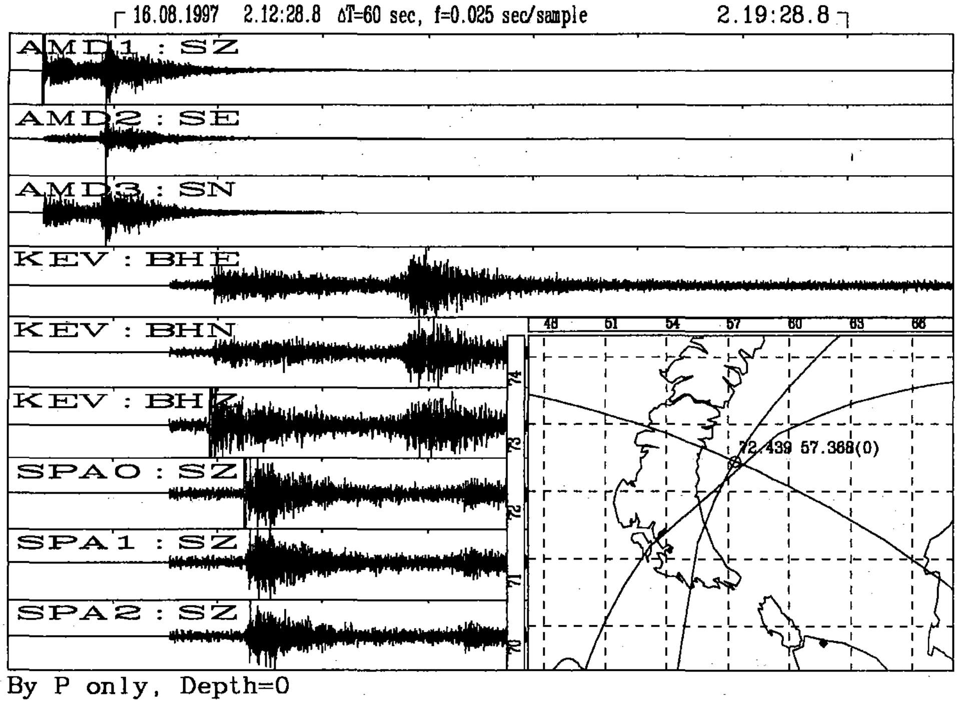

Fig 7.5.3. Illustration of the location of the 16 August 1997 seismic event using P-phases only from three stations Amderma, Kevo, Spitsbergen). See text for comments.

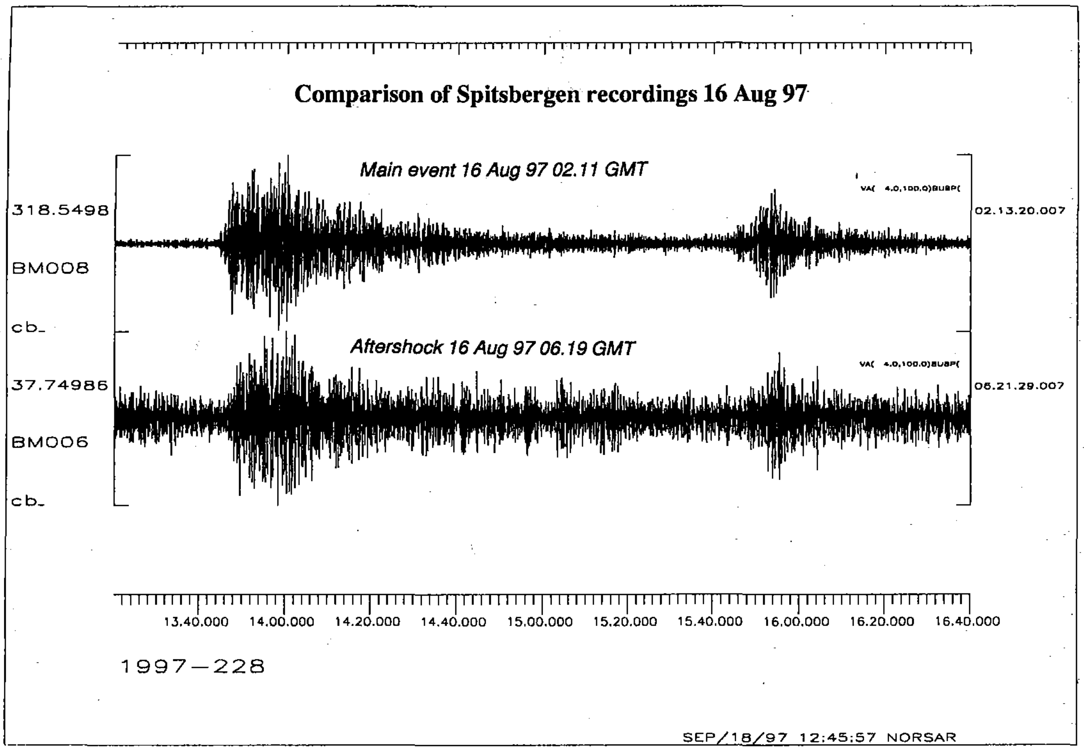

Fig 7.5.4. Recordings by the Spitsbergen array of the two events on 16 August 1997. The traces are array beams steered towards the epicenter, and with an S-type apparent velocity in order to enhance the S-phase. The traces are filtered in the 4-8 Hz band. Note that the traces are very similar, although not identical. The scaling factors in front of each trace is indicative of the relative size of the two events.

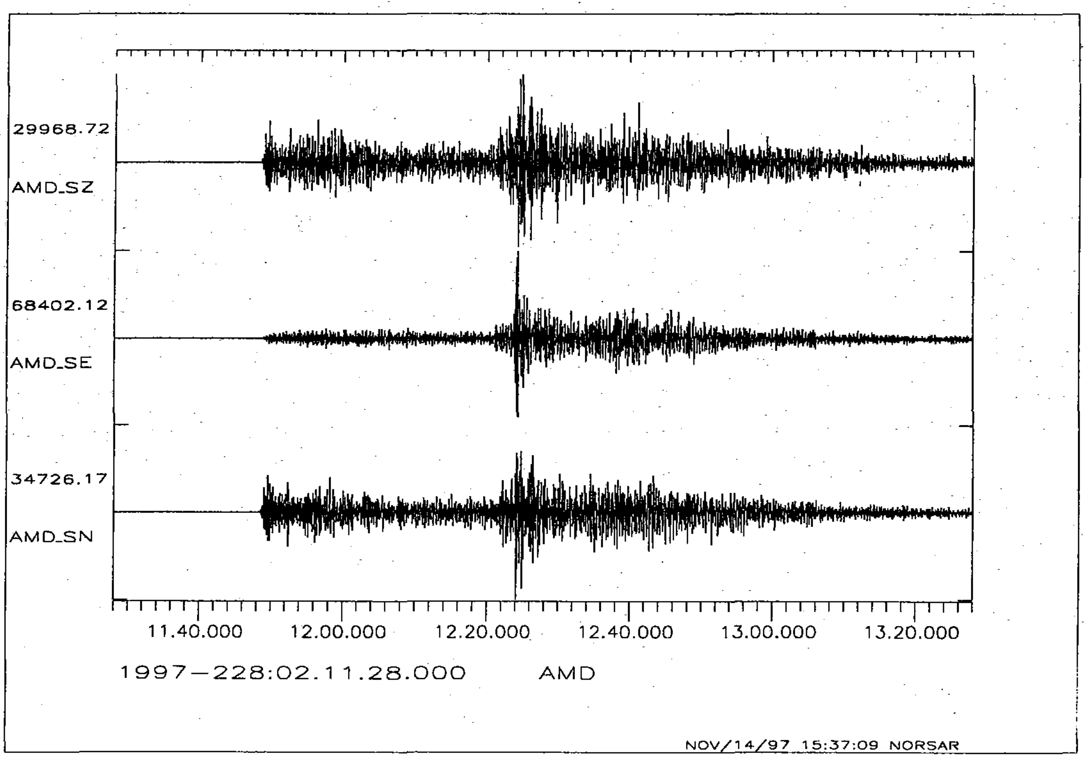

Fig 7.5.5. Recordings by the Amderma 3-component center station of the first event on 16 August 1997. The traces are filtered in the 2-16 Hz band. The scaling factor in front of each trace is indicative of the event size.

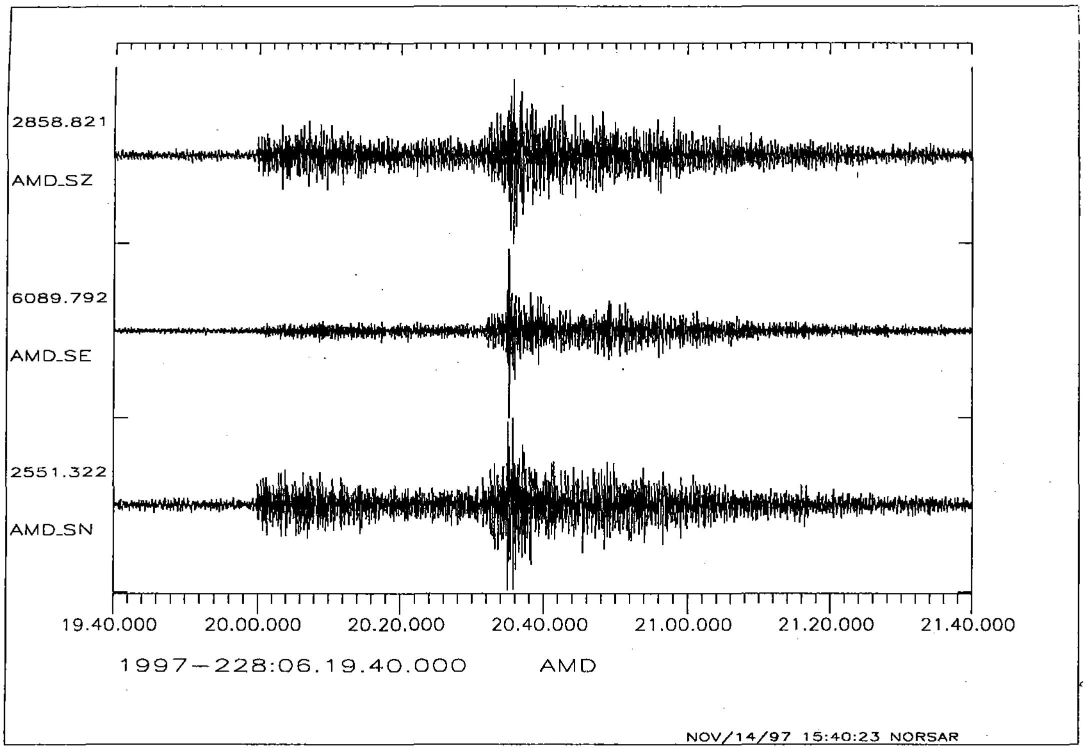

Fig 7.5.6. Recordings by the Amderma 3-component center station of the second event on 16 August 1997. The traces are filtered in the 2-16 Hz band. The scaling factor in front of each trace is indicative of the event size. Note the similarity to Figure 7.5.5.

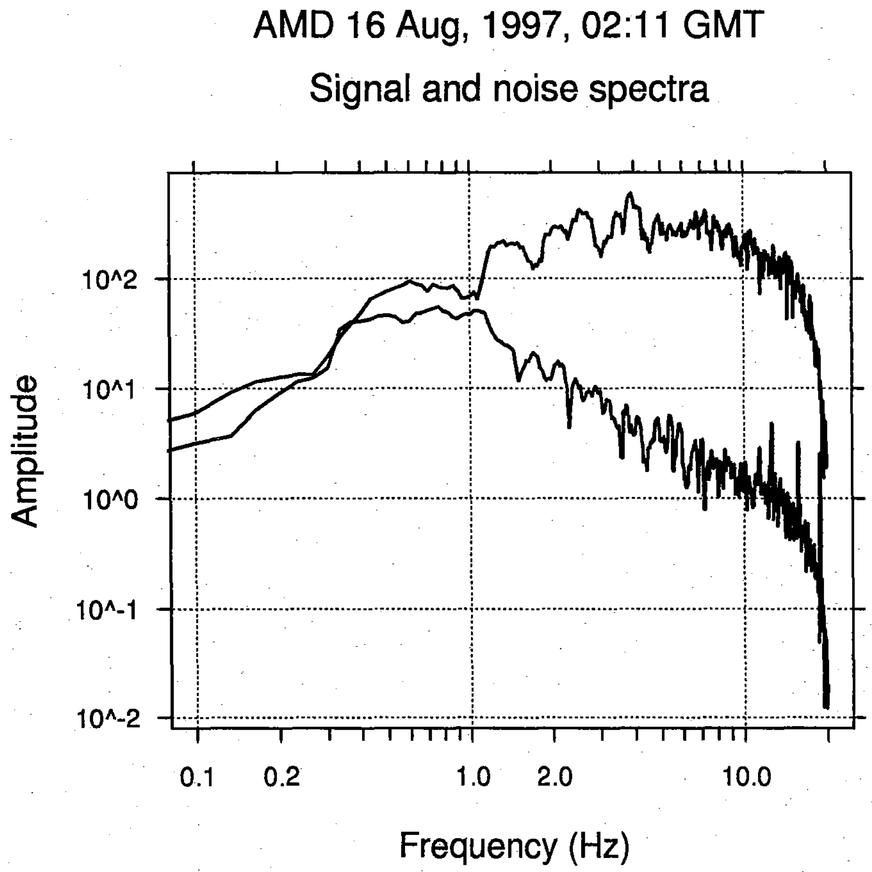

Fig. 7.5.7. P-wave and noise amplitude spectra for the Kara Sea event of 16 August 1997, 02.11 GMT as recorded by the AMD SPZ center seismometer. The spectra represent 30-second windows for both the P-phase and the noise preceding P onset. The spectra have not been corrected for system response.