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7.4 Study of surface waves and M_s:m_b using Apatity LP recordings

Introduction

As part of a project aimed at improving seismic monitoring capabilities for the Arctic region, NORSAR and Kola Regional Seismological Centre (KRSC) are conducting a comprehensive study of seismicity, seismic wave propagation and seismic event characterization in the Barents region. This work is particularly relevant to the development of event screening criteria, which is one of the main tasks of the expert work conducted by the Vienna Working Group B (verification).

The current event screening procedure employed at the IDC focuses on two criteria: event focal depth and M_s:m_b. These are considered to be by far the most robust criteria currently available, but have the disadvantage that they are difficult to apply to small events or events recorded only by few stations. Other criteria, such as the high-frequency P/S ratio, hold the promise of being applicable at much lower event magnitudes, but are currently not proven to be sufficiently reliable (see the study described in Section 7.1 of this report).

By focusing on regional recordings of surface waves, it would be possible to apply the M_s:m_b discriminant to low magnitude events, perhaps approaching m_b=3.0-3.5. This is the motivation for the present study. As is well known, accurate discrimination of seismic events with a regional network requires detailed knowledge of the propagation characteristics of seismic waves in the region. At present, these propagation characteristics are reasonably well known for P-waves in the Barents region, but much work remains to be done regarding surface wave propagation and magnitude estimation. In the following, we describe some initial results obtained for this region.

Station network

The regional seismic network operated by the Kola Recional Seismological Center currently comprises a combination of digital and analog stations. Several stations of the analog type have been in operation for many years (see Fig. 7.4.1), whereas the digital stations in this network have only a few years of available recordings (Asming et al, 1998).

In order to assess surface wave propagation, and in particular to evaluate the M_s:m_b discriminant, it is necessary to take advantage of the historic analog recordings. The station APA in Apatity forms a unique source of such data. This station has had high-quality LP recordings since 1969, and thus a data base is available of regional earthquakes and nuclear explosions dating back almost 30 years.

Data

We have initiated a project to digitize surface waves of selected regional events in the APA data base of LP recordings. The digitization method is illustrated in Fig. 7.4.2, and is based on a semi-automated algorithm. The original seismograms are amplified by photocopying and scanned into an image on a PC. An automatic algorithm calculates the midpoint of each trace for a given time interval, and thus creates an initial digital record. The analyst can interactively verify the output and make corrections as necessary (for example when lines on the seismogram cross each other). Finally, the record is resampled with an equidistant sampling rate.

We have checked this method by comparing digitized analog LP recordings to the digital recordings of a co-located broadband station in order to verify the response characteristics and the quality of the digitization process. This comparison can only be made for the most recent years, during which a co-located broadband Guralp 3-component seismometer has been in operation in Apatity.

An illustration of such a comparison for an earthquake in 1998 near Spitsbergen is shown in Figures 7.4.3 and 7.4.4. It is seen that the quality of the digitized records are excellent, and can be used over a spectral band ranging from 5 seconds to at least 30 seconds period. In fact, the recordings in the various filter band are almost identical, except that for the lowest filter band (0.03-0.04 Hz or 25-33 seconds) the broad-band recordings have slightly more ringing of the signal than the digitized LP recordings. We attribute this difference to the different response characteristics of the seismometers at these frequencies.

Results

We have initially applied this digitization to about 30 seismic events at regional distances and various azimuths from the APA station. About half are nuclear explosions (mostly from the Novaya Zemlya test site) and the remainder are intermediate and low magnitude earthquakes (typical magnitude range 4.0-5.0). All of the earthquakes have continental propagation paths. While the earthquakes (by necessity) are at azimuths different from the explosions, we consider that the variations in azimuths and propagation paths are sufficient to provide a representative sample of the characteristics of the seismic source and propagation effects.

An example of digitized data for two nuclear explosions (separated in time by 12 years) is shown in Fig. 7.4.5 and 7.4.6. We note that the LP signals are very similar across all the frequency bands considered, with about a factor of 2 in amplitude difference. In particular, it is interesting to note the strong signals even at the highest frequency band considered (0.1-0.2 Hz or 5-10 seconds period).

Fig. 7.4.7 shows a map of the propagation paths (to the left) and a comparison of the corrected surface wave spectra (to the right). These corrected spectra have been obtained by calculating the log amplitude of the filtered surface waves in each frequency band, making a distance correction equal to 1.66*log(Delta(deg)) and subtracting the m_b value for each event. Although somewhat simplified, this diagram can be seen as a frequency-dependent M_s:m_b plot, and the separation is quite good at all frequencies considered.

We may add that we also digitized surface wave recordings from a suite of earthquakes in the oceanic part of the Norwegian Sea (very close to the oceanic/continental margin), and compared them to the explosion population. While not shown in a figure, it turned out that they were closer to the explosions than the "continental" earthquakes. This is likely at least partly due to attenuation along the oceanic/continental margin, and confirms that such major tectonic features must be corrected for when carrying out discrimination studies.

One interesting observation in Fig. 7.4.7 is the 1 August 1986 event near Novaya Zemlya. This event, which is traditionally classified as an earthquake (see Marshall et.al., 1989) seems to fall very close to the explosion population. We should note, however, that this is to some extent a consequence of our not having available reliable m_b values for this (or most other) events in the data base. It is therefore premature to use these results to state anything about the nature of the source for the 1 August 1986 event.

The lack of reliable m_b estimates for events in this region is in fact a source of concern, and prevents us at present from carrying out the M_s:m_b study in more detail. As an example, the ISC m_b can at occasions be biased high by one full magnitude unit, *e.g.* when only one or two high-amplitude teleseismic stations have detected a given event. On the other hand, most of the Novaya Zemlya events have a reasonably accurate magnitude estimate (Ringdal, 1997). We plan to carry out a more comprehensive evaluation of m_b , perhaps by using a maximum-likelihood formulation similar to that of Ringdal (1986), in order to obtain more consistent estimates for the events in the data base.

Conclusions

We have demonstrated the capabilities of the APA surface wave recordings to provide a promising separation of earthquakes and explosions in the Barents region using the M_s:m_b discriminant. We have shown that separation between the earthquake and explosion populations can be achieved in a wide frequency band (5-30 seconds period). We note that this gives promise for applying the M_s:m_b discriminants down to lower magnitudes than is possible using teleseismic recordings.

Additional work is required in regionalization of the propagation paths to take into account the major tectonic features in the region. The body-wave magnitudes provided by the ISC are far from good enough for events in this region, and must be reassessed in order to make full use of the earthquake-explosion discrimination potential.

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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. (1986). Study of magnitudes, seismicity and earthquake detectability using a global network, *Bull. Seism. Soc. Am.* 76, 1641-1659.

Ringdal, F. (1997): Study of Low-Magnitude Seismic Events near the Novaya Zemlya Test Site, *Bull. Seism. Soc. Am. 87 No. 6,* 1563-1575.

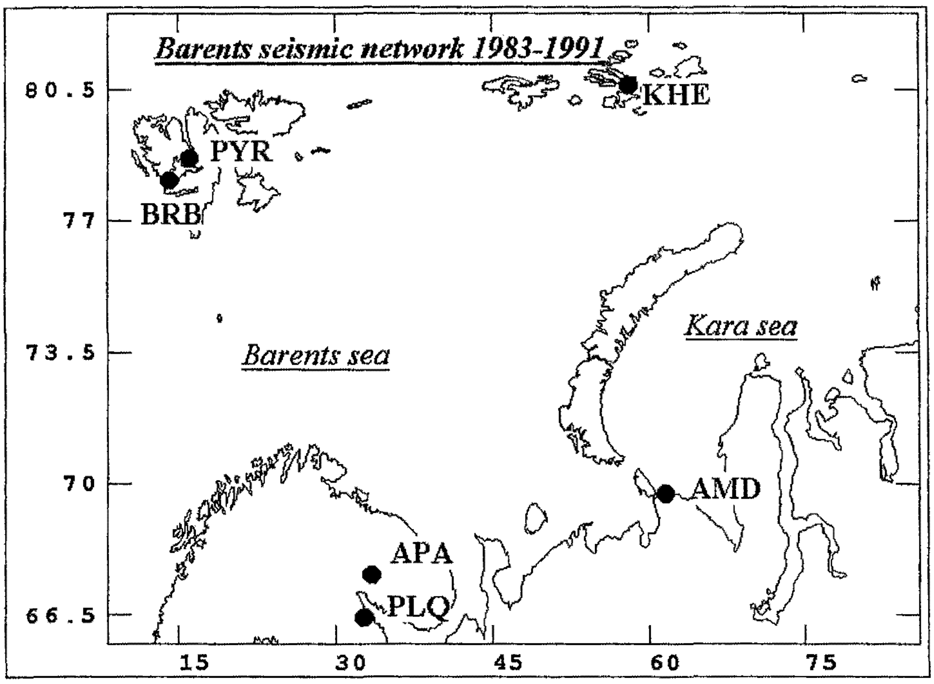

Fig. 7.4.1 Stations in the Barents seismic network operated by KRSC. The station APA, which has both 3-component SP and LP seismometers, has the longest period of operation, from 1969 until present. APA has in addition a Guralp BB digital seismometer, which has been operational since 1991.

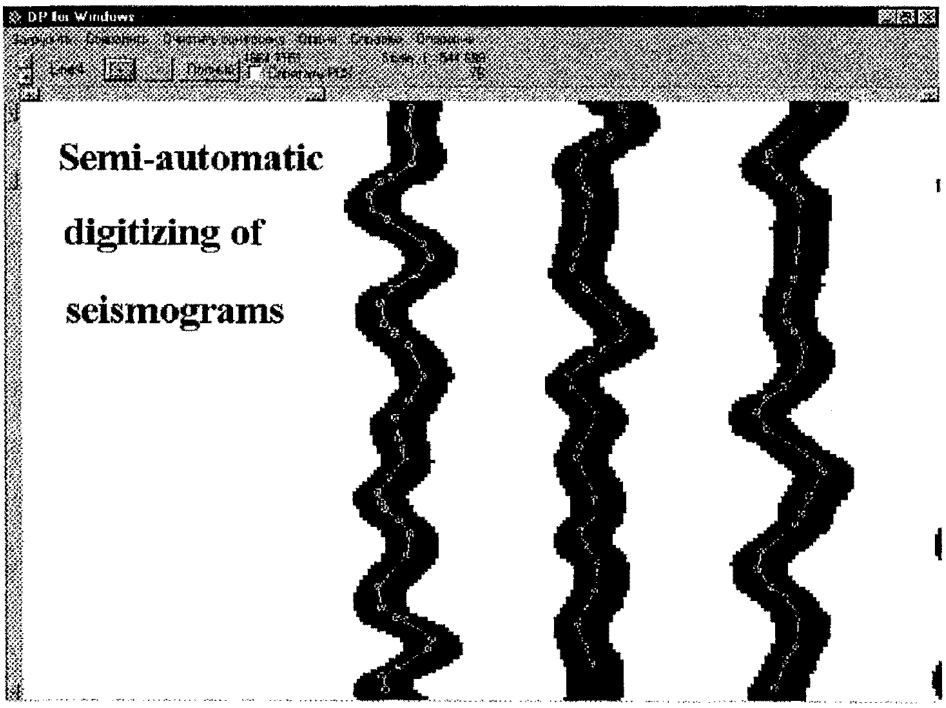

Fig. 7.4.2..Illustration of the semi-automatic method of digitization of analog LP seismograms applied to the APA data base. See text for details.

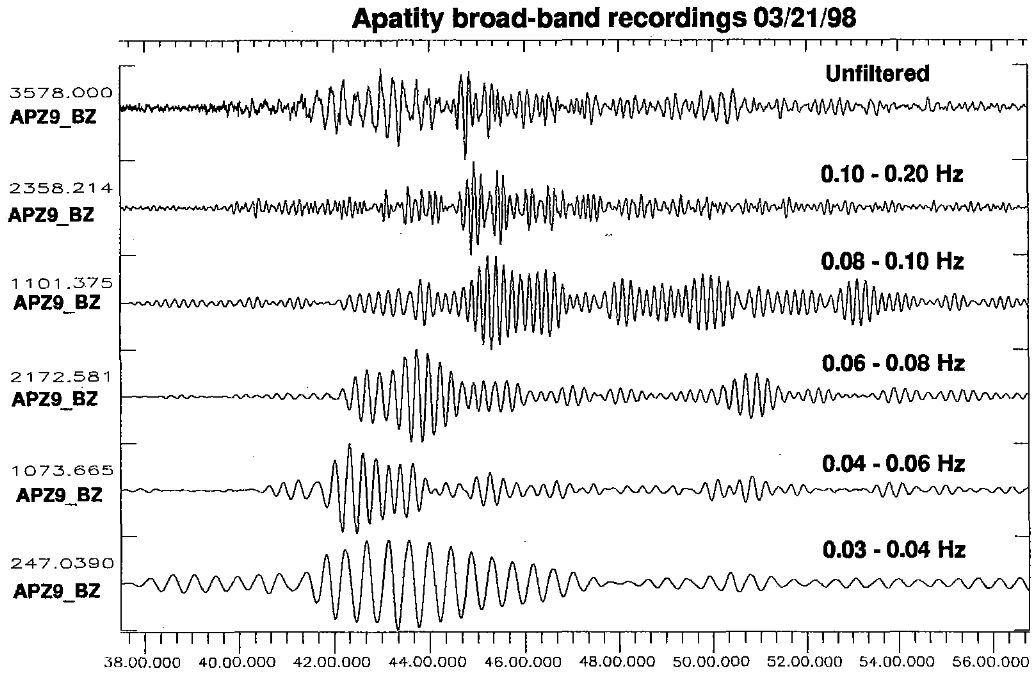

Fig. 7.4.3. Digital recording by the broad-band Guralp vertical seismometer in Apatity for an earthquake near Spitsbergen on 21 March 1998. The unfiltered data are shown in the top trace, with the other traces showing a suite of narrow-band filters applied to the recording.

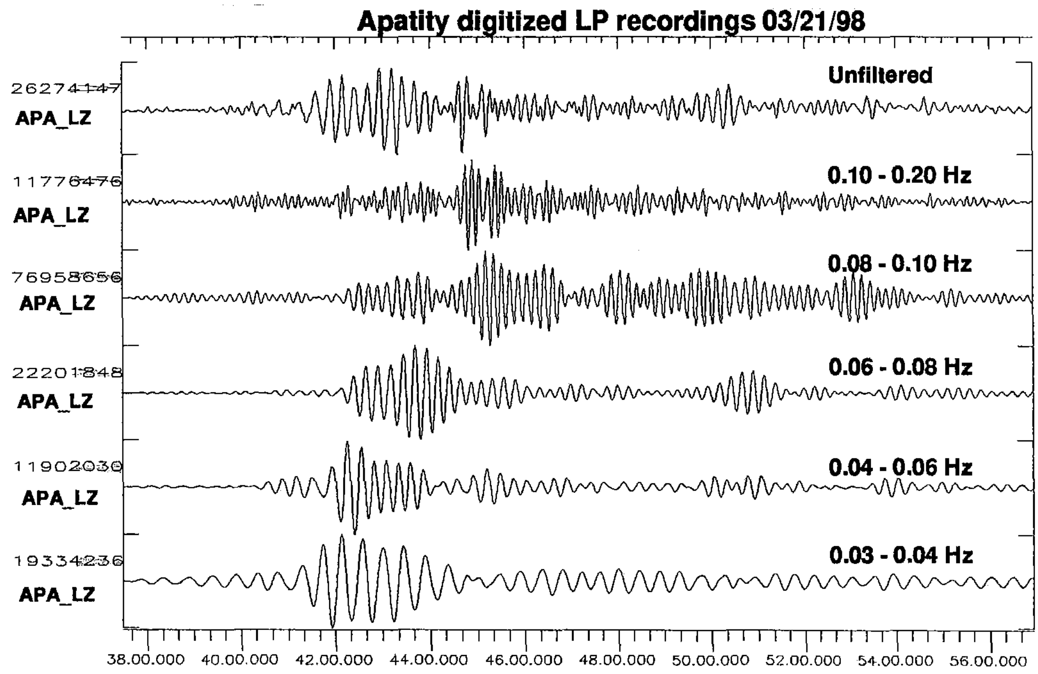

Fig. 7.4.4. Digitized recordings based on the APA LP vertical component co-located with the Guralp BB seismometer for the same event shown in Fig. 7.4.3. Note the close correspondence of the data shown in the two figures.

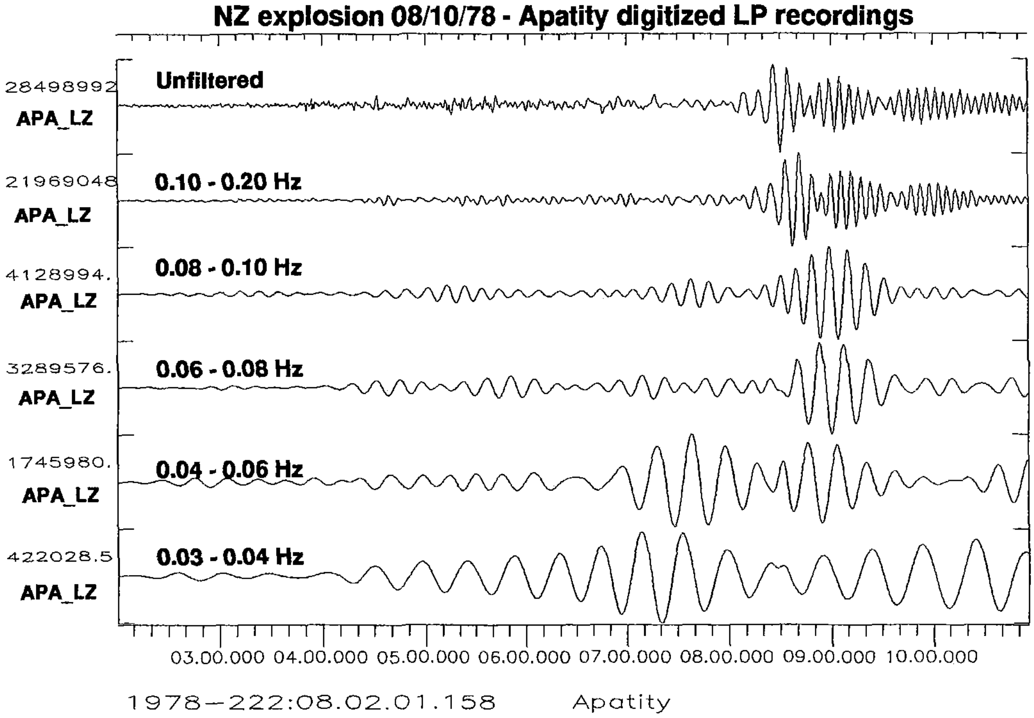

Fig. 7.4.5. Digitized recordings based on the APA LP vertical component seismometer for the nuclear explosion at Novaya Zemlya on 10 August 1978. Note the high SNR in all the filter bands.

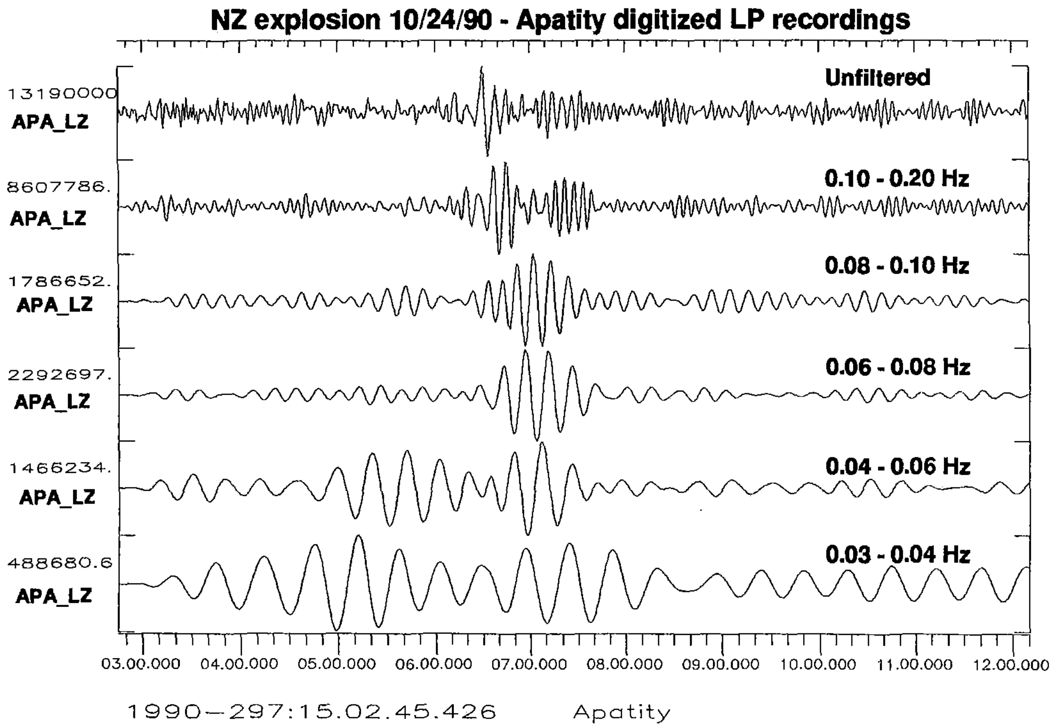

Fig. 7.4.6. Digitized recordings based on the APA LP vertical component seismometer for the nuclear explosion at Novaya Zemlya on 24 October 1990. Note the similarity to the explosion shown in Fig. 7.4.5.

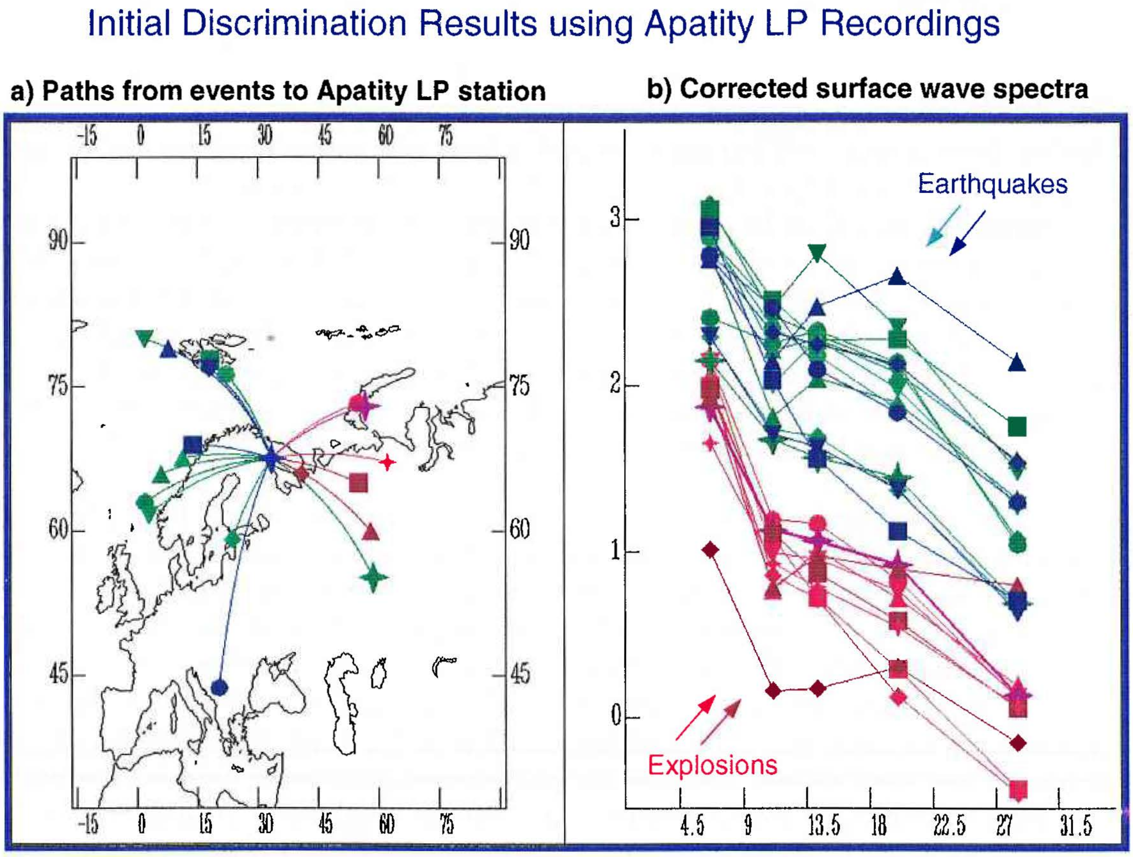

Fig. 7.4.7. Initial discrimination results using regional M_s:m_b for a data base of earthquakes and nuclear explosions with continental travel paths to the APA LP station. The left part shows the events and the travel paths to APA, whereas the right part shows surface wave spectral levels ranging from 5 to 30 second period. The spectral levels have been corrected for distance and body-wave magnitude as described in the text.