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Frode Ringdal (ed.)

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6.6 Study of seismic activity near the Barentsburg mine (Spitsbergen)

6.6.1 Introduction

The work described in this paper is a part of KRSC - NORSAR cooperative activity aimed at a detailed study of seismicity in the Spitsbergen region. Part of the motivation for the study is to improve the quality and availability of well-located reference events ("ground truth data") for location calibration purposes.

Spitsbergen and the adjacent areas are parts of a geologically complex region with moderate to high seismicity. The main seismicity in the area is associated with the North-Atlantic Ridge, and especially the Knipovich Ridge situated at a distance less than 400 km from the archipelago (Sundvor and Eldholm, 1979). In addition, some coal mines are located in the area of Spitsbergen, causing occasional induced seismicity as discussed in this paper.

6.6.2 Station Installation

During the last years an increased occurrence of rockbursts in the mines near Barentsburg, Spitsbergen has been observed. To obtain more information about these events, KRSC and NORSAR installed a digital 3-component seismic station, BRB, in the town of Barentsburg in December 2000. The station is located at a distance of only about 5 km from the mines.

Since the station was not originally designed for continuous data acquisition we developed our own acquisition software. The software package comprises a set of programs for data acquisition, preliminary processing and analysis.

The main acquisition program GBVMOD can store data on hard disk or external devices such as magneto-optical disks or Exabyte cassettes. If external GPS is connected to computer the program uses the GPS signal for timekeeping by sending synchronization commands to the station.

Optionally the program can make preliminary data processing during the acquisition. As a result detection lists and traces for short-term averaged amplitudes (STA time is 1 sec, frequency band 4-12 Hz) are produced. The traces and detection lists can be downloaded via modem.

The processing program STOREGBV makes copying of data from external devices converting them to a compressed format which is suitable for data analysis program VIEWGBV. During the copying it repeats the same processing as mentioned above, i.e., produces lists of detected phases and STA traces.

The program for data analysis VIEWGBV enables to look through the data (both wave forms and STA traces), convert them to ASCII and CSS formats, make filtering, location, etc.

STA traces appeared to be a convenient tool for quick data survey. Traces for many seismic events have very similar shapes. The typical shape is characterized by abrupt jump of amplitude and its smooth decrease. An example of STA trace (top) and wave forms (bottom) for an event in Spitsbergen is shown in Fig. 6.6.1.

For a quick detection of seismic events near Barentsburg station we have made a program which scans STA traces and for each place estimates a rating function. The function depends on amplitude and steepness of its change. Whenever the function appears greater than some threshold the corresponding piece of wave form is extracted and placed to a CSS file for the next analysis.

6.6.3 Event Location

In order to fine-tune the local velocity model, a small calibration explosion was conducted on 18 March 2001 at 11:03:00. The explosion coordinates were 78.067N, 14.36E; yield was 30 kg; the distance to BRB station was 3.12 km.

To calibrate the local travel times we estimated local velocities taking into account that Vp/Vs is about 1.73 and we obtained Vp = 4.54 km/s and Vs = 2.62 km/s. To develop a model for more distant stations we added a low velocity near-surface layer into the BARENTS model (Kremenetskaya et. al., 2001). We fitted the layer's depth using a well recorded (by SPI, KBS, BRB stations) event occurring on 21 December 2000 at 5.18:56. Initially, we located this event with BRB station only using the P and S velocities estimated above. Then we made the event locations using the three stations for several depths of the low velocity layer. The best result was obtained for depth 1.5 km, and this value was therefore adopted for the model (Table 6.6.1).

Table 6.6.1. Spitsbergen Regional Velocity Model.

Depth(km)	Vp(km/s)	Vs(km/s)
0-1.5	4.54	2.62
1.5-16	6.20	3.58
16-40	6.70	3.87
40-55	8.10	4.60
55-210	8.23	4.68
>210	Same as IASPEI 91	

To locate the recorded events with only the BRB station we applied the polarization analysis technique (Asming et al. 1998) for determination of an event azimuth and P and S phase identification. An example of applying the polarization analysis technique is shown in Figure 6.6.2. For estimating the distance to the event the time difference between the P and S phases was used.

6.6.4 Description of the Recorded Events

A total of 541 seismic events have been detected near Barentsburg from 01/12/2000 to 19/04/2001. The amplitudes of the largest events were close to 30000 GBV station units. The largest events were detected at the IMS station Arces (distance 1000 km) and had a local magnitude (ML) of about 3.0.

The events were mostly rockbursts or earthquakes in the mines documented by mining authorities. One of the largest occurred on 25/03/2001. After this event, work in the mines was discontinued for a full month for safety reasons.

Table 6.6.2. Events between 01.12.2000 and 25.03.2001, with amplitudes greater than 4000.

Date	Time (GMT)	Latitude	Longitude	Amplitude
09/12/00	2:24:18	78.077	14.376	9690
17/12/00	6:07:40	78.074	14.366	6460
28/12/00	4:40:14	78.069	14.399	8680
28/12/00	16:16:03	78.074	14.37	7307
07/01/01	0:24:46	78.074	14.365	8317
18/01/01	6:10:59	78.077	14.376	4288
25/01/01	1:35:14	78.068	14.393	5086
27/01/01	18:34:45	78.074	14.368	4116
27/01/01	20:39:05	78.068	14.384	6435
27/01/01	20:42:51	78.068	14.387	14640
28/01/01	11:01:46	78.078	14.359	25384
05/02/01	22:41:55	78.068	14.387	10025
22/02/01	4:03:03	78.074	14.368	4305
23/02/01	11:17:37	78.068	14.387	30183
28/02/01	19:24:33	78.076	14.382	4235
03/03/01	18:52:31	78.074	14.369	4256
04/03/01	1:56:10	78.069	14.39	8000
05/03/01	14:31:34	78.068	14.39	6419
18/03/01	0:46:39	78.074	14.364	4231
23/03/01	6:30:04	78.068	14.387	4459
23/03/01	13:02:12	78.07	14.401	6223
24/03/01	6:44:06	78.076	14.382	7797
25/03/01	17:41:44	78.069	14.387	22807

After the mines were closed down, the number of seismic events decreased significantly. Thus, only 12 events (maximal amplitude 500) occured there during the period from 26/03/2001 to 19/04/2001 (see Table 6.6.3).

Table 6.6.3. Event occurring from 26.03.2001 to 19.04.2001.

Date	Time	Latitude	Longitude	Ampli-tude
27/03/01	20:04	78.067	14.356	38
27/03/01	22:57	78.065	14.355	58
30/03/01	18:32	78.068	14.365	234
31/03/01	21:27	78.067	14.362	63
05/04/01	1:17	78.061	14.329	469
06/04/01	12:28	78.076	14.36	127
14/04/01	14:21	78.076	14.372	39
16/04/01	16:38	78.074	14.369	64
18/04/01	21:51	78.075	14.375	502
19/04/01	5:25	78.071	14.369	37
19/04/01	5:38	78.068	14.356	39
19/04/01	8:32	78.076	14.382	103

All of the events have been located manually as described above. The results are shown in Fig.6.6.3 and Fig. 6.6.4. Figure 6.6.3 shows that the locations of events with higher amplitudes are very concentrated, whereas the smaller events are more scattered in their locations. This suggests that the location errors strongly depends on events amplitudes because it is difficult to pick S onsets correctly for weaker events.

The events can be clearly separated into three groups : 1) events occurring in the South mine area, 2) in the North mine area, 3) outside the mines. Statistical parameters of the groups are shown in Table 6.6.4.

Table 6.6.4. Statistical parameters of groups of seismic events near Barentsburg.

Place	Number of events	Min. Amplitude	Max. Amplitude	Average	Standard Deviation
South	271	36	30183	848	2713
North	252	39	25384	782	2037
Outside	18	27	372	176	98

The parameters of events outside the mines are very different from those occurring in either the South or North mines. But the South and North events parameters seem to be quite similar. This leads us to the conclusion that the events outside the mines have natural reasons whereas the events in the mining areas are mostly technogenic. Thus, the Barentsburg area is unusual in the sense that strong technogenic seismicity is mixed with a significant natural seismic 'background'.

We also checked the hypothesis that the occurrences of events in South and North mines are interrelated. We calculated average numbers of events by tens of days for both South and North mines. The resulting curves are shown in Fig.6.6.5. The correlation between the curves (0.72) indicates the existence of statistical relationship.

This confirms the technogenic nature of these events. This could also mean that the occurrences of events in North and South mines are governed by the same factors.

6.6.5 Conclusions

1. A 3-component digital seismic station has been installed in the town of Barentsburg, Spitsbergen, and has proved to be useful in detecting and locating rockbursts and local earthquakes..
2. A local velocity model has been developed by using a calibration explosion in Barentsburg mine, and combining this information with the regional "Barents" model.
3. A large number of seismic events has been registered and located. Most of them are induced earthquakes or rockbursts. The frequency of events decreased significantly during a time period when the mining activity was discontinued.
4. The Barentsburg area appears to be unusual in the sense that strong technogenic seismicity is mixed with a significant natural seismic 'background'.
5. The large amount of the collected data could be useful for future study of induced seismicity. The data could also be useful for developing and verifying travel time correction for location calibration purposes.

E. Kremenetskaya
S. Baranov
Y. Filatov
V.E. Asming
F. Ringdal

References

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Kremenetskaya, E., V. E. Asming and F. Ringdal (2001): Seismic location calibration of the European Arctic. *Pure and Applied Geophysics*, 158 No. 1-2, 117-128.

Sundvor E. and O. Eldholm (1979): The western and northern margin off Svalbard. - *Tectonophysics*, 59, 239-250.

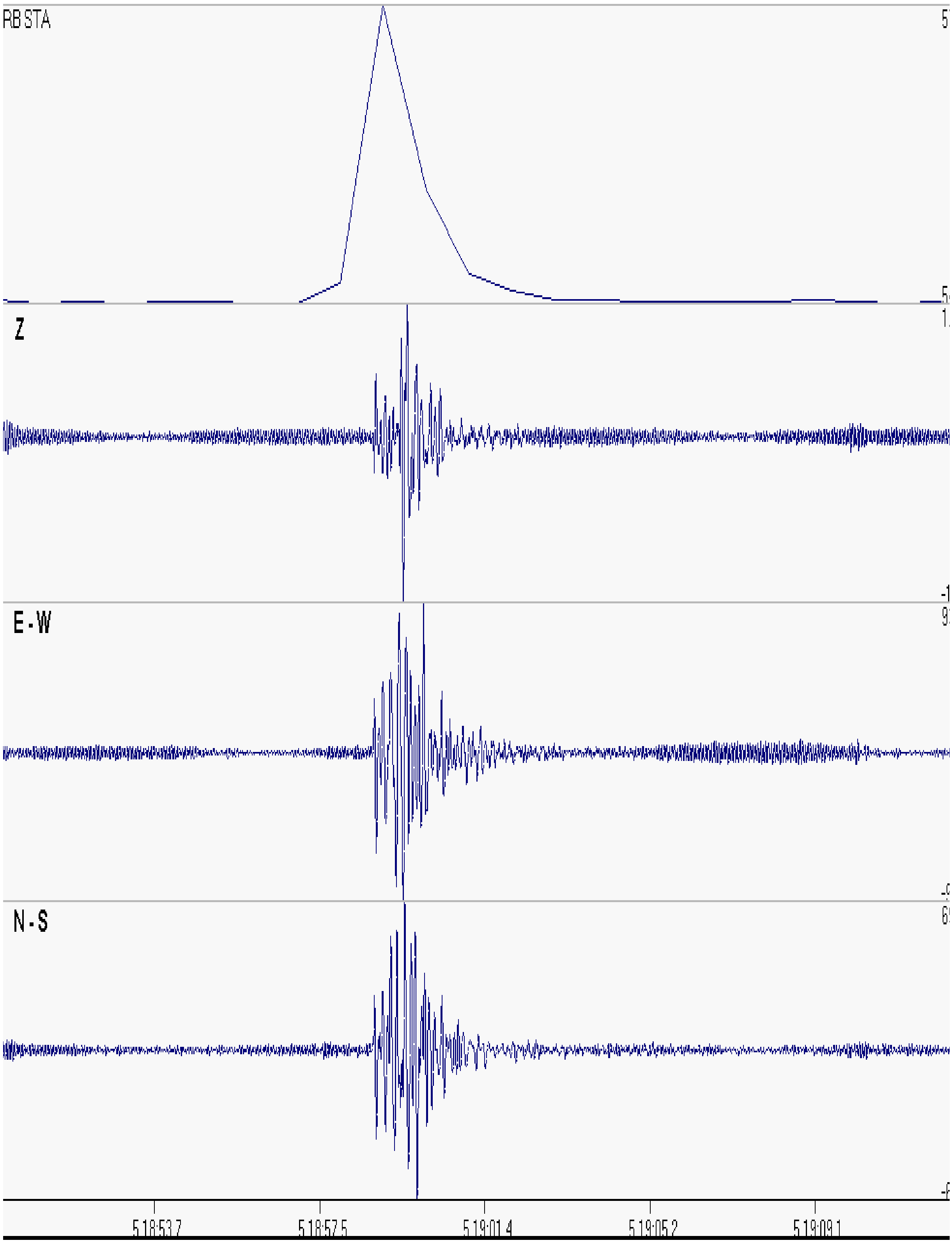

Fig. 6.6.1. An example of STA trace (top) and waveforms (bottom) for the event occurring on 21 December 2000 at 5.18:56 GMT in the Barentsburg mine.

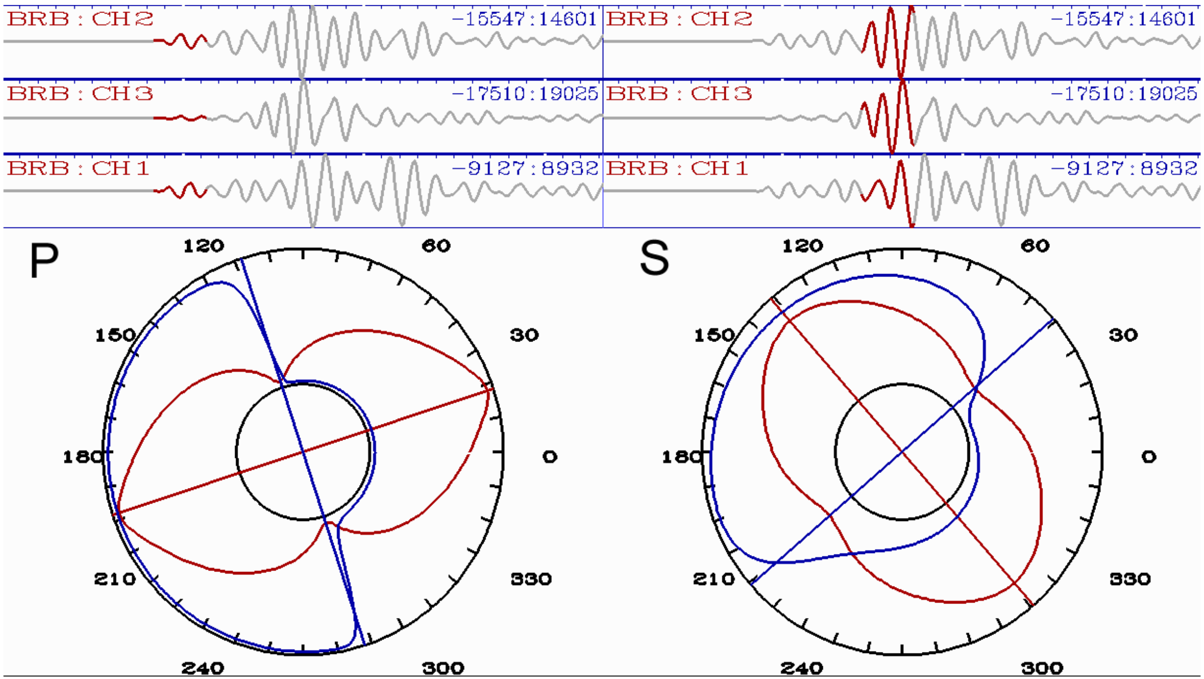

Fig.6.6.2. An example of applying the polarization analysis technique to BRB recordings.

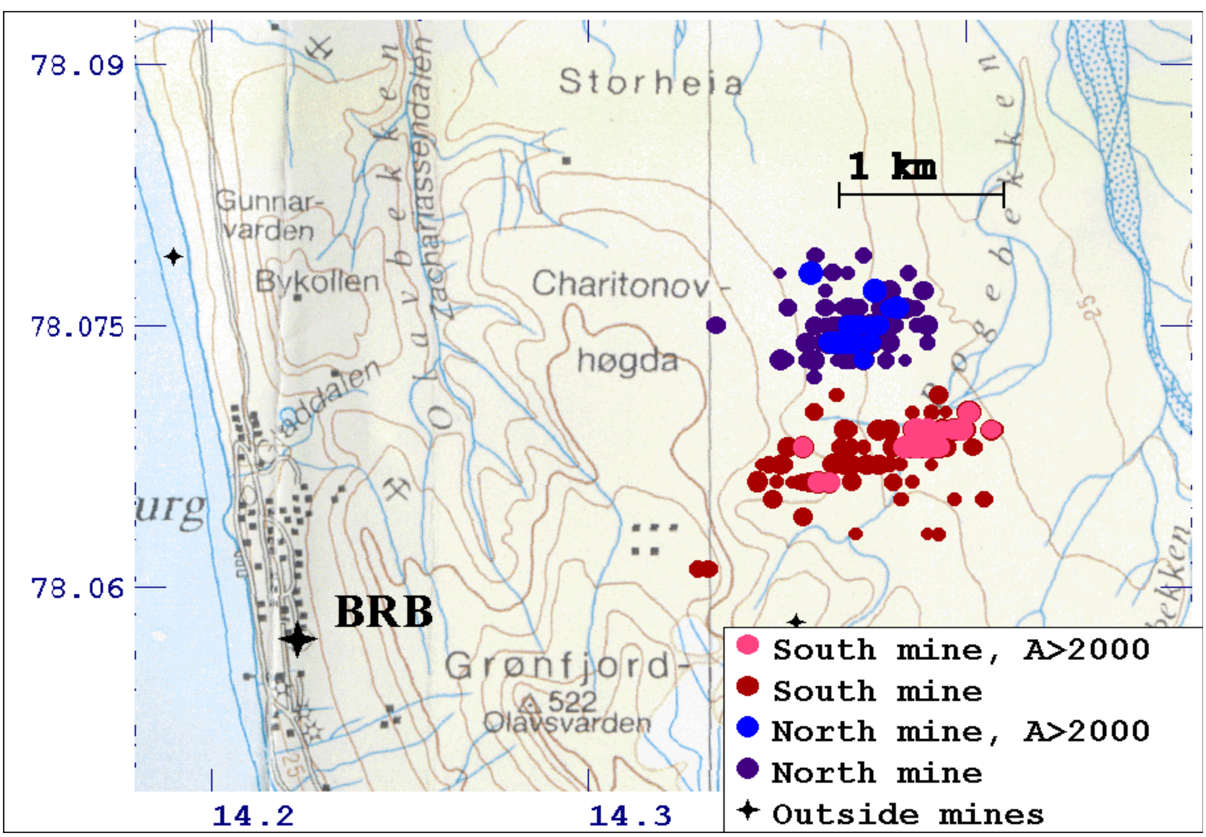

Fig.6.6.3. Seismic events occurring from 01.12.2000 to 26.03.2001.

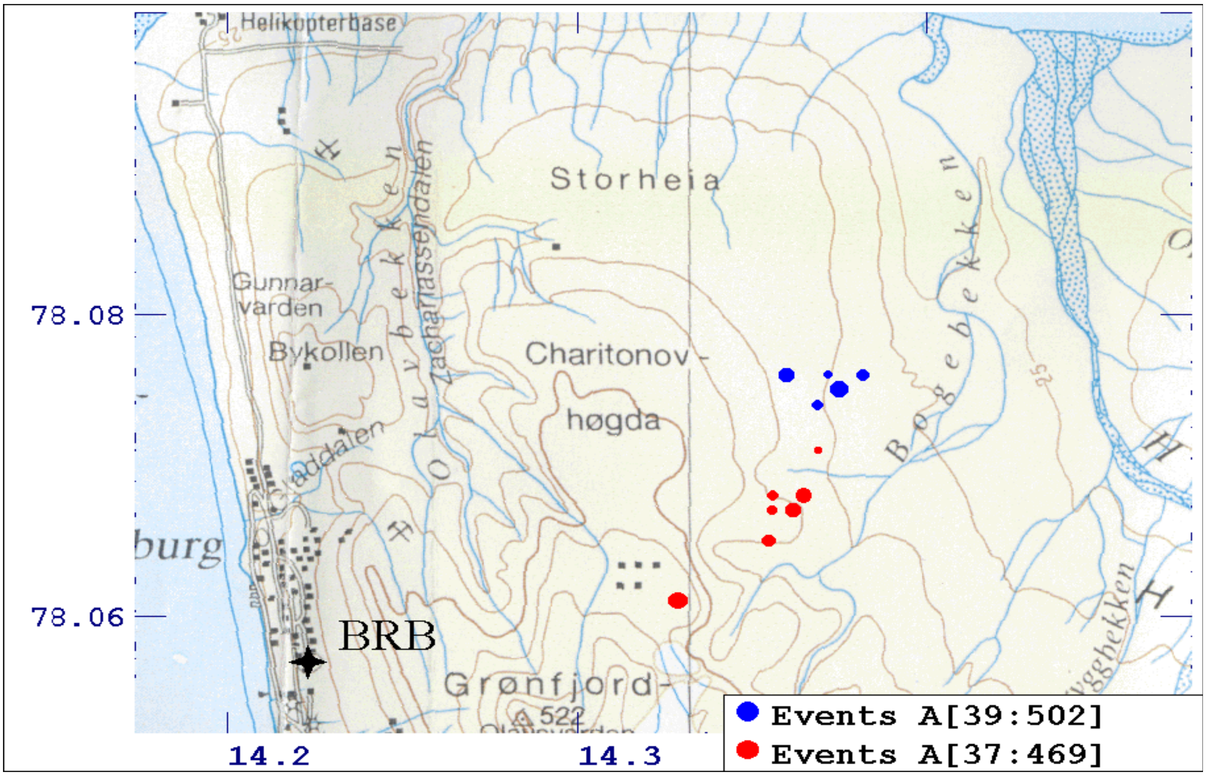

Fig 6.6.4. Seismic events occurring from 26.03.2001 to 19.04.2001.

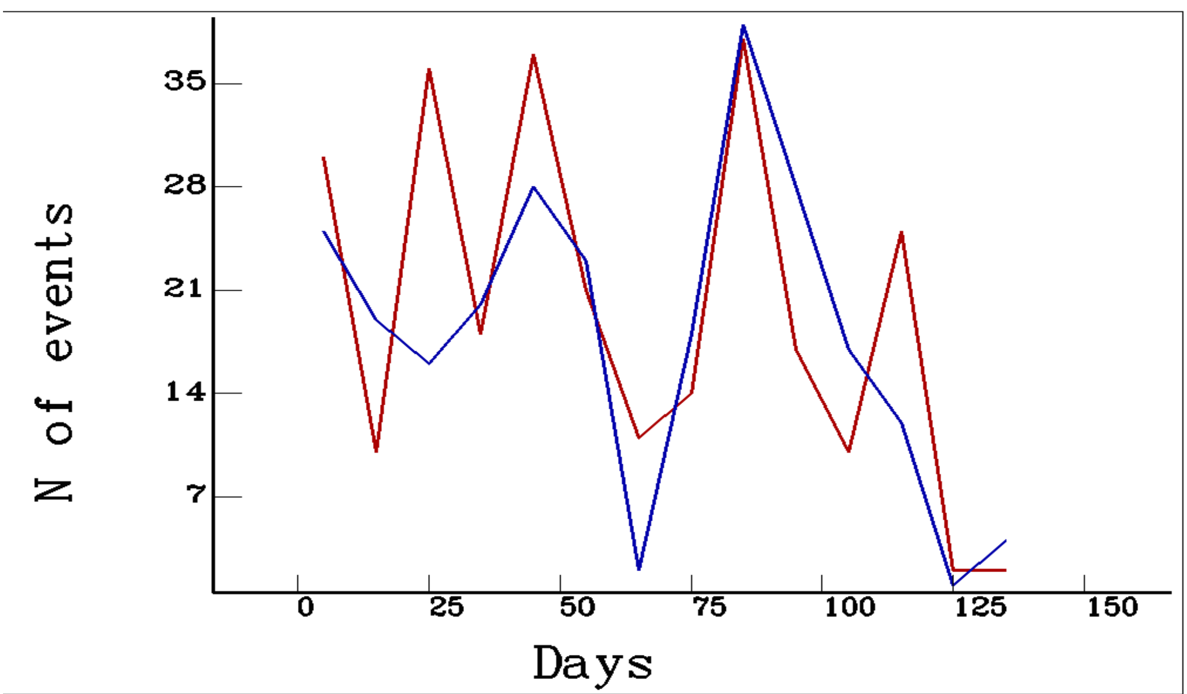

Fig. 6.6.5. Average numbers of events over ten-day windows for the southern (red line) and northern (blue line) mines.