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6.4 Ground Truth information from Khibiny mining explosions

Introduction

Through a cooperative agreement with NORSAR, Kola Regional Seismological Centre (KRSC) has for the past 10 years provided ground truth information for selected mining explosions in the Kola Peninsula. Since 2001, the project has been expanded in scope, and is currently carried out jointly with Lawrence Livermore National Laboratory, in a DOE-funded project. Under that contract, ground truth data for more than 1000 mining explosions from various mines in the Kola Peninsula (see Fig. 6.4.1) have been provided so far.

The mines in the Khibiny Massif are of particular interest in explosion source phenomenology studies. The Khibiny Massif forms a natural laboratory for examining the variations of mining explosion observations as a function of source type, since the mining explosions there are conducted in colocated underground and surface mines, with a variety of different shot geometries. In this paper we provide some examples of the type of ground truth collected, and illustrate some of the characteristic features observed from approximately colocated underground and surface explosions.

Khibiny mine explosions

Recently, seismic instrumentation has been installed inside the mines in the Khibiny Massif of the Kola Peninsula in order to provide origin times of the seismic events as well as to contribute to additional validation of the location accuracy (Ringdal et. al., 2003). These recordings supplement the ground truth information that is routinely obtained by KRSC for mining explosions in the Kola Peninsula. Our cooperative project with Lawrence Livermore National Laboratory includes the installation of additional seismometers along profiles in Norway, Finland and the Kola Peninsula, for recording over a period of at least one year. The station Ivalo (IVL) in Figure 6.4.1 is one of these temporary stations.

Some interesting results are emerging from comparing underground and surface explosions. For example, two explosions, one underground and one at the surface occurred in the neighbouring Rasvumchorr and Central mines in Khibiny on 16 November 2002. The underground explosion was a ripple-fired explosion of about 250 tons, whereas the open-pit explosion comprised four separate ripple-fired explosions, set off with about 1 second intervals, from south to north. The total charge of the four surface explosions was 430 tons.

The approximate layout of the explosions is shown in Figure 6.4.2. The surface and underground explosions were only 300 m apart, so that differences in path effects at the more distant stations can be ignored. Nevertheless, the recorded signals, e.g. at the temporary station in Ivalo, Finland at approximately 300 km distance, were remarkably different: The vertical component of these recordings is shown in Figure 6.4.3 in different filter bands. At lower frequencies (2-4 Hz), the underground explosion was stronger by a factor of 10 in amplitude, whereas above 10 Hz, the surface explosion had by far the stronger signals. A similar spectral difference between open-pit and underground explosions has been observed also in other cases.

The detailed geometry of the underground explosion is shown in Figure 6.4.4. The charges were distributed over a horizontal area approximately 100 m in diameter, and were detonated in 19 groups, with a delay of 23 ms between each group. The individual charge size of each group is given in Table 6.4.1, where the group numbering corresponds to the numbers shown on Figure 6.4.4.

Compact explosions

A particularly interesting type of underground explosions in the Khibiny Massif is the so-called compact explosions, which typically comprise 2-3 groups of charges of about 700 kg for each group, detonated with a small delay (typically 20 ms) between each group. These explosions are intended to remove small rock masses remaining after larger explosions have been conducted. They are detonated near the end of tunnels, and sometimes several such explosions are carried out in the same tunnel. The compact explosions are the closest approximation to single, well-tamped underground explosions that are currently available in the Khibiny area.

It is interesting to compare the characteristics of such small compact explosions to the features of the large ripple-fired surface and underground shots. Figures 6.4.5 - 6.4.7 shows ARCES Pn beams for, respectively, the 257 ton underground explosion on 16 November 2002, the 430 ton surface explosion of the same day, and a 1 ton compact explosion in the Rasvumchorr mine on 20 August 2003. Using the procedure described by Kvaerna (2004), we show on each figure the ARCES Pn beam, the corresponding semblance coefficient, and the Pn beam weighted with the semblance coefficient. The frequency band used for this analysis was 4 - 8 Hz.

We note that the large underground explosion and the small compact explosion show similar features in these plots, with a clear single P-onset. In contrast, the open-pit explosion shows evidence of multiple onsets over a time interval of 3-5 seconds, corresponding to the delays in the detonations of the four explosion groups. We add, however, that even the compact explosions show significant variability when considering a number of such explosions, as documented by Harris et. al. (2003).

Video recording

The Mining Institute of the Kola Science Centre have made a video recording of the explosions on 16 November 2002. This video has been made available to us, and Figure 6.4.8 presents snapshots of the explosions. Particularly noteworthy is the formation of a “fault” or large crack in the mountainside at the same time that the underground explosion was detonated. A close-up picture of this crack is shown in one of the snapshots. Also, the video provides timing information, enabling us to verify the time delays between the four groups of surface explosions.

Such video recordings may become available for additional mining explosions, and will provide important corroborating information to the ground truth data supplied by the mining authorities.

Conclusions

The type of ground truth data already assembled for Kola Peninsula mining explosions, in addition to future more detailed information of shot configurations, is expected to contribute toward improved understanding of the nature of seismic wave generation from such sources. In particular, the compact explosions are of interest. In the ground truth data base developed until now, we have assigned each compact explosion to one of the Khibiny mines (typical diameter of one mine is 1-2 km). We will in future projects try to obtain more precise relative locations of groups of such compact explosions, in order to study the variability of the waveform features both within groups of nearby explosions and between such groups in different tunnels.

We also plan in the future to investigate the possibilities to arrange for single, contained underground explosions in the same mines in which the compact explosions are conducted, so as to enable detailed analysis of the resulting differences in waveform characteristics between single, fully contained explosions and compact explosions.

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Harris, D. B., F. Ringdal, E. O. Kremenetskaya, S. Mykkeltveit, J. Schweitzer, T. F. Hauk, V. E. Asming, D. W. Rock and J. P. Lewis (2003). Ground-truth Collection for Mining Explosions in Northern Fennoscandia and Russia. "*Proceedings of the 25th Seismic Research Review - Nuclear Explosion Monitoring: Building the Knowledge Base*, Los Alamos National Laboratory, *LA-UR-03-6029*, Tucson, AZ, Sept. 23-25, 2003.

Ringdal, F., T. Kværna, E. O. Kremenetskaya, V. E. Asming, S. Mykkeltveit, S. J. Gibbons and J. Schweitzer (2003). Research in Regional Seismic Monitoring. "*Proceedings of the 25th Seismic Research Review - Nuclear Explosion Monitoring: Building the Knowledge Base*, Los Alamos National Laboratory, *LA-UR-03-6029*, Tucson, AZ, Sept. 23-25, 2003.

Table 6.4.1. Distribution of charges for the underground explosion in Rasvumchorr mine, Khibiny on 16 November 2002. A total of 19 groups of charges were fired, with a delay of 23 ms between each group. The geometry of the shot is shown in Figure 6.4.4.

Delay #	Charge (kg)	Delay #	Charge (kg)
0	21,934	10	17,746
1	161	11	14,063
2	17,707	12	17,553
3	856	13	15,259
4	14,890	14	19,690
5	1,592	15	19,228
6	14,611	16	21,449
7	10,812	17	10,737
8	16,072	18	8,011
9	11,119		

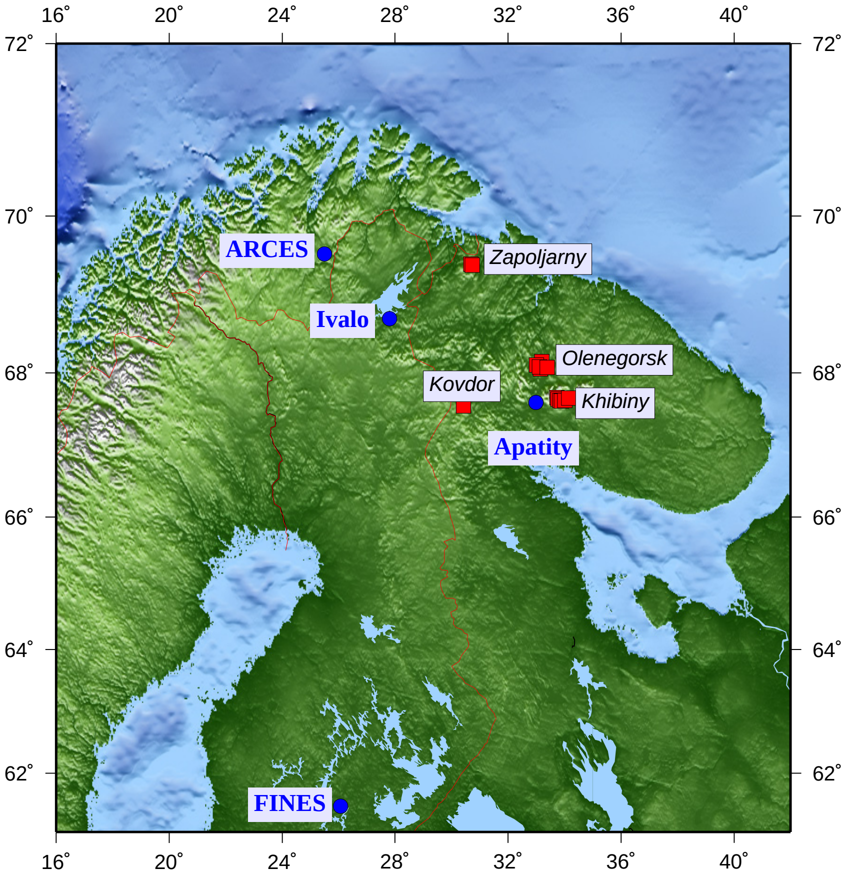

Figure 6.4.1. The map shows the main mining sites in the Kola Peninsula, marked as red squares. Some key seismic stations in this region are marked as filled (blue) circles.

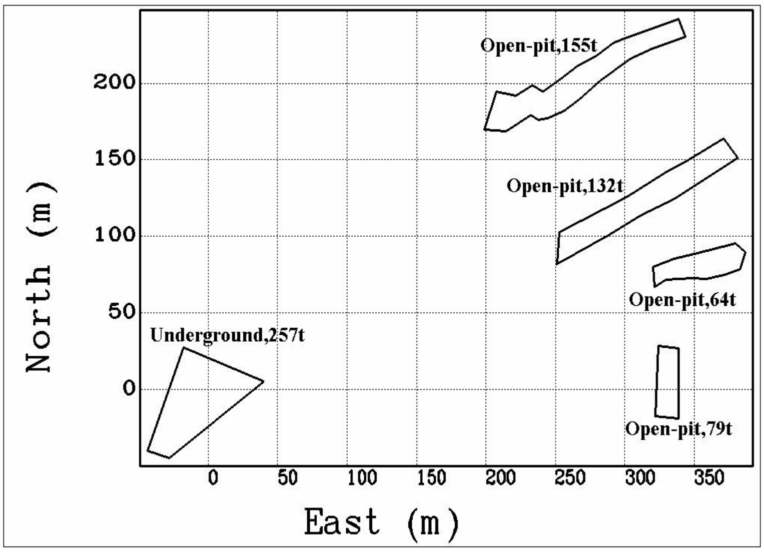

Figure 6.4.2. Schematic view of the shot configuration for the two explosions in Khibiny on 16 November 2002. Geographical coordinates of the point (0,0) are 67.6322N 33.8565E. See text for details.

Khibiny underground (1) and open-pit (2) explosions 16 Nov 2002

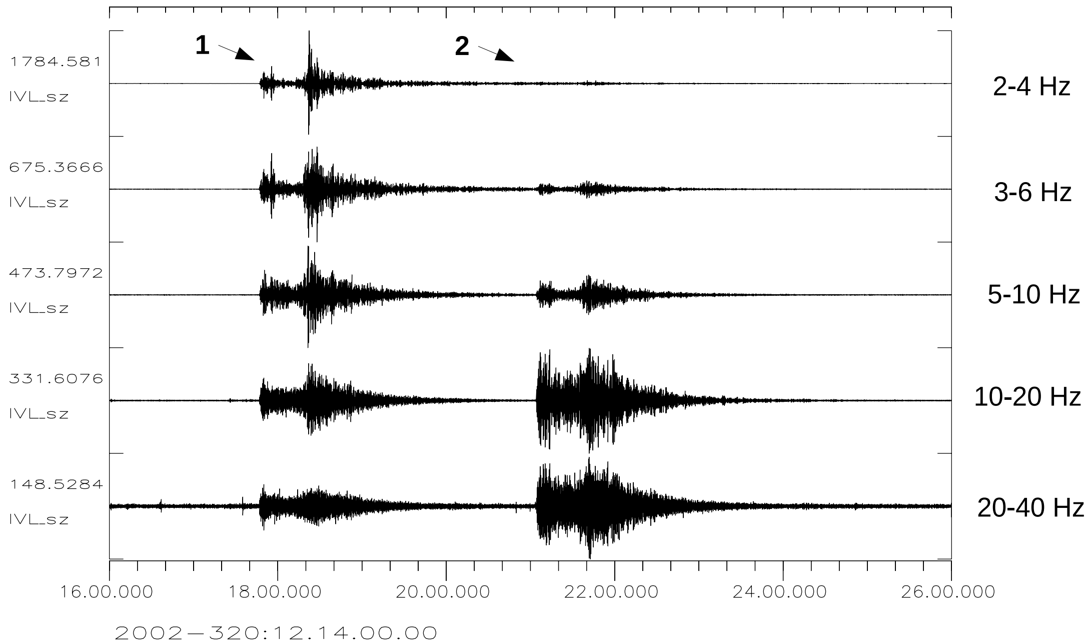

Figure 6.4.3. Recorded SPZ waveforms at station Ivalo (northern Finland) for the two explosions in Khibiny on 16 November 2002. The data have been filtered in five different frequency bands. Note the significant difference in relative size of the two events as a function of frequency.

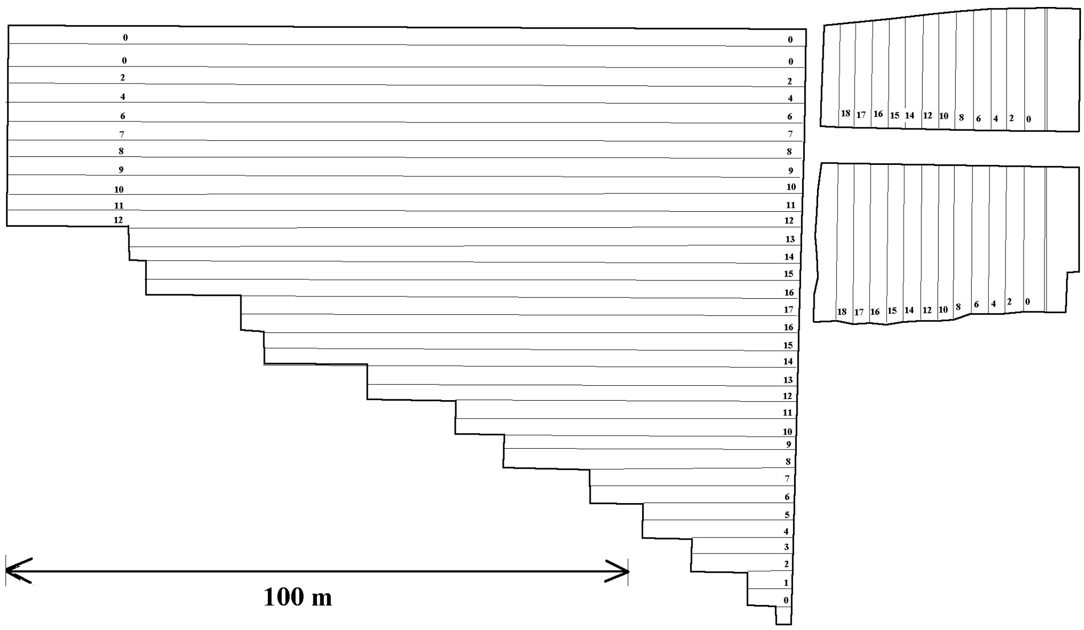

Fig. 6.4.4. Geometry of the underground mining explosion in Khibiny 16 November 2002. The charges were detonated in 19 groups (delay 23 ms between each group). The sequence is indicated by the numbers, with the charge sizes listed in Table 6.4.1. Note that the explosions begin at the outer edges (charges numbered 0), and continue towards the center.

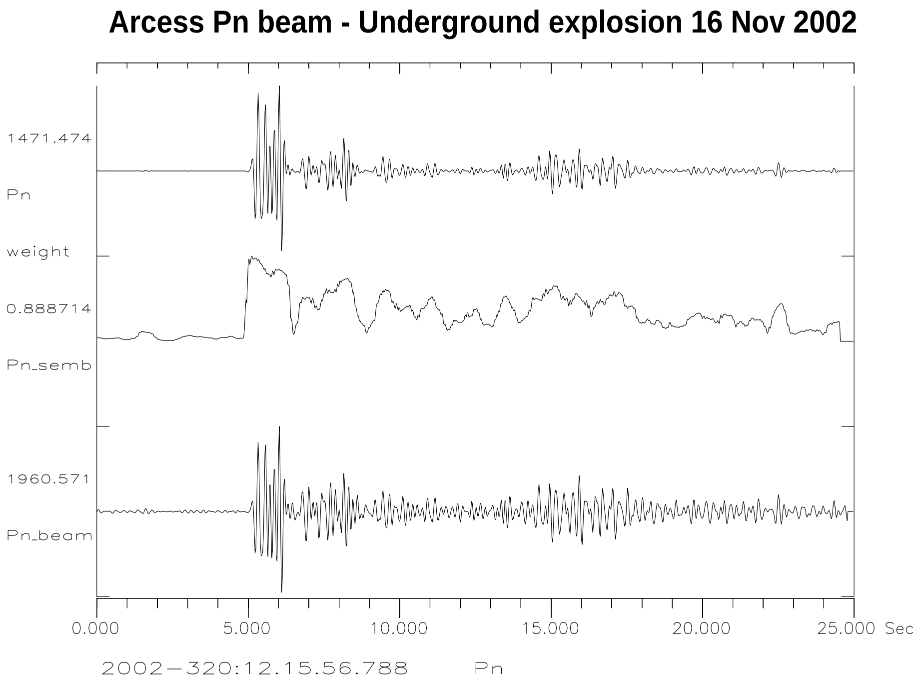

Fig. 6.4.5 ARCES Pn beam of the underground explosion on 16 Nov. 2002. See text for details.

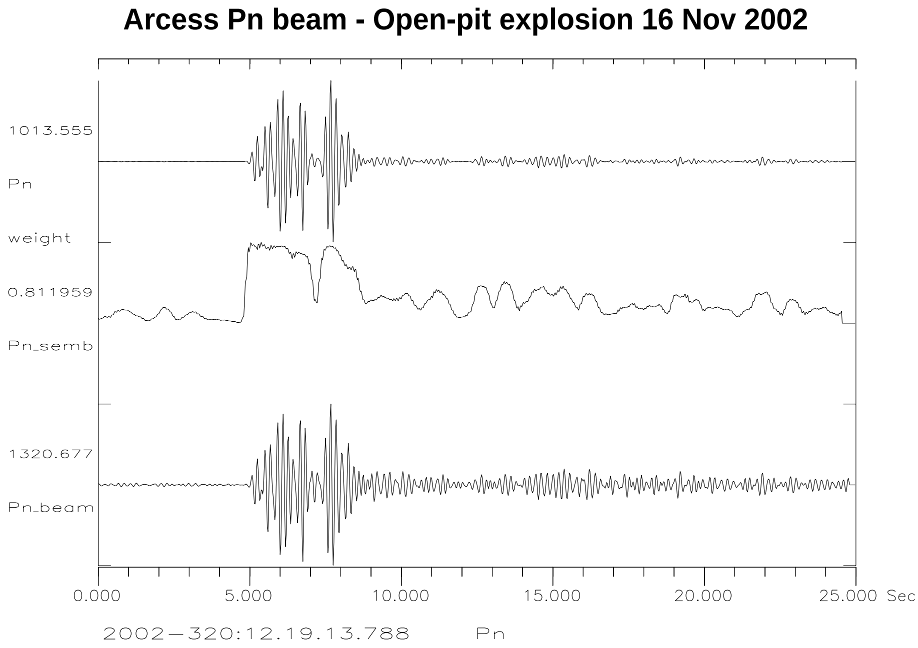

Fig. 6.4.6 ARCES Pn beam of open-pit explosion on 16 Nov. 2002. See text for details.

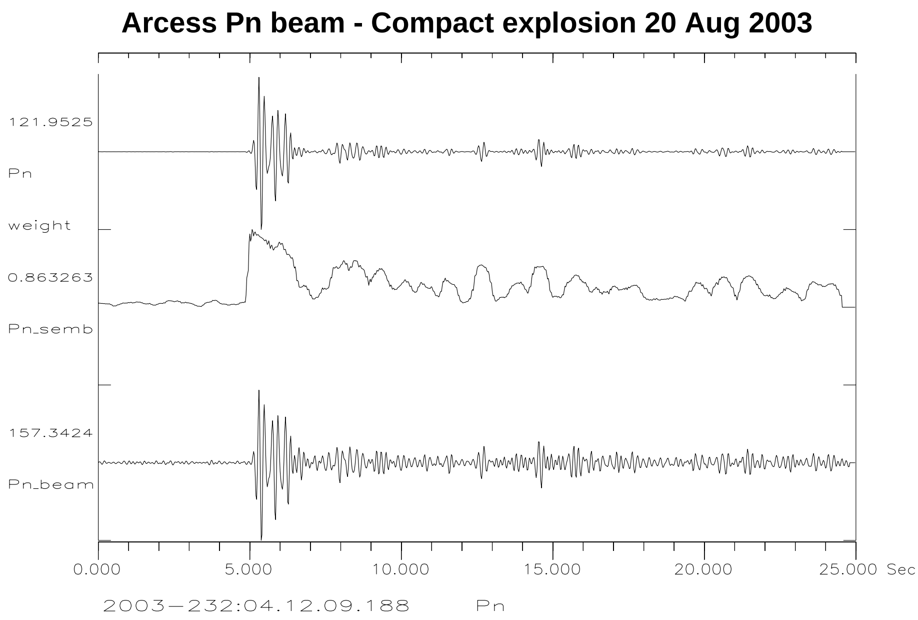

Fig. 6.4.7 ARCES Pn beam of compact explosion on 20 Aug. 2003. See text for details.

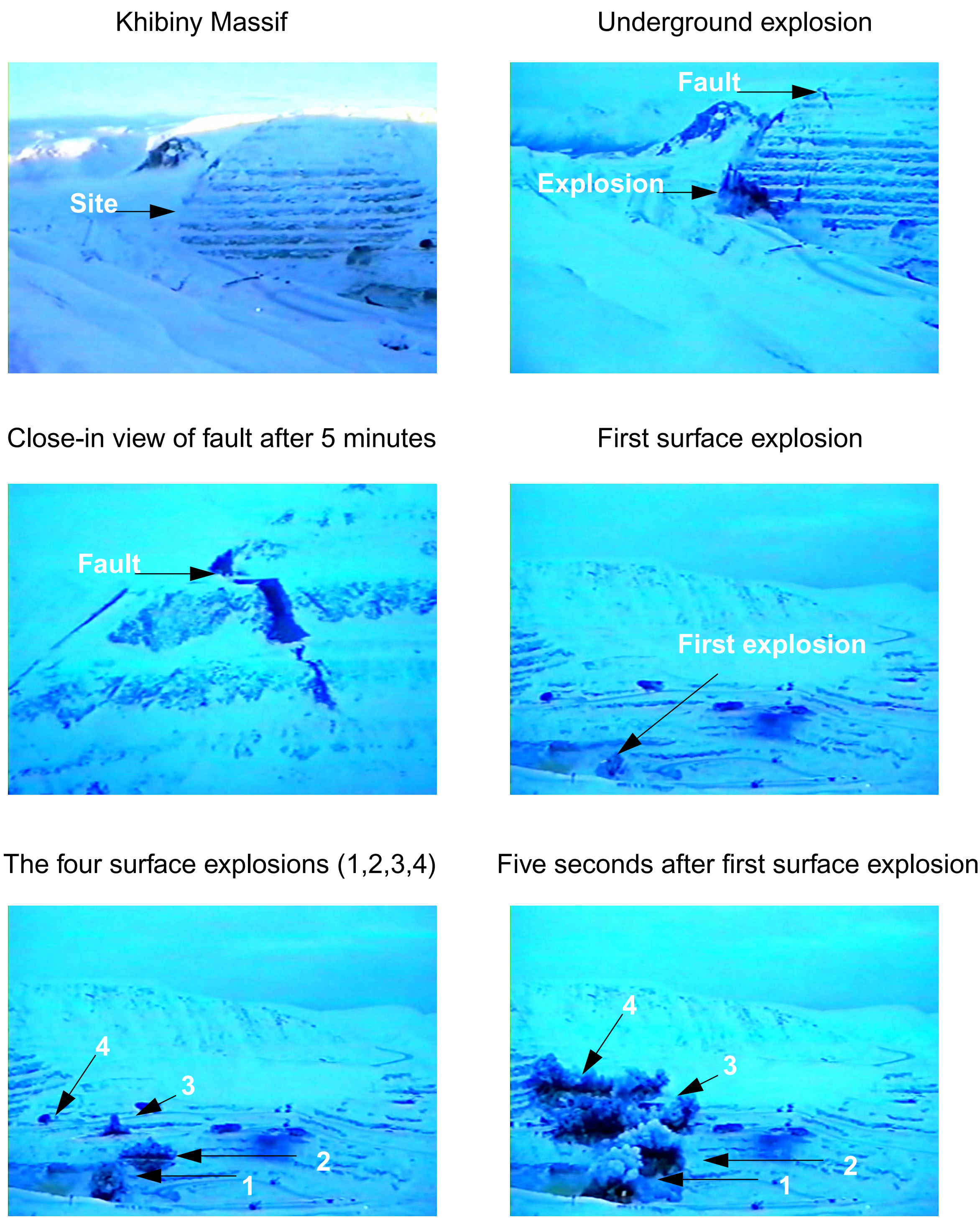

Fig. 6.4.8. Snapshots of video from the sequence of Khibiny explosions on 16 November 2002 Note in particular the large crack ("fault") opening up in the mountainside at the time of the first (underground) explosion.