Final Report
Contract No. F61708-94-C0016

# Study of Rockbursts in the Khibiny Massif

Elena O. Kremenetskaya
V.E. Asming

Submitted to
USAF European Office of Aerospace Research and Development

by
Kola Regional Seismological Centre

19990204 011

Apatity, Russia
August 1995

# REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188



| 1. AGENCY USE ONLY (Leave blank) | 2. REPORT DATE | 3. REPORT TYPE AND DATES COVERED |
|---|---|---|
| | August 1995 | Final Report |

4. TITLE AND SUBTITLE

Study of Rockburts in the Khibiny Massif

5. FUNDING NUMBERS

F6178904C0016

6. AUTHOR(S)

Dr. Elena Kremenetskaya

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Kola Regional Seismological Center
14 Fersman St
Apatity 184200
Russia

8. PERFORMING ORGANIZATION REPORT NUMBER

N/A

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

EOARD
PSC 802 BOX 14
FPO 09499-0200

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

SPC 94-4069

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

A

13. ABSTRACT (Maximum 200 words)

This report results from a contract tasking Kola Regional Seismological Center as follows: Compile a catalog of rockbursts and associated information from the Kibiny Massif area from data recorded over 20 years.

14. SUBJECT TERMS

EOARD

15. NUMBER OF PAGES

69

16. PRICE CODE

N/A

| 17. SECURITY CLASSIFICATION OF REPORT | 18. SECURITY CLASSIFICATION OF THIS PAGE | 19, SECURITY CLASSIFICATION OF ABSTRACT | 20. LIMITATION OF ABSTRACT |
|---|---|---|---|
| UNCLASSIFIED | UNCLASSIFIED | UNCLASSIFIED | UL |

# Contents

# Abstract

In the last several years there has been a great increase of seismicity in the Khibiny Massif. This began to manifest itself after large volumes of rocks had been extracted from a high-stress environment in connection with the mining activity for the Khibiny apatite deposits. In particular, the increase in the seismicity has been significant after 1980. During this same time period the annual ore excavation at the Khibiny mines has increased from 19.1 to 46.5 million tons. A geometrical correspondence between the configuration of the mines and the coordinates of Khibiny earthquake epicenters has been detected.

The largest earthquake in Khibiny took place on 16 April 1989 ($M_L = 4.1$). This event was felt with intensity VIII in the upper levels of the Kirovsk mine and caused considerable destruction. The maximum measured displacement was 15-20 cm and it occurred along a fault striking at 125-135$^o$ and dipping at 30-35$^o$ NE. This displacement was traced along the surface for 1200 m and observed to a depth of at least 220 m. The earthquake was felt with intensity V-VI in the Kirovsk area, and it was followed by several hundred aftershocks during the next two months. The earthquake on 16 April 1989 occurred simultaneously with a 240 ton explosion in one of the Kirovsk mines. It thus appears that the explosion triggered the earthquake.

A detailed study of the Khibiny seismicity has demonstrated that such triggering effects often occur at underground mines, when the depth of the mining has exceeded 100 meters. Currently about 30% of all underground explosions have been found to trigger significant rockbursts or earthquakes. By "significant", we mean that the events are detectable by seismographs at a distance of at least 50 km. The triggered rockbursts usually occur within a few tens of seconds after the underground explosion. Our studies have not revealed any similar triggering effect for open-pit mining explosions in Khibiny.

We have reviewed the mining practice in the Khibiny Massif, and compiled detailed statistics on explosion times and explosive charge sizes. We have demonstrated a correlation between the yields of underground explosions and their magnitudes. The overall correlation (using all underground explosions) is about 0.72, but it is as high as 0.89 when considering explosions from Mine 3 only. This mine has deeper underground part and well recorded underground explosions. When considering open-pit explosions, we note that other investigators have been unable to find any correspondence between the (aggregate) yields and the seismic magnitudes. We attribute this difference to the different shot practice for open-pit and underground explosions.

Some of the increased seismicity in the Khibiny Massif is possibly connected with the open-pit mining, and could be associated with the removal of large volumes of rock, causing a change in the stress regime. In particular, this manifests itself in a gradual displacement of lines of equal seismic energy release in the direction of Mine 4. Our results thus support the conclusions in previous studies that the rock extraction from a high-stress environment can cause increase in overall seismicity.

# 1.0 Introduction

This report is the final report for Contract No. F61708-94-C0016. The study has comprised the following tasks:

- *Conduct a study of rockbursts and mining explosions in the Khibiny Massif*

The basis for conducting this task is the seismological network in the Apatity region, comprising in particular the Apatity SP array and the broad-band 3-component station at the Kola Science Centre. Data from these stations are recorded continuously at the KRSC data center in Apatity. Detected events from the Khibiny Massif have been located and analyzed, making use also of data provided by the network operated by NORSAR in Fennoscandia. This cooperation with NORSAR, which is essential to this work, is made possible through the continued operation of the direct satellite link connecting the two data centers.

- *Compile a catalog of past seismic events in the area*

A catalog of all located earthquakes and rockbursts in the Khibiny Massif from 1948 through 1994 has been compiled. The catalog is annexed to this report (Appendix B). Naturally, the most accurate locations and the most complete coverage is for the most recent years, but the increased number of events over the years also reflects increased mining-induced seismicity as discussed by Kremenetskaya and Trjapitsin (1995). It has in general not been possible to separate tectonic earthquakes and rockbursts in this list. However, in special cases, such separation can be made. For example, the largest event in the list (16 April 1989, $M_L = 4,1$) can be classified as tectonic in origin, since fault slippage could be traced after the event occurred.

- *Study space-time statistics of rockbursts relative to mining explosions*

Data collection for this task has comprised both an earthquake catalog and a list of underground and open-pit explosions in the Khibiny Massif. The time-correlation study has focused on the distribution of events by time of day and day of week, and a correlation has been found between underground explosions and subsequent rockbursts, which often occur with a delay of only a few seconds relative to the explosions. Details are given in Chapter 5 of the report. Generally, such triggered rockbursts occur very close to the mine in which the explosion took place.

- *Study magnitude-energy statistics of rockbursts in the Khibiny Massif*

The basis for this study has been the catalog in Appendix B. This study has been carried out using magnitudes ($M_L$) by KRSC which are generally consistent with magnitudes computed at the NORSAR Data Center.

- *Compile vital statistics for selected large mining explosions*

Contact has been established with the mining companies for the purpose of collecting relevant statistics on the details of selected large explosions. This was a considerable effort, which required numerous visits and detailed checking of previous information. This also involved field visits by KRSC personnel to check the coordinates of the mines and selected explosions. Chapter 4 summarizes the relevant information on mining practice in the Khibiny Massif, whereas a detailed list of underground explosions during 1991-94 and their yields is presented in Appendix C.

The report also briefly summarizes the cooperative research between KRSC and NORSAR, Norway. Since 1991, NORSAR and the Kola Science Centre (KSC) have had a cooperative agreement on geophysical research and development. This led to the establishment in Apatity of an advanced observatory and data center for integrated geophysical monitoring. A dedicated 64 Kbps satellite link was established between Kjeller and Apatity to exchange data on seismic and acoustic measurements. This link currently enables users at the Kola Regional Seismological Centre (KRSC) to have wideband access to Internet through NORSAR. The exchange and information made possible by this cooperation has been essential in the research described in this report.

# 2.0 The Kola Regional Seismological Network

## 2.1 The Station Network

The regional seismic network of the Kola Science Centre began to be established in 1982. By 1990, 7 seismic stations were used to monitor the seismic activity of the Barents Sea and the NW part of Russia. The stations are shown on Figure 2.1 and listed in Table 1. All stations are equipped with short-period seismometers with photo sensitive analog recording, and paper speed 60 mm/min. A three-component digitally recording station was installed in Apatity in June 1990. For better location of seismic events in the Barents Sea platform, data from the seismic station KHE in Franz Josef Land (80.37°N, 58.03°E) are used, even though this station is not part of the network.

**TABLE 1. List of seismic stations operated by the Kola Science Centre**

| Name | Latitude | Longitude |
|---|---|---|
| APA | 67.568N | 33.388E |
| AMD | 69.742N | 61.655E |
| BRB | 78.073N | 14.240E |
| PLZ | 67.400N | 32.533E |
| PLQ | 66.410N | 32.750E |
| PLG | 62.320N | 36.930E |
| KEM | 64.956N | 34.635E |
| APO (Array) | 67.603N | 32.994E |

## 2.2 Cooperation with NORSAR

In 1991, a cooperative agreement was established between the seismological observatory NORSAR at Kjeller, Norway, and the Kola Science Centre (KSC) in Apatity, Russia. The initial agreement focused upon scientific cooperation in seismology between NORSAR and the Kola Regional Seismological Centre (KRSC), which is a department of the Kola Science Centre, but opened up for cooperation in other areas of geophysics as well.

The cooperative agreement related to the following specific projects:

- Establishment of an advanced seismic observatory of the array type near Apatity
- Establishment of a data center with modern computer facilities at KRSC
- Establishment of satellite communication between Kjeller and Apatity
- Cooperative research and development in areas of mutual interest.

The development of the seismic array, the computer facilities and the satellite communication link were sponsored by the United States Advanced Research Projects Agency (ARPA), which continued to sponsor the project until 1994.

## 2.3 System description

In late September 1992, the seismic array was installed approximately 17 km to the west of KRSC in Apatity, at the location indicated in Fig. 2.2. The seismometers are placed on two concentric rings plus one in the center, and the aperture is approximately 1 km. Seismic data registered at the array site are digitized on-site and transmitted via three radio channels to Apatity, where an array controller of type NORAC receives, time-tags and stores the data. Timing is provided by a GPS receiver.

Fig. 2.3 shows the current configuration of the data acquisition and analysis system at the KRSC. The figure shows the local Ethernet established, the NORAC array controller that receives data from the digitizers, three SUN Sparcstations (kan, imandra and umb) and a SUN X-terminal, and the Cisco router that provides the gateway connection to NORSAR via the dedicated satellite link. Also shown schematically is the multiplexing equipment used for a phone/fax connection via the same satellite channel. IDU is the satellite indoor unit containing the modem and other communications equipment. The system described in Fig. 2.2 allows the staff at the KRSC to perform on-line processing as well as interactive analysis of the data recorded at Apatity. Using the satellite link, NORSAR and KRSC can retrieve directly data from each other's systems, and use them in their analysis.

The overall picture related to the Apatity developments is given in Fig. 2.4. It shows in particular the satellite link, which is of type NORSAT B, and has a capacity of 64 Kbps. This link is available continuously, 24 hours a day.

## 2.4 Research cooperation

The seismological research has focused upon the monitoring of regional seismicity in the Barents area, especially in the Khibiny Massif induced by the extensive mining and extraction of ore. General seismicity studies and studies related to the earthquake risk on the Barents shelf in connection with installation of oil platforms and pipelines have also been carried out. From NORSAR's viewpoint, it has in addition been of interest to use the Apatity array data in conjunction with NORSAR's own data for the purpose of research in monitoring underground nuclear explosions. This research is important for the development of a global monitoring system to help verify a nuclear test-ban treaty, which is now being negotiated in Geneva.

A new dimension was added to the research cooperation in 1994, when KRSC installed infrasound sensors in the Apatity array. These data were subsequently integrated into the existing data acquisition system at KRSC. Three liquid microbarographs were installed at the Apatity seismic array site at the inner ring of seismometers. Microbarophs or geophones are widely used to provide an additional portion of information to be utilized in detecting the weak air explosions and in a mid-atmosphere investigation. The liquid microbarographs allow registering of an infrasound signal in the interesting frequency range of 1-0.01 Hz and are simple to operate.

## 2.5 Plans for further developments

The future developments of the seismological network in NW Russia will be closely integrated with the developments in the Nordic countries, in particular by continued cooperation between NORSAR and KRSC. In addition, KRSC plans to establish new stations at selected locations in Karelia and the Urals. The IRIS station in Lovozero (just north of Khibiny) will be integrated into the processing at the Apatity data center, with a direct radio link enabling these data to be recorded on-line. The Lovozero station will be particularly valuable for improving the location of Khibiny events and studying their source mechanisms, since it is supplements the other stations in the network by filling a gap in the azimuthal coverage. This will be a main topic in our further studies of Khibiny rockbursts.

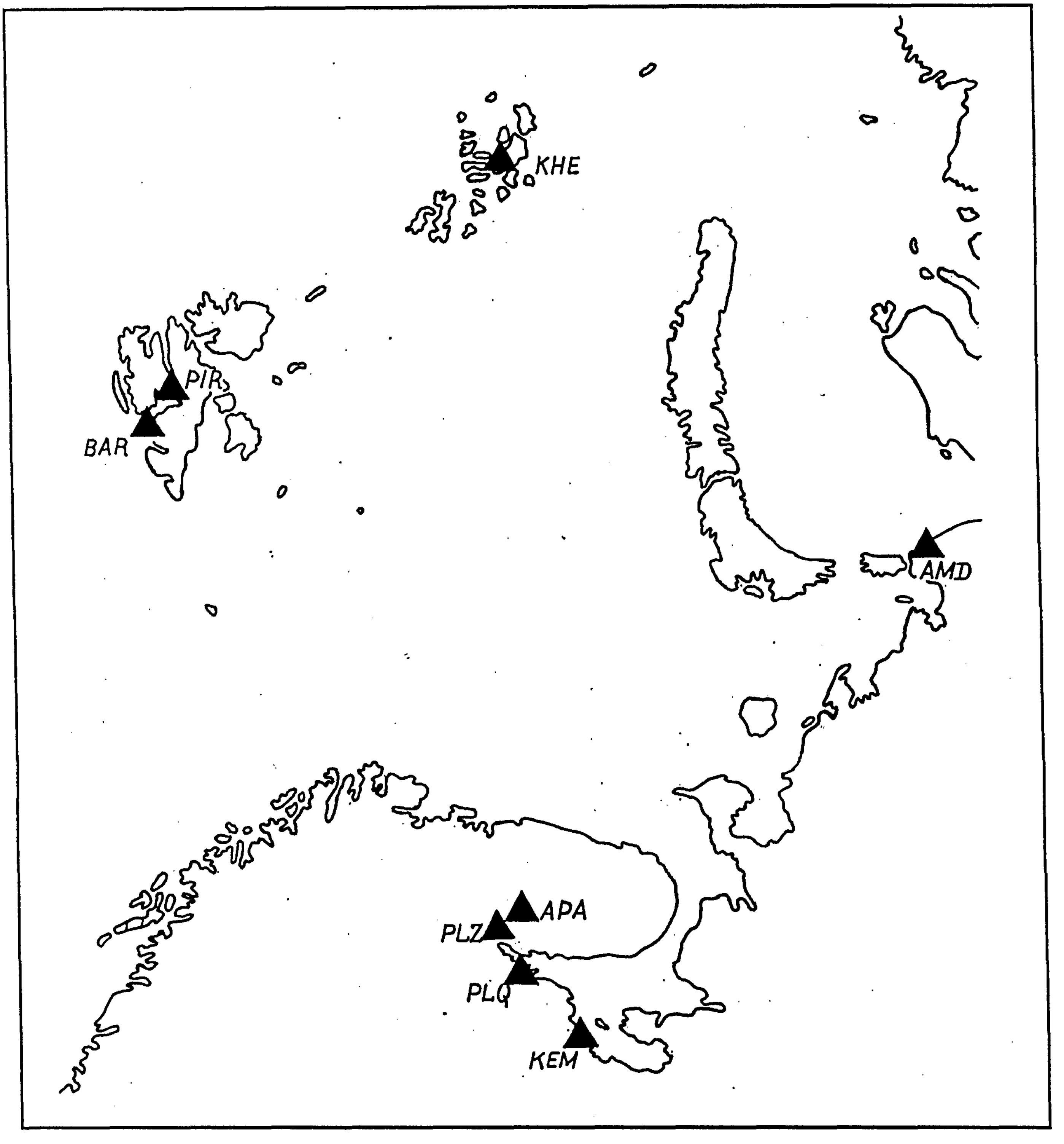



**FIGURE 2.1. Map showing the location of the regional seismic network operated by Kola Regional Seismological Centre.**

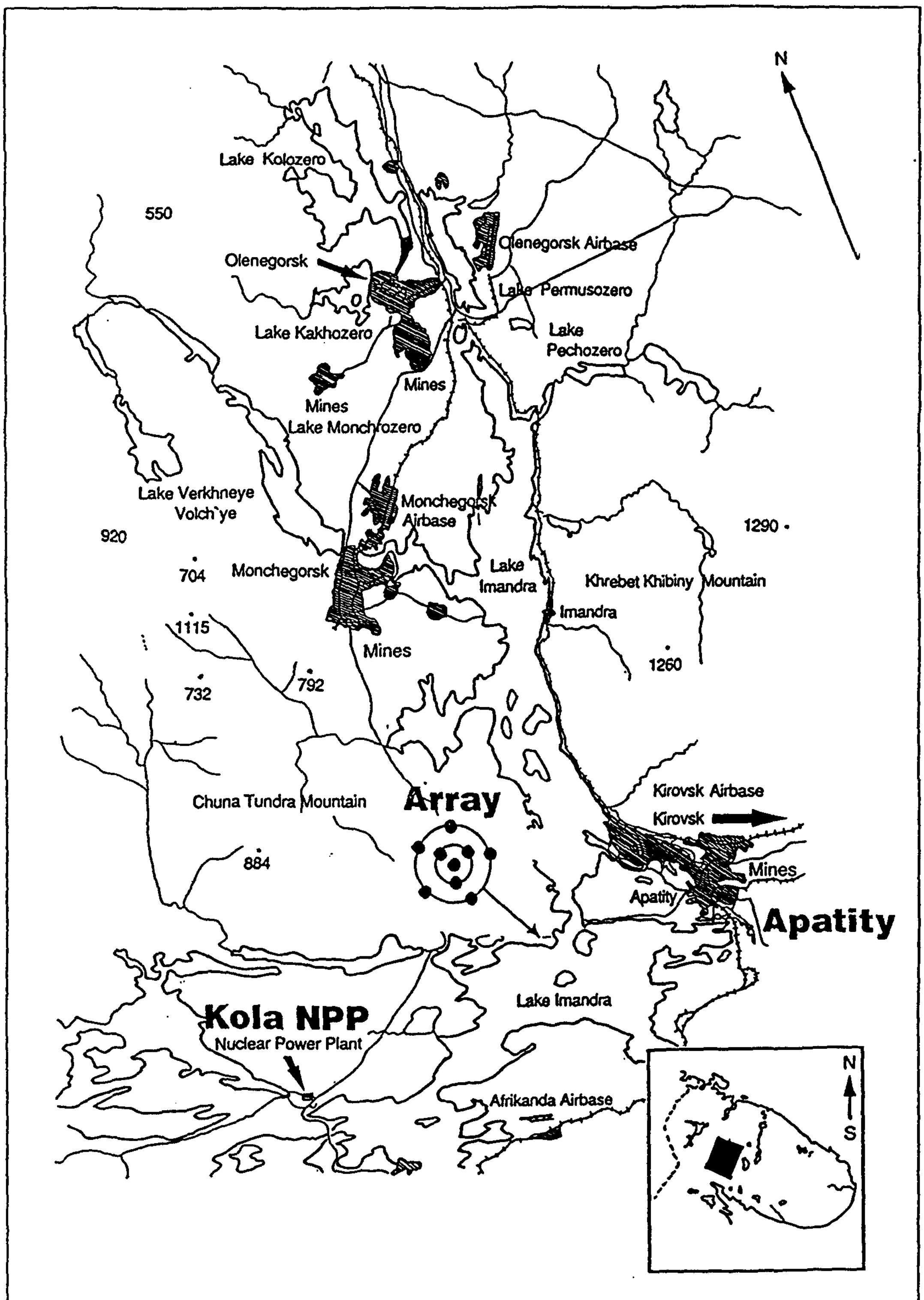



FIGURE 2.2. The regional seismic array in Apatity is situated close to the Kola Nuclear Power Plant. Data are transmitted continuously to the KRSC data center in Apatity.

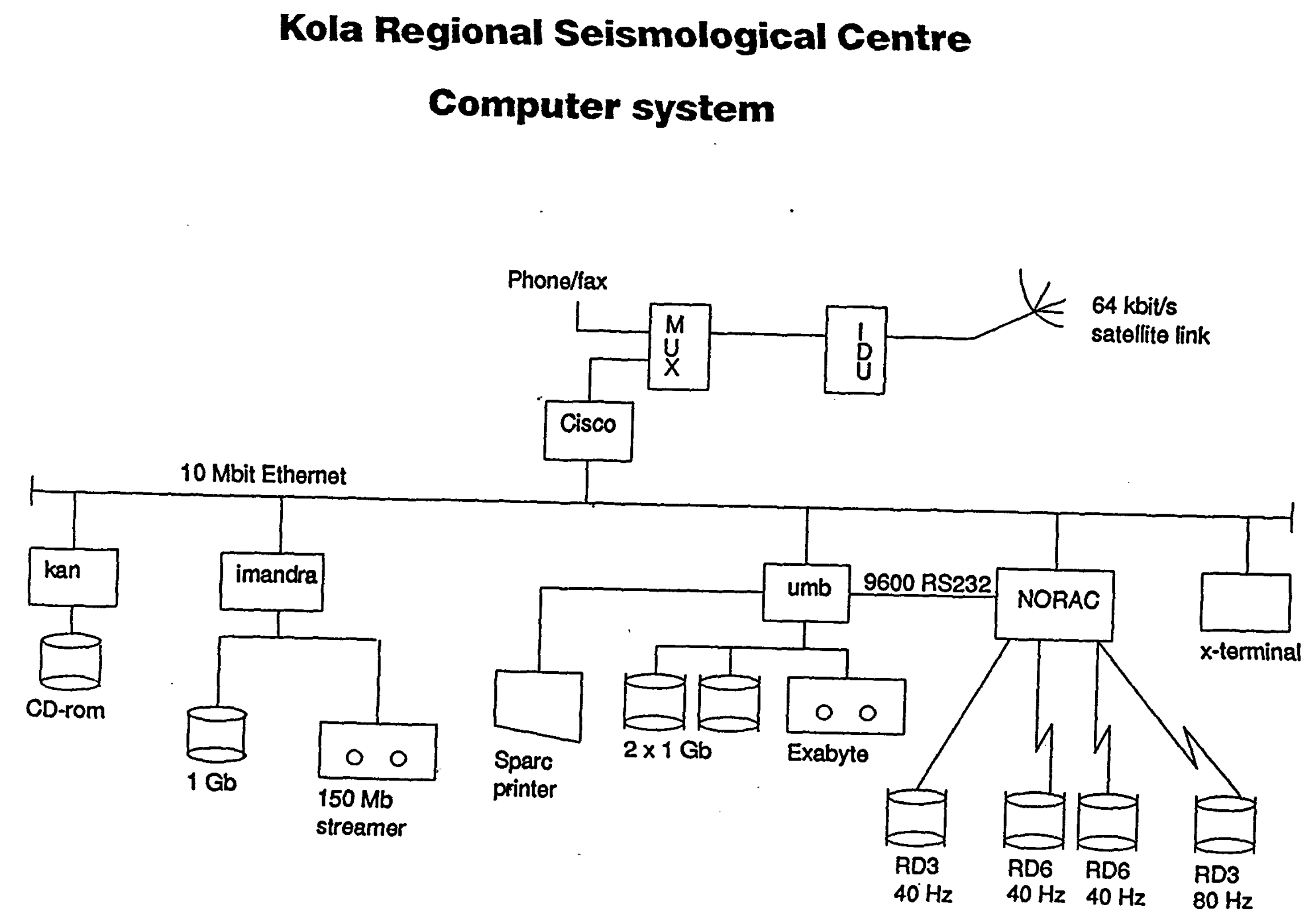



FIGURE 2.3. The KRSC Data Centre in Apatity comprises three Unix workstations, Ethernet and various peripheral equipment. The Centre interfaces the Apatity array as well as a satellite link to NORSAR, Norway.

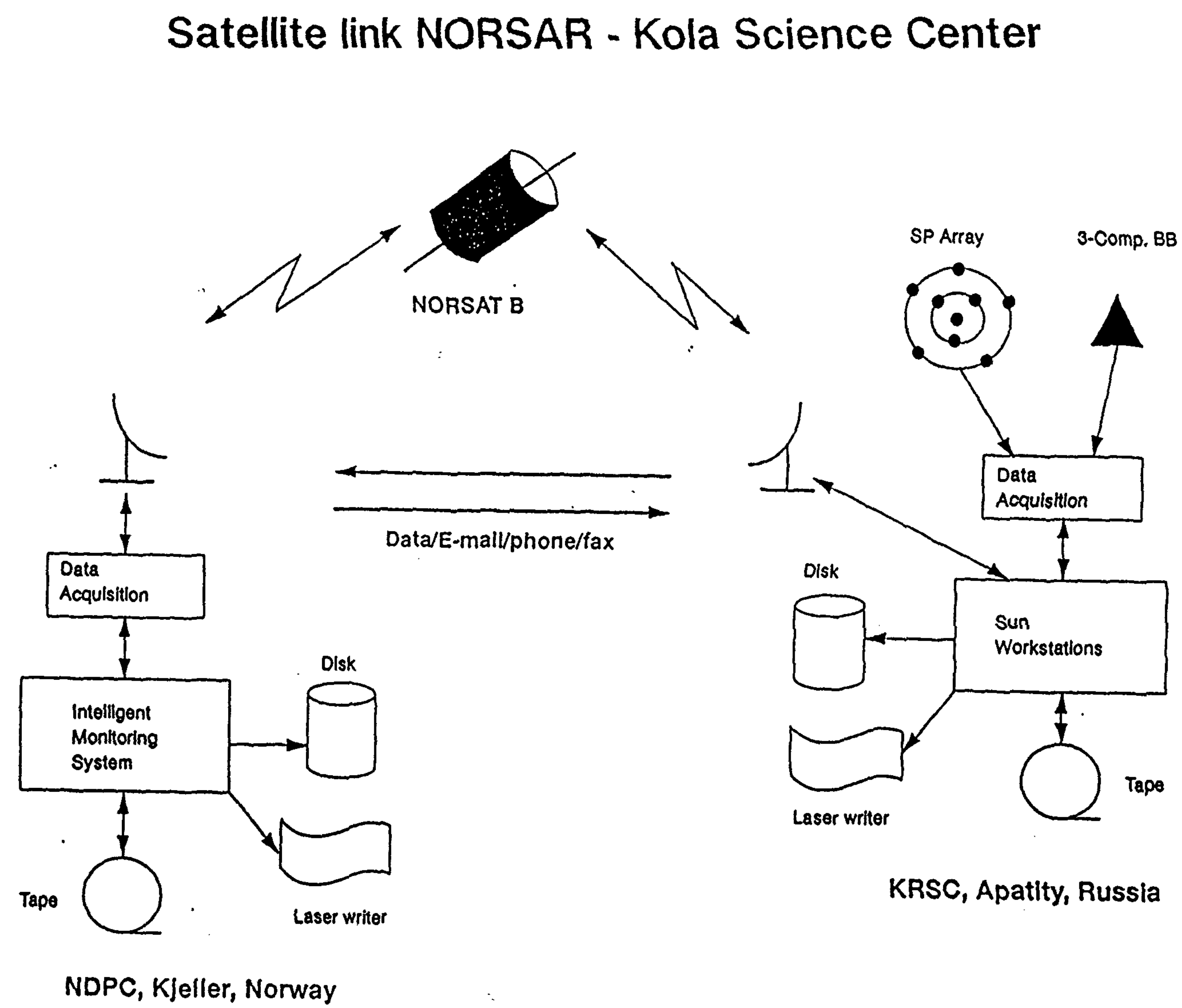



**FIGURE 2.4. The satellite connection NORSAR - Kola Science Centre connects the data centers of the two institutions, and provides a 64 Kbps continuous connection, supporting data exchange, E-mail, telefax and telephone.**

# 3.0 Seismicity of Kola and Adjacent Regions

## 3.1 Seismicity and seismic zones

Strong earthquakes are known from as far back as the 17th century for the eastern Baltic Shield (T. Ahjos and H. Korhonen, 1984), and before the seismic networks in this region were installed, it was suggested that only large earthquakes could take place here, because the crust of the rigid ancient shield was believed not to be able to produce many small earthquakes (e.g., Panasenko, 1969). Now this opinion has been revised.

The contemporary seismicity in northern Europe is shown in Fig. 3.1. Most of the earthquakes shown are for the past 30-year period, but some historical epicenters are also included, dating back as far as the year 1542. The earthquake activity is characterized by small and moderate size earthquakes. The largest earthquake in the Baltic Shield in recent years was the $m_L = 5.2$ event of 20 May 1967, located at 66.6°N, 33.7°E (Meyer and Ahjos, 1985). It was felt with MSK intensity VII in Karelia, and generated a small tsunami in the White Sea.

*The Kola-Finnmark zone*

Information about the seismicity of the Kola-Finnmark zone was known already from 1772 when an earthquake with maximum intensity VI took place near Murmansk (68.7°, 33.3°E). The largest earthquake known in the Kola-Finnmark zone (Kola Peninsula) during this century occurred on 10 April 1981 (68.8°N, 36.0°E). The magnitude estimated for this event ranges from 4.5 $M_L$ (Upp) to 4.7 $m_b$ (ISC). The 1981 earthquake had two shocks about 10 seconds apart and was felt with intensity V at Murmansk.

During 1986-1990 some tens of events were registered from the Kola-Finnmark zone. One of the larger of these was the earthquake that occurred on 16 June 1990 (69.14°N, 35.15°E) with $M_L = 4.0$, which was felt with intensity IV at Murmansk.

The seismicity of the Murmansk-Finnmark zone is largely confined to intersections of faults separating the Murmansk Block from the South Barents Sea platform, i.e., the so-called Karpinsky lineament, and to NS-trending faults which are clearly discerned from Landsat imagery (Fig. 3.2). Fig. 3.3 presents a fragment of the neotectonic framework for these earthquakes.

*The Khibiny Massif*

In the last several years there has been a great increase of induced seismicity in the Khibiny Massif. This began to manifest itself after large volumes of rocks had been extracted from a high-stress environment (Kremenetskaya and Trjapitsin, 1995).

Exploration of the Khibiny apatite deposits was started in 1930. The first earthquake on record in the Khibiny area occurred on 23 September 1948 and was felt with intensity IV in populated areas.

The largest earthquake in Khibiny took place on 16 April 1989 ($M_L = 4.1$). This event was felt with intensity VIII in the upper levels of the Kirovsk mine and caused considerable destruction. The maximum measured displacement was 15-20 cm and it occurred along a fault striking at 125-135° and dipping at 30-35° NE. This displacement was traced along the surface for 1200 m and observed to a depth of at least 220 m.

The earthquake was felt with intensity V-VI in the Kirovsk area, and it was followed by several hundred aftershocks during the next two months. The earthquake on 16 April 1989 occurred simultaneously with a 240 ton explosion in one of the Kirovsk mines. It thus appears that the explosion triggered the earthquake. Supporting this assertion is the observation of analogous events at the Kirovsk mine on 29 August 1982, when an earthquake with maximum intensity VI took place at the same time as a large explosion. Similar trigger effects have been observed in many instances, as listed in Appendix B and C.

A more detailed discussion of Khibiny Massif seismicity and earthquake triggering effects is given in Chapter 5.

*NE Archangelsk and Novaya Zemlya*

The seismic station Amderma (AMD) began operation in 1983. The station was established to study seismic activity of the Barents Sea Platform. The first investigations identified two zones of weak seismic activity in the NE Archangelsk region (Assinovskaya, 1989). The shaded area in Fig. 3.4 shows the seismic zone to the southeast of Amderma. No definite information exists about the nature of the events recorded in this region, but neotectonic conditions are consistent with this zone being seismically active.

A seismically active zone has also been found on Novaya Zemlya. Of particular interest is the earthquake on 1 August 1986 with $m_b = 4.6$ near the south coast of the Matochkin Shar strait. The location of this event is shown in Fig. 3.5 together with the system of lineaments and faults. There were at least four more earthquakes in this area, information about which has been provided by Kremenetskaya (1991).

In conclusion, we find that the seismicity of the NW part of Russia is characterized by clustering of the most intense earthquakes at sites of intersections of NS and EW trending fault zones.

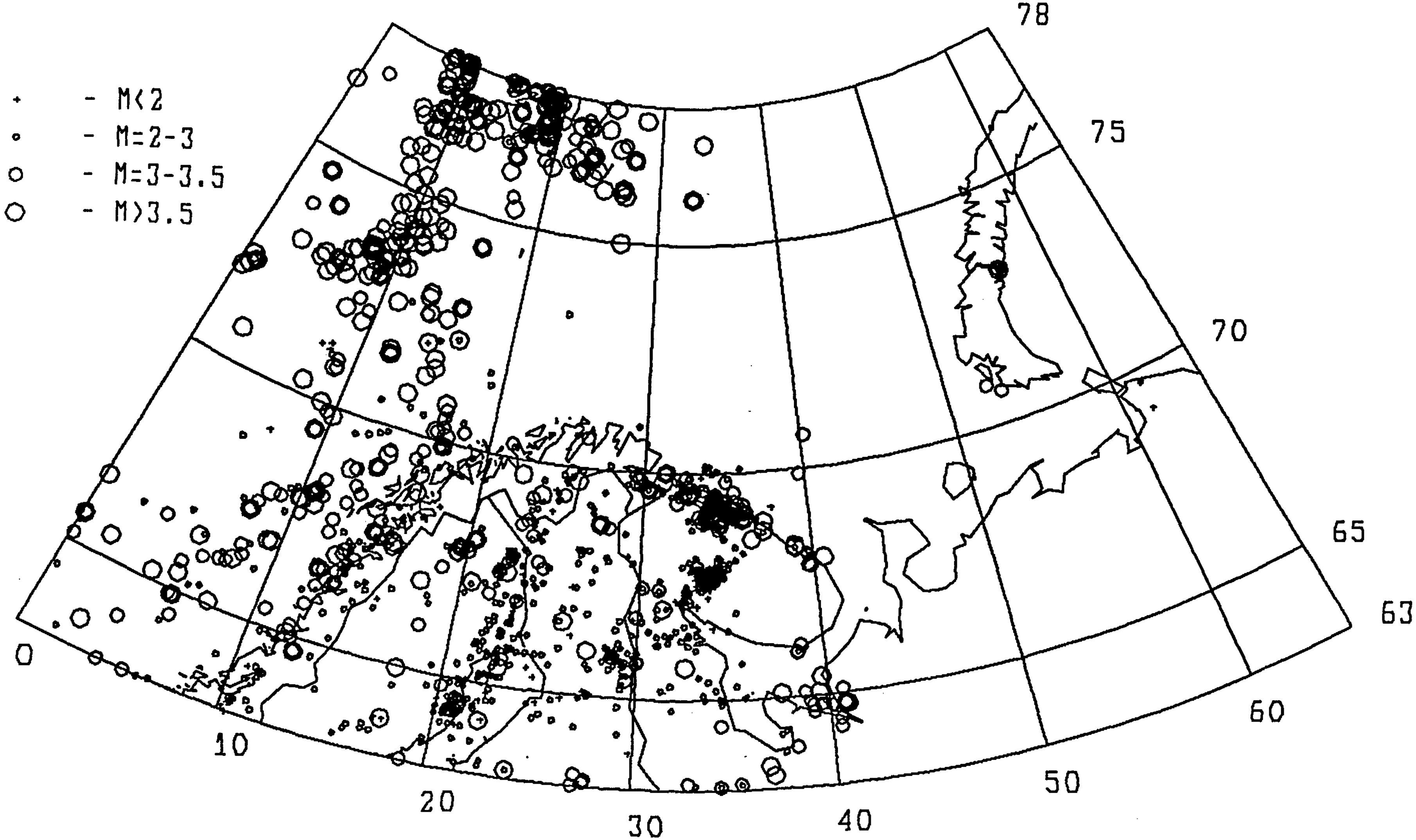



FIGURE 3.1. Seismicity of the Barents region 1970-1994, as registered in the KRSC data base. Note the two concentrated earthquake zones in the Kola Peninsula, near Murmansk and Khibiny.

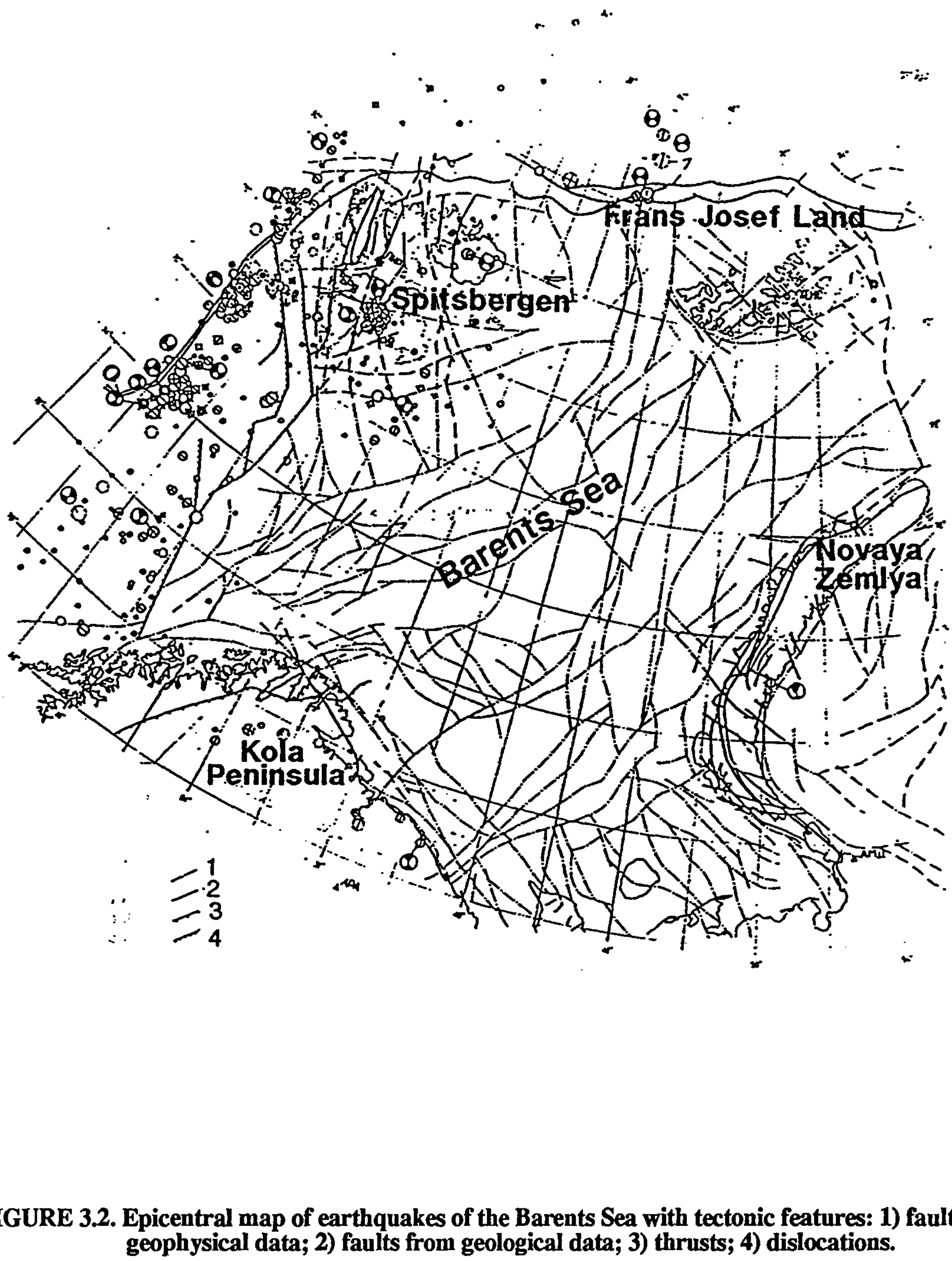



**FIGURE 3.2. Epicentral map of earthquakes of the Barents Sea with tectonic features: 1) faults from geophysical data; 2) faults from geological data; 3) thrusts; 4) dislocations.**

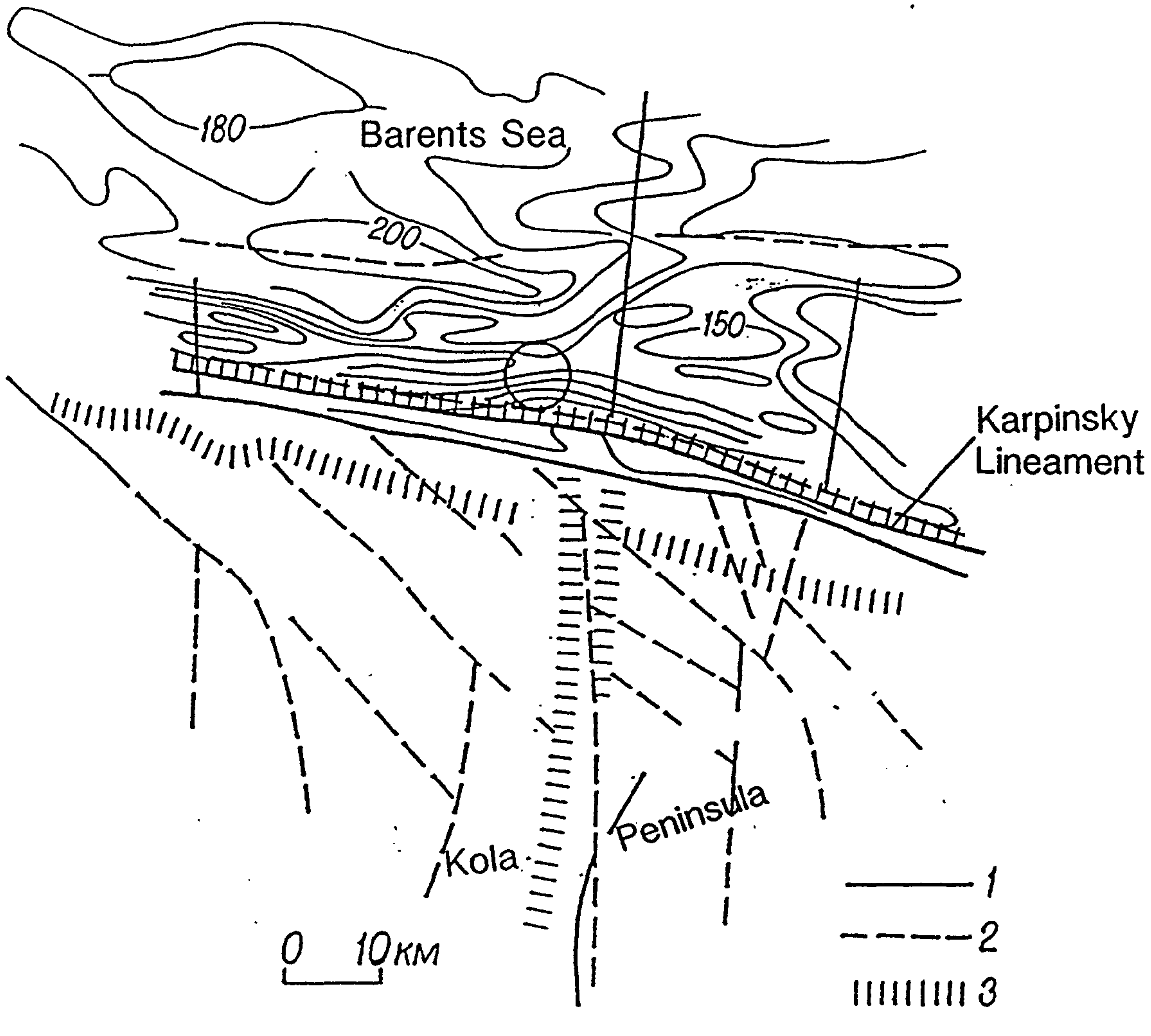



FIGURE 3.3. Neotectonic framework for earthquakes of the Murmansk coast: 1) faults from geophysical data; 2) dislocations; 3) deep structures. The epicenter of the earthquake of 10 April 1981 discussed in the text is marked as a circle near the center of the map.

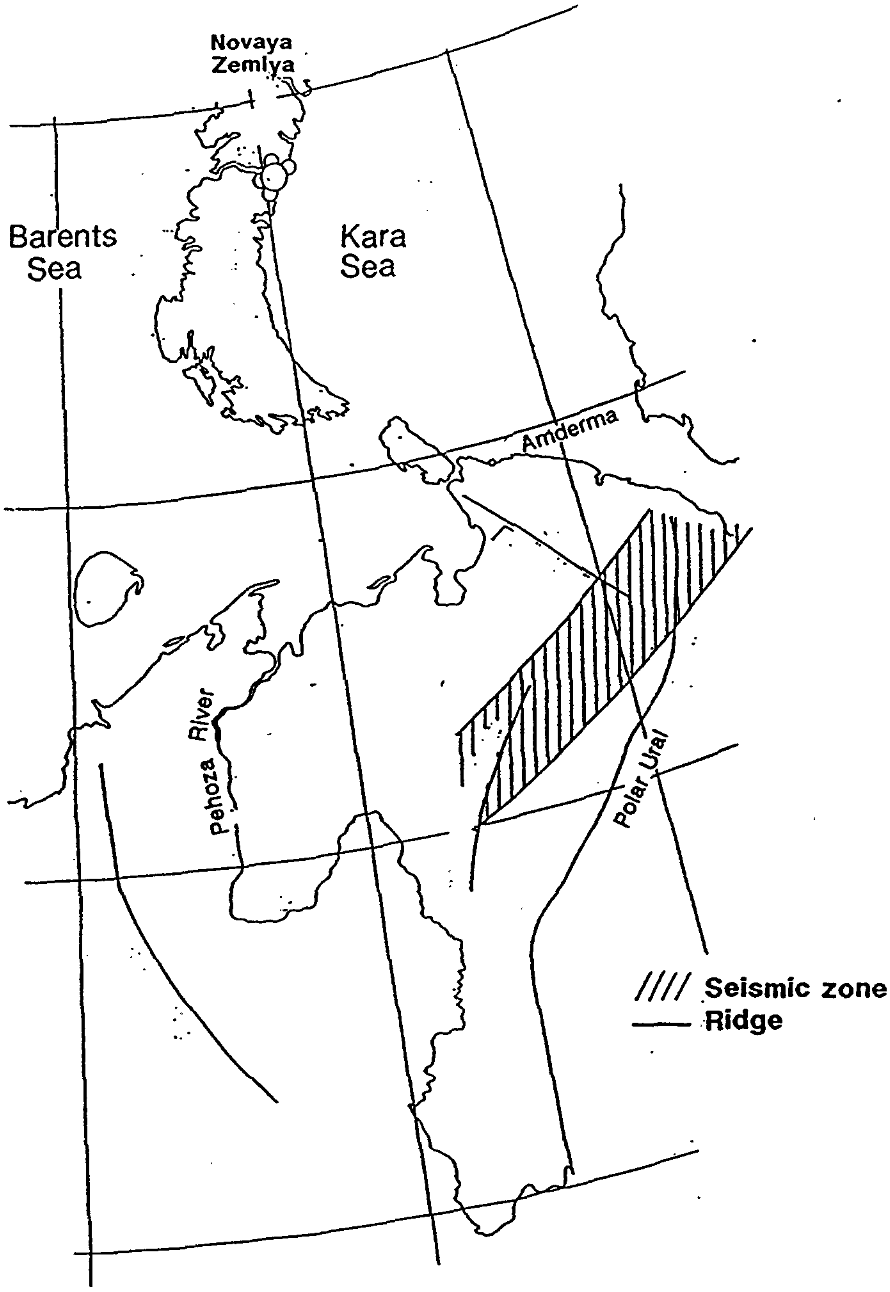



**FIGURE 3.4. The seismic zone southeast of Amderma. Epicenters of the Novaya Zemlya earthquakes (Kremenetskaya, 1991) are also shown.**

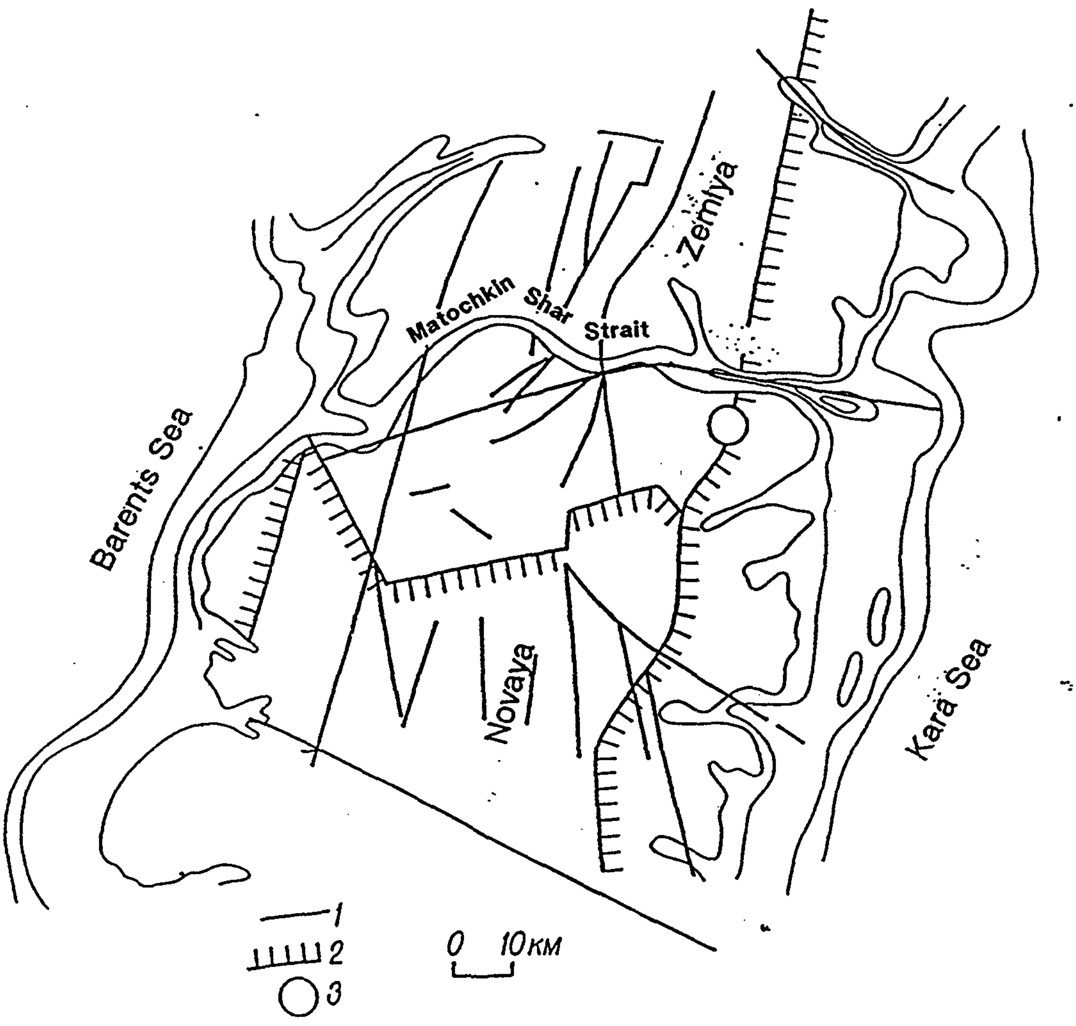



FIGURE 3.5. The position of the Novaya Zemlya earthquake of 01.08.86 with some neotectonic features: 1) faults; 2) boundaries of blocks; 3) epicenter.

# 4.0 Mining Explosions in the Khibiny Massif

## 4.1 History of mining activity in the Khibiny Massif

The "Apatit" joint stock company is the largest enterprise in the world for phosphorus ore extracting and enrichment. The sources of raw material for the company are the apatite - nepheline deposits of the Khibiny massif. The massif is a great alkaline intrusion connected with a regional tectonic fracture. It has oval shape, a size of about 1300 square km (36x45 km) and is situated about 900-1000 m higher than the surrounding plain of the Kola peninsula.

Apatite - nepheline ores in Khibiny comprise thick (100-200 m) stratum-like deposits (Kukisvumchorr (Kirovsk), Yukspor, Rasvumchorr) as well as a system of ore seams of 25-50 m thickness (deposits Koashva, Nyurkpakh). The correspondence between these deposits and the mines (1-6) shown on Fig. 4.1 is given in Table 2. A more detailed map of mines 1-2 is given in Fig. 4.2.

**TABLE 2. Reference numbers and coordinates of the Khibiny mine**

| Name | Mine No | Latitude | Longitude |
|---|---|---|---|
| Kirovsk | 1 | 67.670 | 33.729 |
| Yukspor | 2 | 67.647 | 33.761 |
| Rasvumchorr | 3 | 67.631 | 33.835 |
| Central | 4 | 67.624 | 33.896 |
| Koashva | 5 | 67.632 | 34.011 |
| Nyurkpakh | 6 | 67.665 | 34.146 |

Surface mining in Khibiny began in 1930 with 250,000 tons of apatite extracted during the first year. In 1934 the extraction volume had increased to 1,136,000 tons. In 1933 the construction of Kirovsk underground mine was initiated. The first ripple-fired explosion of mine charges was made in 1936 during the Kukisvumchorr deposit development. By 1936 the ore extraction had reached 2,6 million tons per year.

During most of the Second World War the mines were not in operation. Mining was restarted in 1944. The pre-war level of ore extraction was re-achieved in 1950.

In 1951 the construction of the Yukspor mine was started and in 1955 it began operation. Since 1963 the Rasvumchorr and Central mines have also been in operation.

From 1965 to 1980 the annual ore extraction increased from 19.1 to 46.5 million tons. Since 1980 the Vostochny mine, which covers the Koashva and Nyurkpakh deposits has been operational.

By the early 1990s the mining company had achieved its highest annual volume of the ore extraction - about 60 million tons. In the underground mines the volume was: Kirovsk mine — 11.3, Rasvumchorr — 5.4, Yukspor — 5.1, and in the open mines: Central — 25, Vostochny — 7.0 million t. The rest of the volume was extracted by surface mining at the Northern and Saamsky open mines of Kirovsk and at the mountain part of the Rasvumchorr mine.

Nowadays Kirovsk and Yukspor mines are operated jointly and the work of the Nyurkpakh open mine is finished. Total volume of ore extraction in 1994 was 21 million tons: joint Kirovsk mine — 7,046,000 tons (994,000 tons from open mines), Central mine — 8,382,000 tons, Vostochny mine (Koashva deposit) — 4,081,000 tons, Rasvumchorr mine — 1,500,000 tons (400,000 tons from open mines).

## 4.2 Underground explosions

Analysis of ripple-fired explosions carried out at underground mines during 1981-1994 shows that since 1981 the average explosion size has increased from 68 to 140 tons of explosive material (EM). Since 1988, the average total charge size of ripple-fired explosions has been within the range 120 - 240 tons of EM, all of the largest ones (>180 tons) taking place at the southern part of the Kirovsk mine and at the horizon +320 m of the Yukspor mine.

At the same time as the total charge of ripple-fired explosions has increased, the typical maximum individual charge size has also gone up, from 11 to 27 tons and it sometimes amounts to as much as 35 tons. The time delay of the largest individual charge (commonly the 3rd one) is typically 46-69 ms after initiation.

Nowadays the average number of underground explosions per year is about 40, and most of the explosions take place during the 1st and 4th quarters of the year.

## 4.3 Open-pit explosions

Ripple-fired explosions at the Central and Koashva mines are carried out weekly. During an explosion day (commonly Friday) 1-5 such explosions take place. Average release of explosive material for such a day amounts to 150-180 t. The maximal volume of fractured ore is about 500,000 cubic meters.

The technique in use is multi-row explosions with short delaying intervals (about 35 ms) using diagonal and diagonal-radial schemes. Average weight of EM per delaying phase is 2-3 tons and it sometimes amounts to 9 tons.

Blocks are exploded sequentially with time delays from 1 to 5 seconds. If the blocks are close to each other the simultaneous initiation of two blocks is possible (cascade exploding). Otherwise, if the blocks are far from each other, the time delay between the respective explosions may be up to 5-10 min.

The explosions at the open mines of Kirovsk usually are combined with underground explosions, but are carried out after them. Typical total weight of EM for the open mines is 10-15 tons, with 2-3 tons per delaying phase.

The open explosions at Rasvumchorr mine are not usually combined with underground ones. The total weight of EM is not more than 15 tons, with typically 2 tons per delaying phase, and a delay interval of 35 ms.

## 4.4 Magnitudes and yields of underground explosions

Appendix C lists underground explosions at Khibiny for the four years 1991-94. The table contains information on mine number, seismic magnitudes (local magnitude $M_L$ and coda magnitude $M_C$), as well as the total yield (weight of explosive material).

We recall that there are 6 mines (with different kinds of explosions) in Khibiny. Mines 1, 2 and 3 have underground parts and quarries, whereas at mines 4, 5 and 6 there are open (quarry) explosions only. At mines 1 and 2 the underground and open (quarry) explosions take place on the same day (sometimes at very close times, with delays from seconds to hours). At mine 3 underground and open explosions are usually carried out on different days.

The underground explosions are single (ripple-fired) explosions with typical shot delays of 20-35 ms and typical total duration of a few hundred milliseconds.

The quarry explosions are made by separate charges situated at different places (distances up to 2 km) and the time shift between the individual explosions amounts to dozens of minutes.

Aggregate yield (total weight of explosive material) is:

15-400 t for underground explosions (mines 1,2,3, single (ripple-fired) charge);
0.5-50 t for quarry explosions at mines 1,2,3 (separate charges)
10-400 t for quarry explosions at mines 4,5,6 (separate charges)

The main source of information on types and yields of the explosions is the mine administration, whereas data on their times and magnitudes are taken from our seismic recordings.

When we started to study mining explosions in 1994, we found no direct correlation between aggregate yields of explosions and their magnitudes. For example, the data listed by Mykkeltveit (1992) show no distinct trend between magnitude and total yield. We have found that there are several reasons for this:

- numerous errors in messages from the mine staff
- different characteristics of open and underground explosions
- for open explosions it is impossible to determine which charge was exploded first
- impossiblity to separate simultaneous open and underground explosions
- absence of exact information about the times of explosions
- sometimes rockbursts take place immediately after an explosion, influencing the recording and, hence, the magnitude.

A bar diagrams of numbers of explosions per mines and total yields of explosive material for the period 1991-1994 are shown in Fig. 4.3, 4.4 and Table 3. Mine 4 has most of the open-pit explosions while underground explosions at the first three mines are weaker but play a significant role in triggering earthquakes.

**TABLE 3. Total numbers of Khibiny explosions and their aggregate yields during 1991-1994.**

| Mine | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| N | 173 | 67 | 120 | 448 | 174 | 74 |
| Yield | 5932 | 5843 | 3961 | 67760 | 17563 | 10791 |

Since underground explosions are more compact in time and space and more similar to each other when compared to open-pit ones, the relationship between their yields and measured magnitudes exists. We have carefully checked our data and selected only underground explosions which are well distinguishable from rockbursts and open explosions (total more than 110 underground explosions at mines 1,2,3).

Plots of log(Yield) versus magnitude are given in Figs. 4.5 and 4.6. Note that the data in these two figures cover the three full years 1991-93. These two figures indicate that a positive correlation exists. The following correlations between magnitudes MC and ML and yields for underground explosions at all the mines have been calculated :

**TABLE 4. Correlation matrix for all underground explosions 1991-1994**

| Corr(ML,Log(Yield)) | Corr(MC,Log(Yield)) | Period |
|---|---|---|
| 0.684 | 0.73 | 1991-93 |
| 0.615 | 0.77 | 1994 |
| 0.678 | 0.73 | 1991-94 |

(Total set of underground explosions comprises more than 110 events)

Linear regressions calculated by least square method are :

LOG(Yield) = 0.6258 + 0.5744*ML;  (Corr 0.7)
LOG(Yield) = -0.7539 + 1.0813*MC;  (Corr 0.72)
LOG(Yield) = -0.4639 + 0.2844*ML + 0.7029*MC; (Corr 0.76)

For the 3rd mine separately (by 29 explosions in 1991-1994) we obtained the correlation matrix :

**TABLE 5. Correlation matrix for underground explosions at Mine 3**

| | ML | MC | LOG(Yield) |
|---|---|---|---|
| ML | ---- | 0.8014 | 0.8905 |
| MC | 0.8014 | ---- | 0.7452 |
| LOG(Yield) | 0.8905 | 0.7452 | ---- |

and linear regression : LOG(Yield) = 0.8309 * ML + 0.09124 (Corr 0.89)

The correlation for the 3rd mine is significantly greater than for all of the mines taken together. This mine has deeper underground part and well recorded underground explosions.

The results described above show that the magnitude-yield correlation is statistically reliable.In addition we used a rank-order test to estimate the quantitative agreement between yields of underground explosions and their magnitudes ($M_L$). We checked the possibility to predict relative yields given the magnitudes, i.e., P(Y1>Y2) when $M_L 1 > M_L 2$. We used 105 explosions, and for all pairs of them calculated the number of cases when the sequence of yields coincides with the sequence of magnitudes (N good) and otherwise (N bad).

| | | |
|---|---|---|
| N total | = | 5460 (105*104/2) |
| N good | = | 3977 (about 73%) |
| N bad | = | 1483 |

The number 73% is very close to the linear correlation for all mines taken together, and confirms that the yields and magnitudes are indeed correlated.

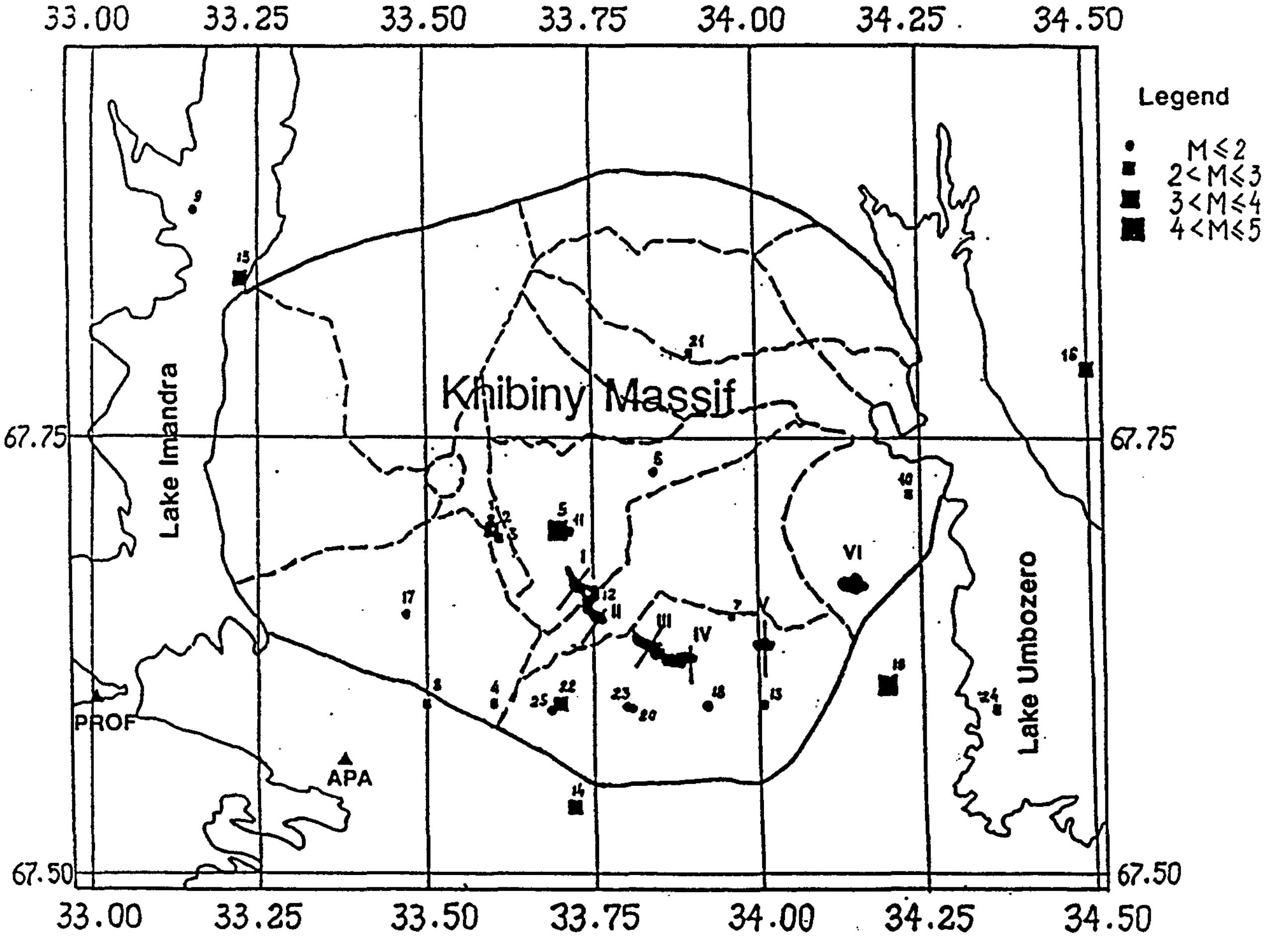



**FIGURE 4.1.** The position of mines (I-VI) in the Khibiny Massif together with fault structures and earthquakes. Mines I, II and III are underground, whereas IV, V and VI are open-pit mines. The location of the Apatity seismic station (APA) is also shown. (After Kremenetskaya and Trjapitsin, 1995.)

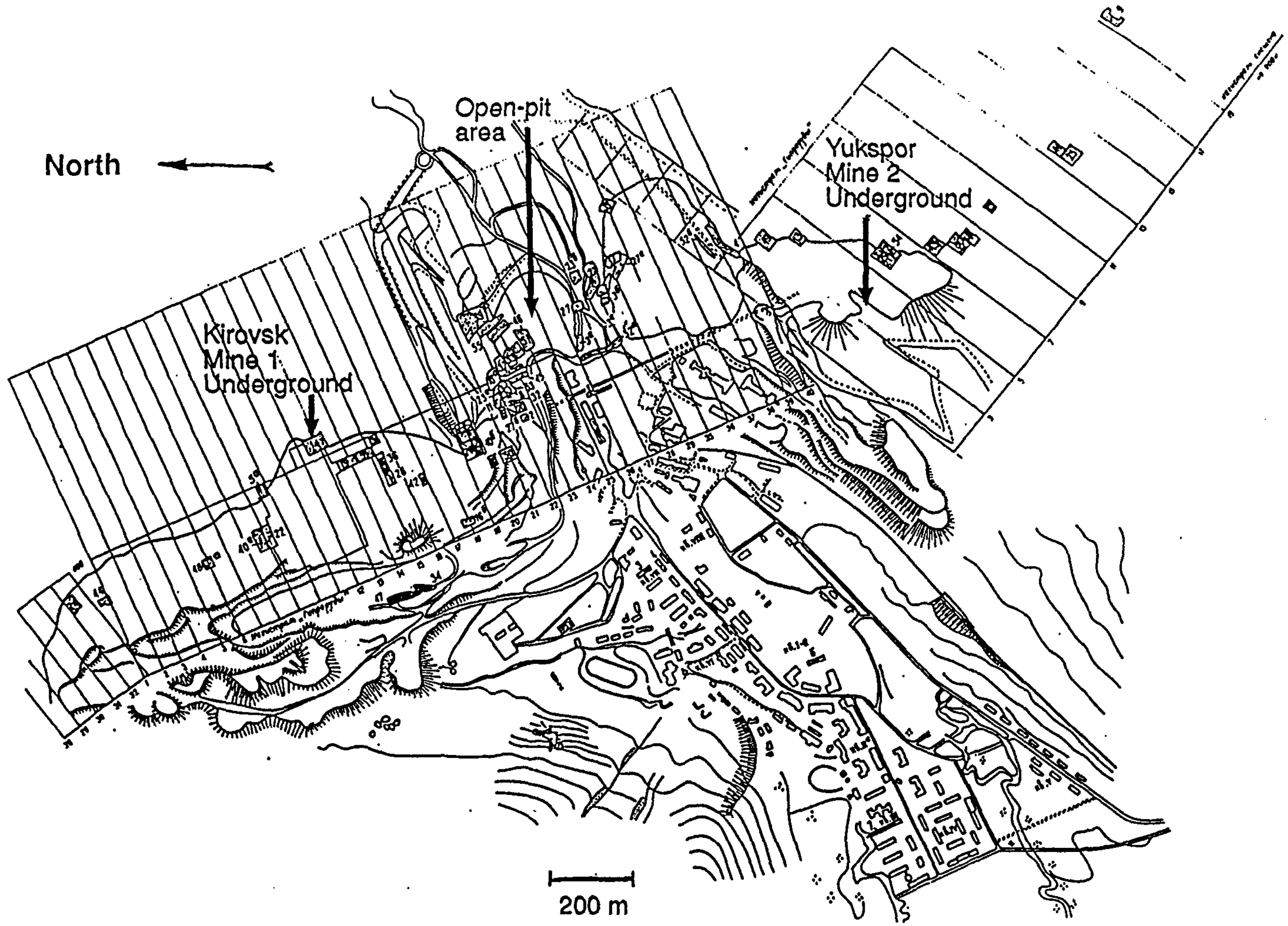



FIGURE 4.2. Schematic plan of Mines 1 and 2. Part of the town Kirovsk is seen on the map.

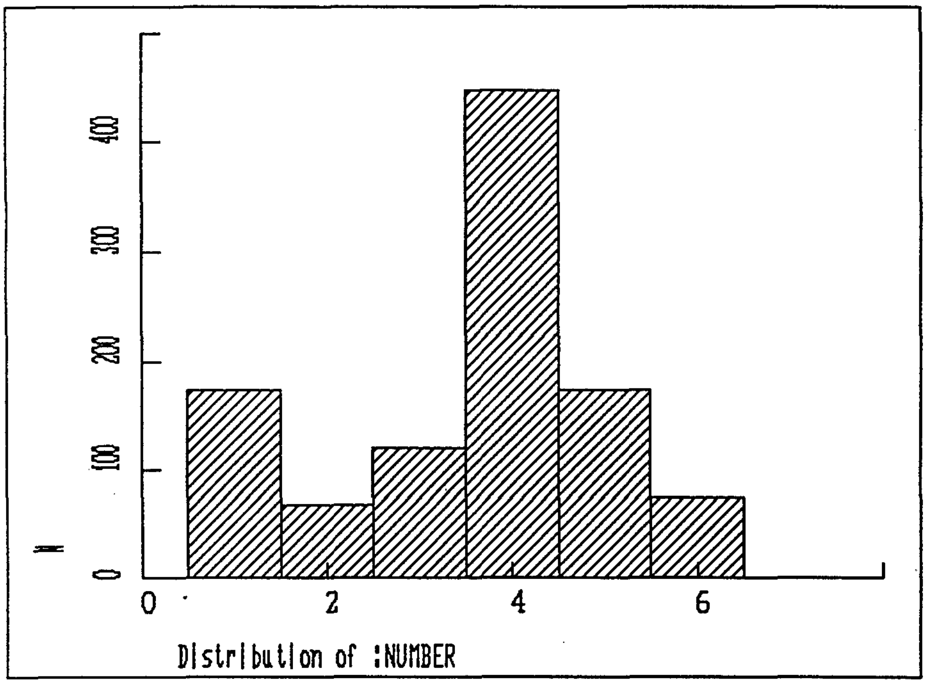



**FIGURE 4.3. Number of explosions for each of the six Khibiny mines during 1991-94.**

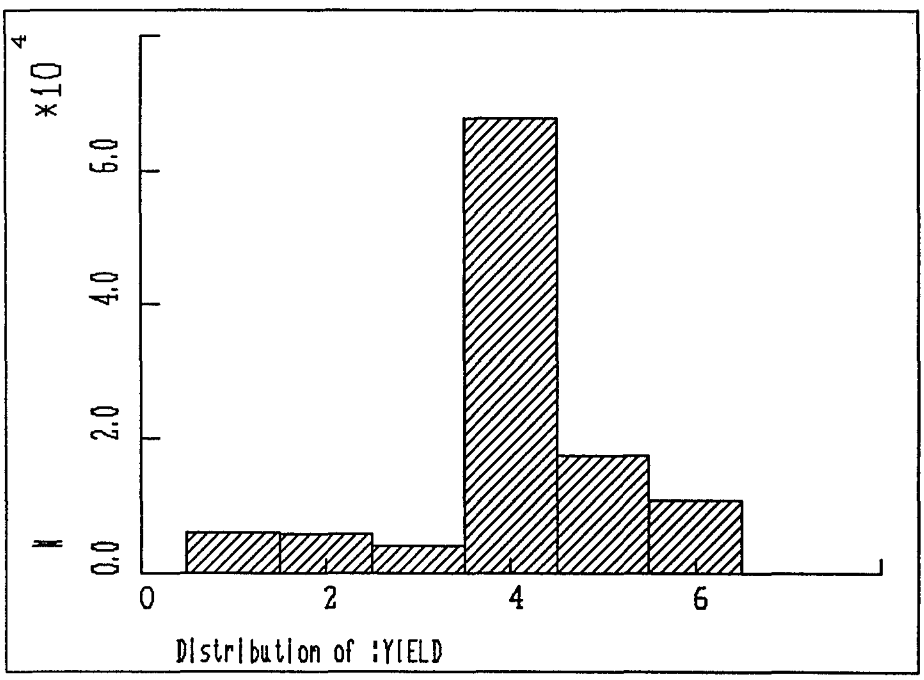



**FIGURE 4.4. Total (aggregate) yields (in $10^4$ tons) of explosions conducted at each of the six Khibiny mines during 1991-94.**

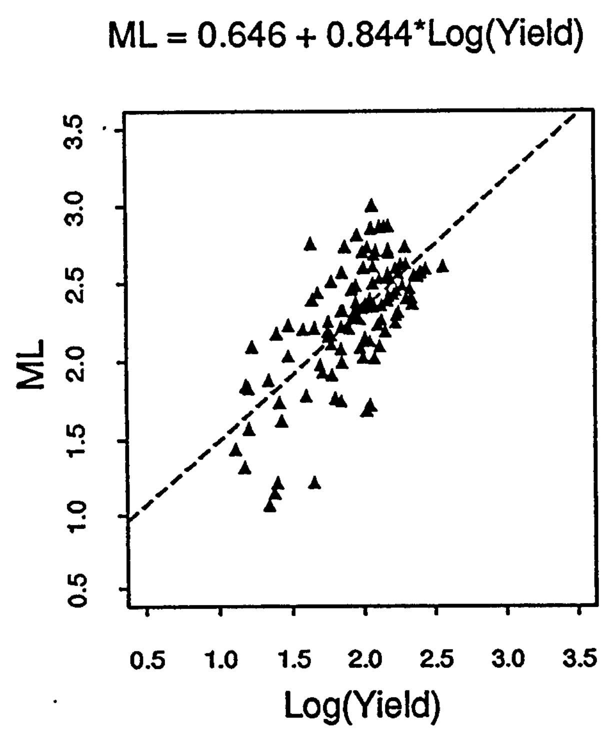



FIGURE 4.5. Plot of $M_L$ versus log(Yield) (in tons) for underground explosions 1991-93.

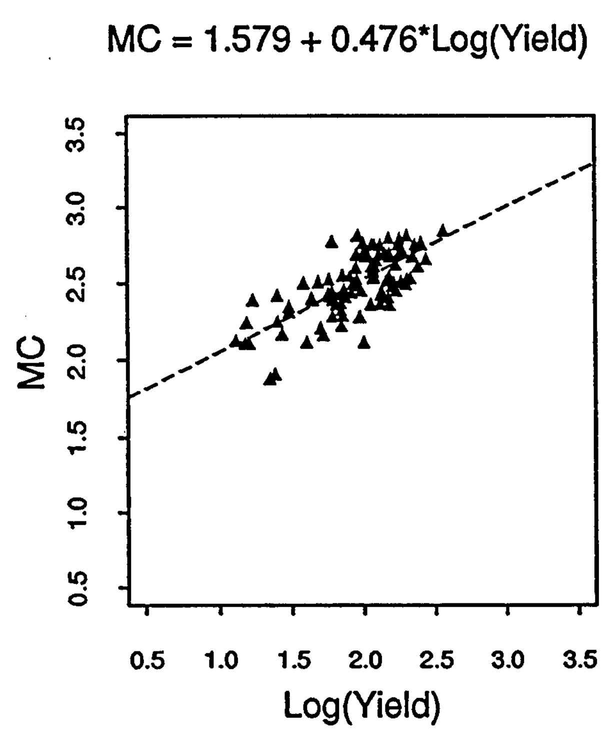



FIGURE 4.6. Plot of $M_C$ versus log(Yield) (in tons) for underground explosions 1991-93

# 5.0 Induced Seismicity in Khibiny

## 5.1 The Khibiny Massif.

The Khibiny complex occupies a mountainous territory of 1327 square kilometers in the central part of the Kola Peninsula, north - western Russia. It is one of the world's biggest alkaline plutons. The complex belongs to the Kola Alkaline Province of the Baltic Shield. The eastern contact of Khibiny is only 5 km away from the Lovozero massif, therefore these massifs can be regarded as two parts of a single intrusive complex having similar ages. These alkaline intrusions consist of nearly the same rock types but differ in their internal structure. The Khibiny massif intruded in the contact zone between Archaean gneisses and Middle Proterozoic volcanic - sedimentary complexes. According to geophysical data and drilling, the outer contacts of the massif are subvertical down to a depth of 3 km. At deeper levels the western and southern contacts plunge towards the centre at an angle of 50-60 degrees. The eastern contact dips outwards at an angle of 80 degrees thus showing the possible joining with the Lovozero complex.

Geological investigations indicated that the massif consists of concentric bodies of different alkaline rocks formed in several stages of igneous activity from the periphery to the core. The geometric centres of each sickle-shaped body have eastward shift towards the Lovozero massif.

A simplified scheme of the massif in a form of different blocks separated by faults was shown in Fig 4.1 of Chapter 4.

The massif is tectonically unstable. Its seismic activity has been characterized by groups of a few earthquakes with typically 8-10 years between groups (Panasenko, 1969). The recent crustal movements are in the range from 2 to 4 mm/year (Yakovlev, 1982).

An increase in seismicity in seismic areas and generation of seismicity in aseismic areas have been observed as a result of deep underground mining and large-scale surface quarrying, the injection of fluids in rocks at depth, the removal of fluids from subsurface formation, and the detonation of large underground explosions (Johnston, 1992; McGarr, 1991; Gibowicz, 1990).

The exploitation of the Khibiny apatite ores started in 1930 and since then about $2.5*10^9$ tons of the rock have been excavated from an area of about 10 sq. km. This corresponds to a decrease of the gravitational component by typically 2.5-3.0 MPa, and for some parts of the Massif by as much as 9-12 MPa.

## 5.2 Seismicity and Mining Activity

At the present time more than $10^8$ tons of ore are extracted annually from three underground and three open-pit mines. The velocity of the uplift of the near-surface parts is of the order of 70 mm/year for some tunnels (Panasenko and Yakovlev, 1983).

Now the Kola Peninsula is a typical example of increasing seismic activity caused by rock deformation due to the extraction of 100 million ton of rock per year in Khibiny Massif and a trigger mechanism of large underground explosions. Thus, for instance, the first case of dynamic activity caused by rock stress had been detected at Mine 1 after the beginning of mining works deeper than 50-100 m.

Seismicity induced by mining is usually defined as the appearance of seismic events caused by rock failures as a result of changes in the stress field in the rockmass near mining excavations (Cook, 1976; Johnston, 1992). Measurements of the lithostatic stress, made inside mines (Markov, 1977), have shown that the values of the stress horizontal components are about 30-80 MPa for the Khibiny Massif. And the extraction about 25% rockmass has led to a decrease of the vertical components for some parts of the Massif by 9-12 Mpa (Panasenko, 1983).

The extensive mining has disrupted the natural geodynamic process in the area, causing a redistribution of crustal stress, which in turn has led to increased seismic activity.

The dependence between seismic activity and the extracted deposit volume has long been known from obsevations (Glowacka and Kijko, 1989). In the Khibiny Massif a more intensive excavation began in the mid-1960s, while the first significant tremors occured in 1981. During that year four felt earthquakes (intensity I = 3-4 on the MSK scale) occurred in the vicinity of the mines. Some of these earthquakes were accompanied by sonic effects.

Around the same time, many rockbursts occurred near mines 1 and 2, each of them displacing large amounts of rock (1-10 cubic meters). In fact, during five hours on 17 May 1981 more than 20 rockbursts occurred. And for the first time the occurrence of a new earthquake at the time of an explosion was observed. Now such a situation is ordinary for events of the Khibiny Massif.

Below we give a brief characteristic of the Khibiny mines in connection with their possible influence on local seismicity. The mines 1 and 2 are close to each other and comprise both underground parts and quarries. Nowadays underground mining there is carried out at 500 m and deeper. The 3rd mine has a deeper underground part (up to 600-700 m) and a small quarry. It is close to the 4th mine where only open-pit quarry explosions take place. These two mines are suspected to act as a couple 'contributing jointly' to induce seismicity. At mines 5 and 6 only open-pit quarry explosions are carried out, with mine 6 being no longer in operation. They are far from the other mines and from the most part of well-located earthquakes so we can consider their influence to be negligible.

The goal of this work is to study statistically some space and time patterns of this relationship to reveal triggering effects and influence of rock excavation on local seismicity.

## 5.3 Location of Earthquakes

Registration of Khibiny seismic events has taken place already for a very long time but their location was not exact enough to show spatial relationship between the earthquakes and Khibiny mines. A more accurate empiric model of apparent velocities has been derived especially for Khibiny events by means of statistical analysis of travel times from known

Khibiny explosions to the closest stations /APO,APA/ and extension of the travel-time curves to a set of far stations /PLQ, ARC, NRS/ (See Appendix A).

This has enabled us to re-calculate more correctly coordinates and magnitudes of many Khibiny earthquakes. The results are shown in Fig. 5.1 (map of Khibiny earthquakes), Fig. 5.2 (map of lines of equal number of events during 1991-1994), Fig. 5.3 (map of energy release for Khibiny earthquakes during 1991-1994). The figures show clearly that the lines of equal number of earthquakes surround mines 1,2,3 and partly 4, with the majority of events appearing to be in the vicinity of the 1st mine. The most energy release took place near the mine 1 and mines 3-4 and was dominated by a few events of large magnitudes. This is further illustrated in Fig. 5.4, which is based on earthquakes of magnitude less than 3.0. Also on this figure,, mines 1 and 3-4 show the main energy release, whereas there are lines of smaller energy release surrounding the other mines.

## 5.4 Magnitude-Frequency Relationship

Magnitude - frequency dependencies for Khibiny earthquakes are shown in Fig.5.5. These are cumulative plots made for 3 time periods: from 1980 to 1994, from 1991 to 1994 and for the year 1993 only. Linear regressions calculated over the rightmost parts of the curves for the relationship

LOG(N) = A - B*ML

normalized to 1 year of observations are as follows :

**TABLE 6. Coefficients of magnitude-frequency relationship**

| T observation | A | B |
|---|---|---|
| 1980-1994 | 2.66 | 0.967 |
| 1991-1994 | 3.747 | 1.448 |
| 1993 | 3.169 | 1.065 |

Such instability of the results (near the same relative numbers of small earthquakes and sufficiently lower number of large earthquakes in later years compared to the whole time interval 1980-94) might appear to be an argument in a favor of the hypothesis of increasing induced seismicity if one suspects that induced earthquakes could not amount to extremely large magnitudes (i.e. stress release is caused by earthquakes of small and medium magnitudes). However, the fact that the year 1993 (which had two large earthquakes) has a B-value similar to the entire period cautions against too detailed interpretation.

## 5.5 Time distribution of Earthquakes and Explosions

Time distributions of Khibiny explosions are shown in Fig. 5.6, 5.7, 5.8. From Fig. 5.6 we observe that the earthquakes are relatively uniformly distributed by time-of-day, while explosions take place during rather narrow time intervals. Typical time is about 10 a.m. for open-pit explosions and about 5 a.m. for underground.

Fig. 5.7 shows that open-pit explosions most often take place on Fridays, while the usual days for underground explosions are Saturday and Sunday. Earthquakes are again more evenly distributed, but we note that there is a peak in the earthquake activity on Fridays.

In order to investigate further the correspondence between the peaks in the number of both earthquakes and explosions on Fridays, we present a time-of-day plot for Fridays only (Fig. 5.8). The main purpose was to see if we might accidentally have included some explosions among the earthquake populations. However, we note that the distributions are not very different from the overall distributions (Fig. 5.6), so there is no reason to assume that any explosions have been misclassified.

## 5.6 Earthquakes Triggered by Explosions

We considered two kinds of induced seismicity. The first one is triggering when a rockburst or earthquake takes place near the place of explosion and immediately after it. The most striking examples of such events are two earthquakes which occured in 1984 after very weak underground explosions (about 40 kg of explosive material) at the 2nd mine. (19.6.1984 and 29.11.1984). The first one amounted to a magnitude 3.9 and was accompanied by destructions at the mine. About 40 cubic meters of rock have been thrown out.

To reveal such an effect we have made a search in our data base for those cases when an underground explosion was followed by rockbursts or earthquakes, with the time between the explosion and rockbursts being less than 2 hours. The result for the period 1991-1994 included 28 such cases with 29 explosions (two of them are close in time to each other so their influence is not distinguishable) and 44 rockbursts. Distribution of the difference in time between rockbursts and triggering of explosions is shown in Fig. 5.9 and in Table 7. (Tables of underground explosions and Khibiny earthquakes are presented in Appendix B and Appendix C, respectively). It is worth mentioning that all these cases were preceded by open-pit explosions at the 4th mine one or two days before.

**TABLE 7. Time distribution of triggered rockbursts after underground explosion**

| Time after an explosion (minutes) From | To | Number of Rockbursts |
|---|---|---|
| 0 | 10 | 27 |
| 10 | 20 | 4 |
| 20 | 30 | 3 |
| 30 | 40 | 1 |
| 40 | 50 | 2 |
| 50 | 60 | 1 |
| 60 | 70 | 0 |
| 70 | 80 | 1 |
| 80 | 90 | 1 |
| 90 | 100 | 1 |
| 100 | 110 | 2 |
| 110 | 120 | 1 |

Fig. 5.9 and Table 7 clearly show that a significant triggering effect is observed during the first half hour after underground explosions. The number of events occuring later is small and indistinguishable from the total seismic background.

This proves the existence of a trigger effect, but it comprises only a small number of Khibiny rockbursts and earthquakes. The same investigation made for open-pit explosions showed no similar trigger effects. This forces us to conclude that some other mechanism of inducing seismicity, possibly connected with the volume of ore excavation, must exist.

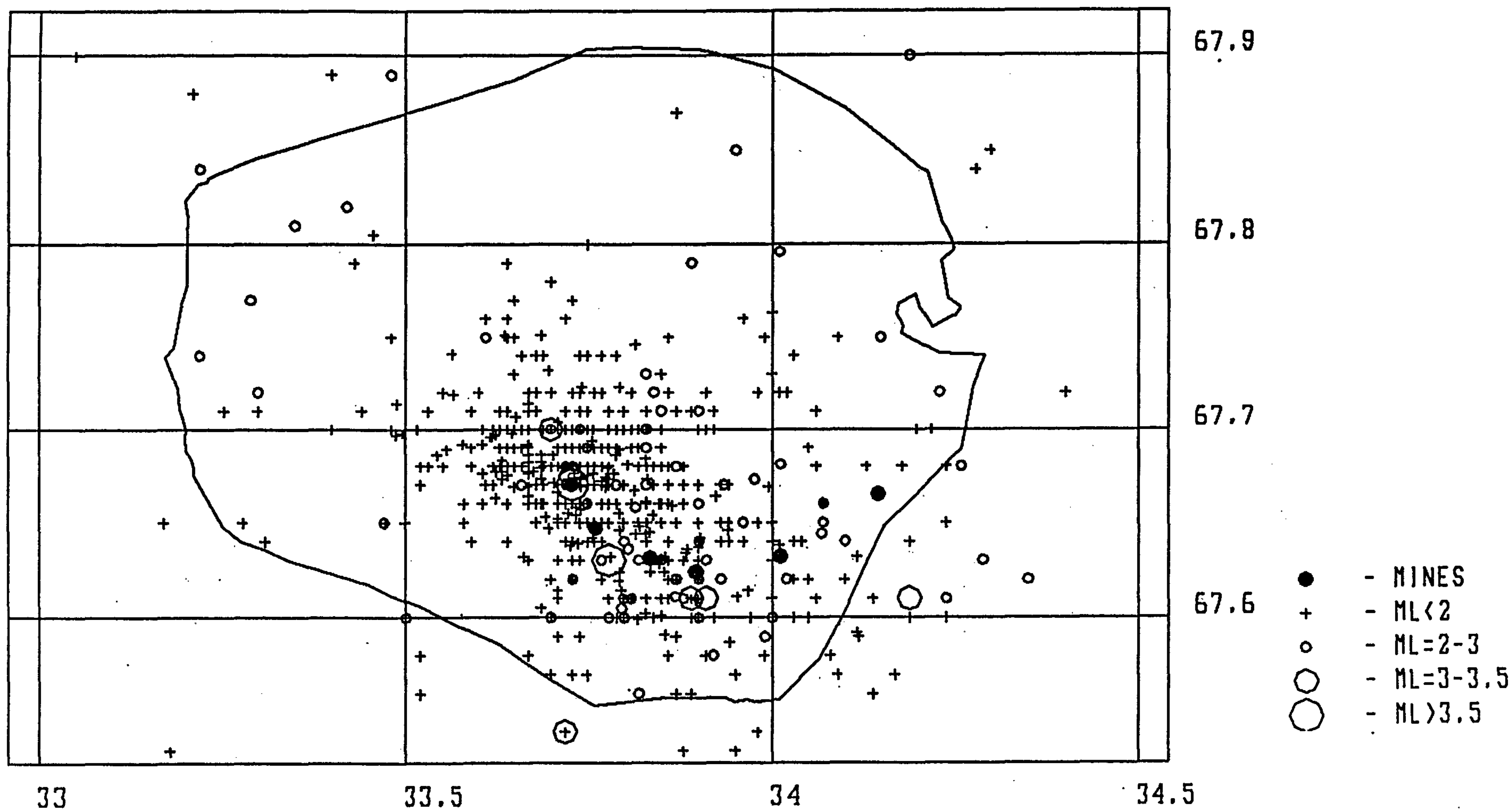



FIGURE 5.1. Map of epicenters of all recorded Khibiny earthquakes 1980-1994. The location of the six Khibiny mines are shown as filled circles.

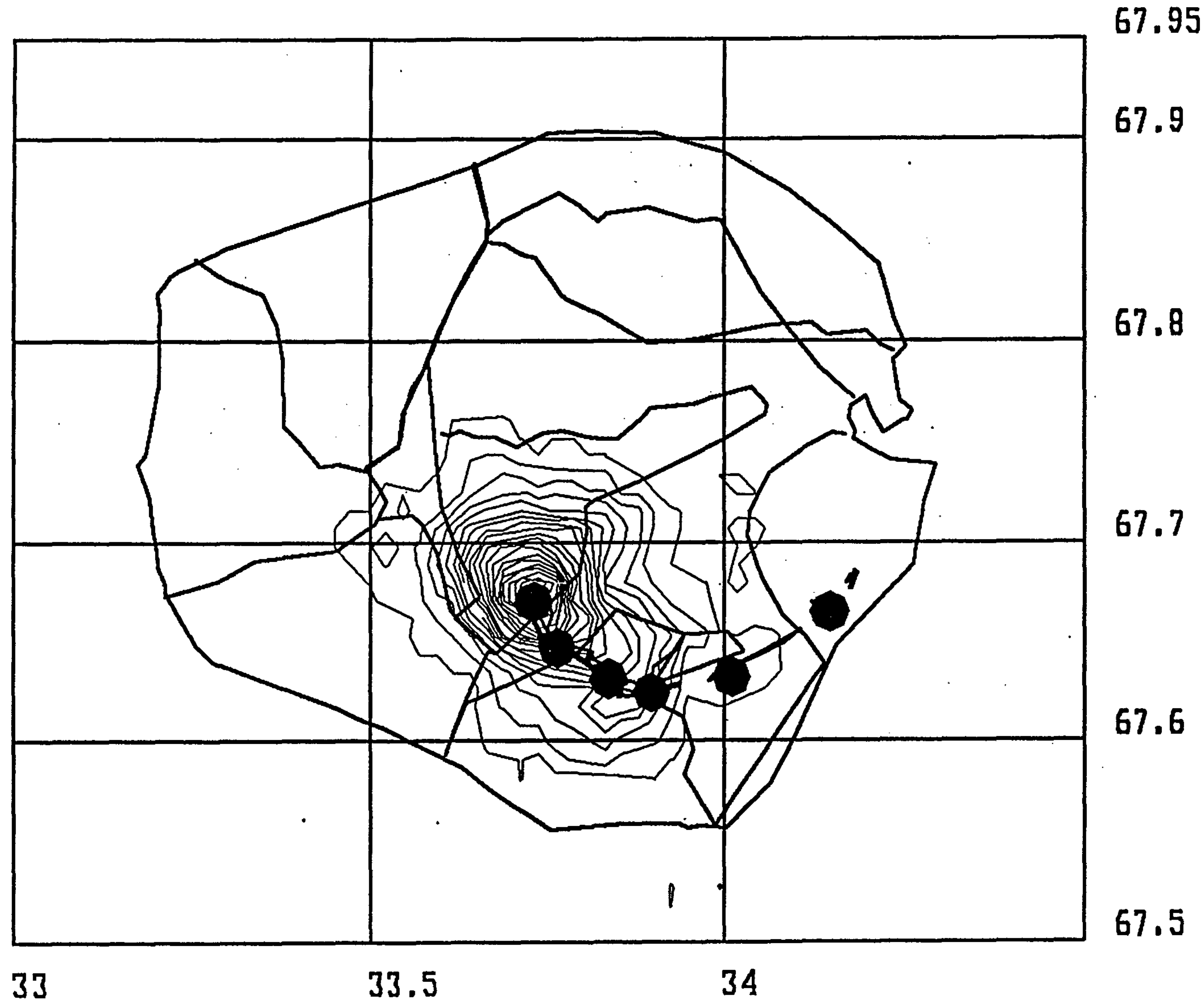



FIGURE 5.2. Isolines for number of earthquakes in Khibiny during 1991-94. Note the concentration near Mine 1 (marked as the leftmost filled circle).

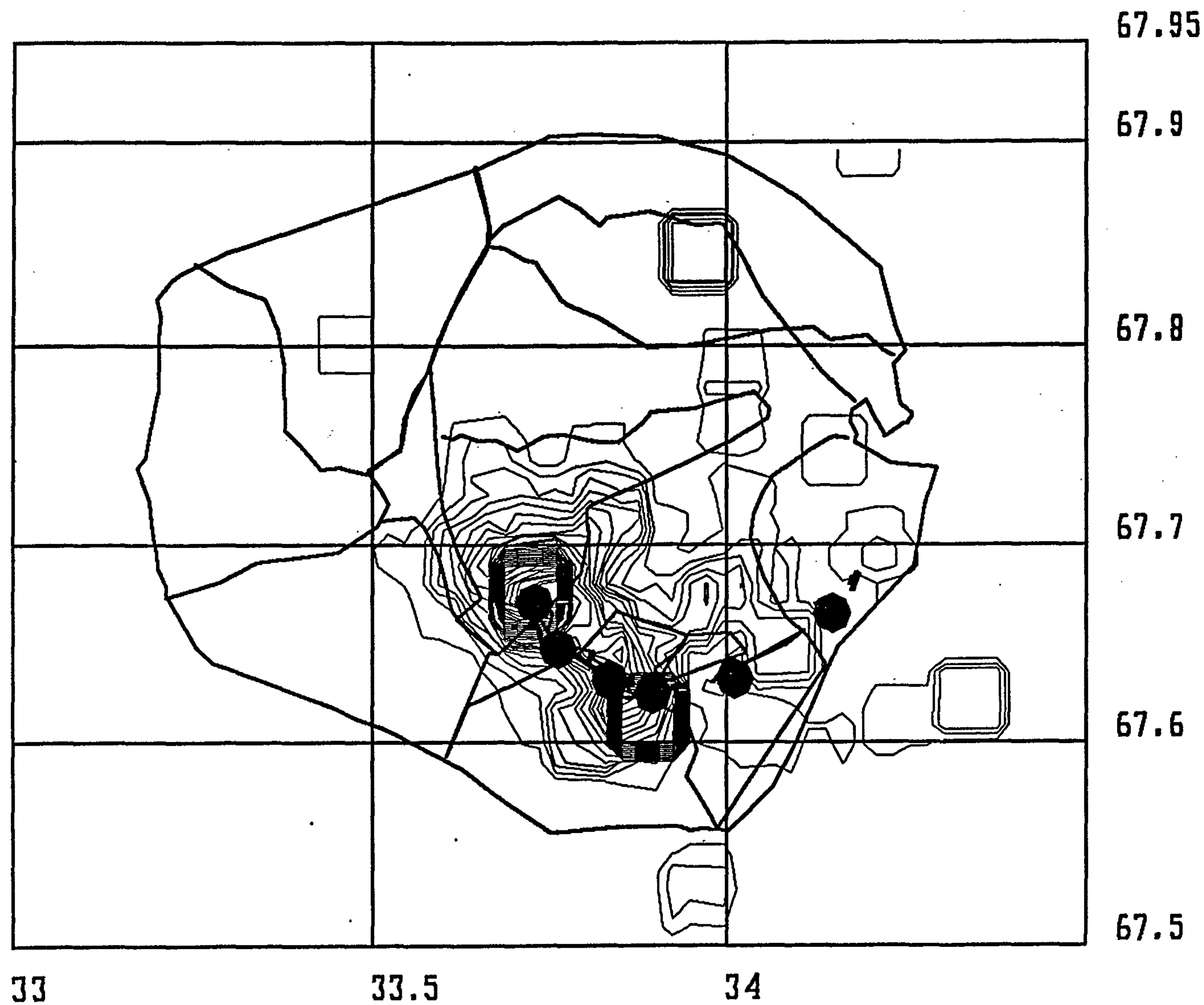



FIGURE 5.3. Isolines for released seismic energy for Khibiny earthquakes during 1991-94. Note the concentration near Mines 1 and 4.

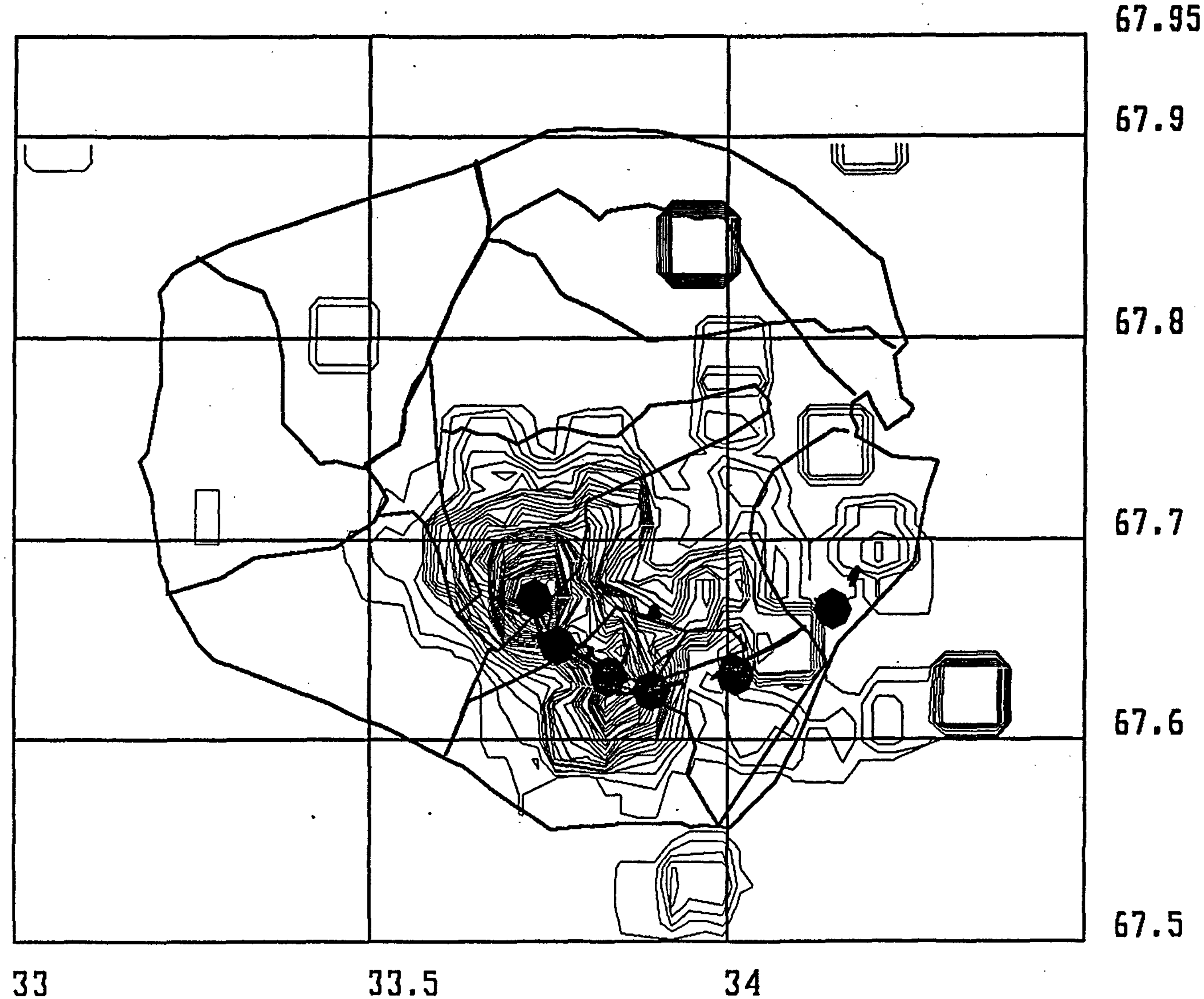



FIGURE 5.4. Same as Fig. 5.3, but only for earthquakes of $M_L < 3.0$. The picture is now less clear, but the main released energy remains near Mines 1 and 4.

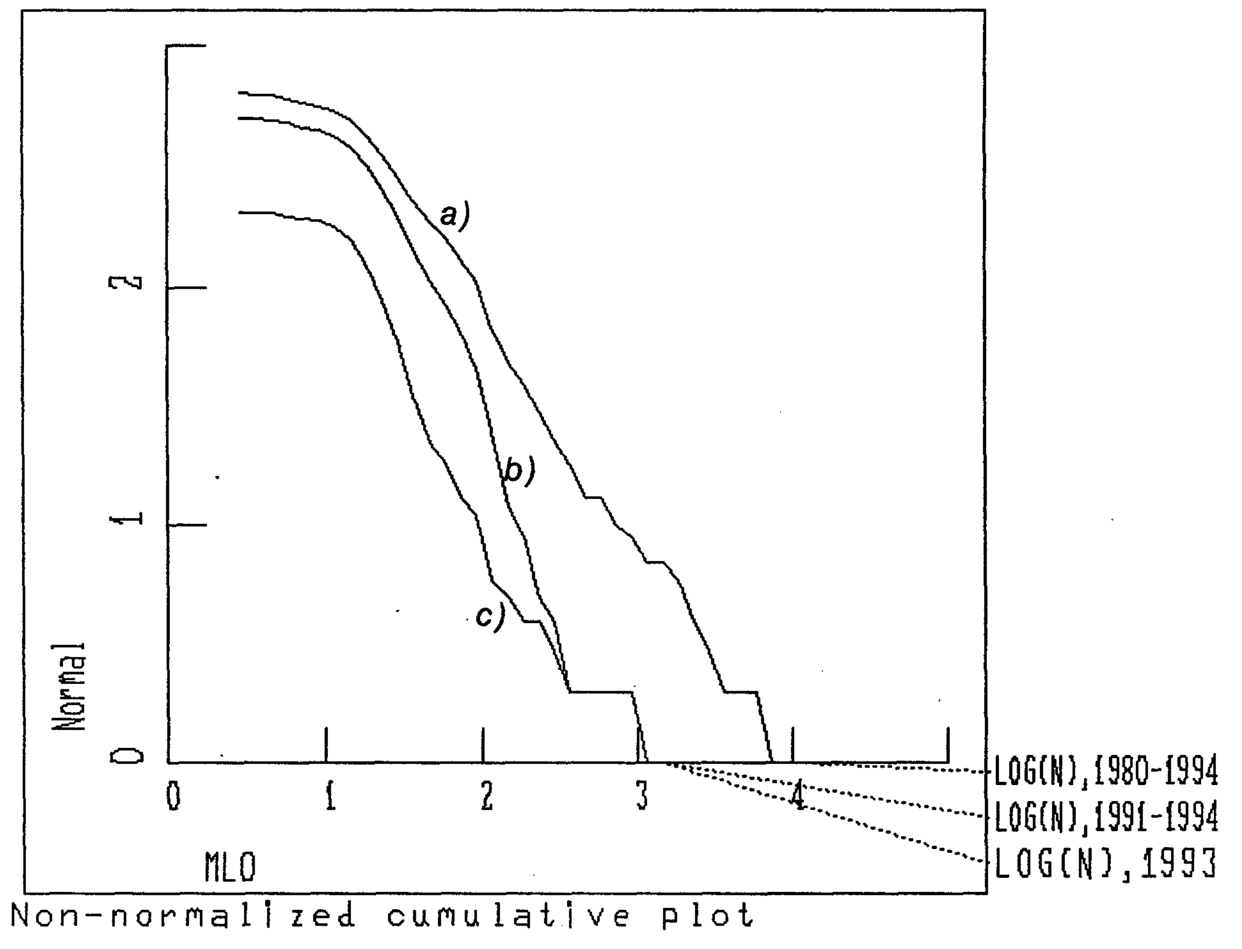



**FIGURE 5.5. Cumulative magnitude-frequency plot for Khibiny earthquakes. a) 1980-1994, b) 1991-1994 and c) 1993 only. Note the instability of the slope (B-value) as discussed in the text.**

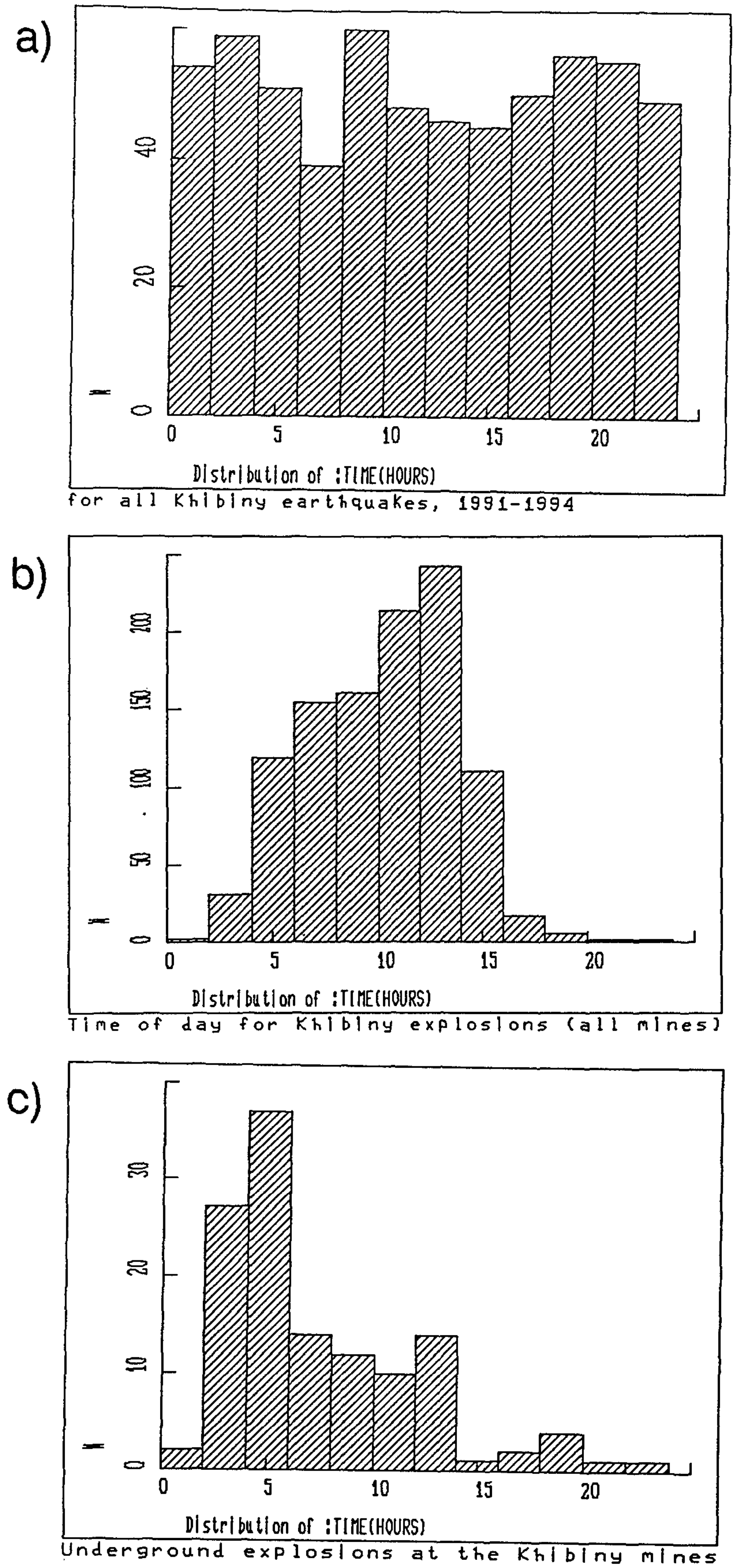



**FIGURE 5.6. Distribution by hour-of-day of the number of events for: a) Khibiny earthquakes, b) all explosions and c) underground explosions. Note the even distribution of earthquakes compared to the pronounced peaks of explosion times.**

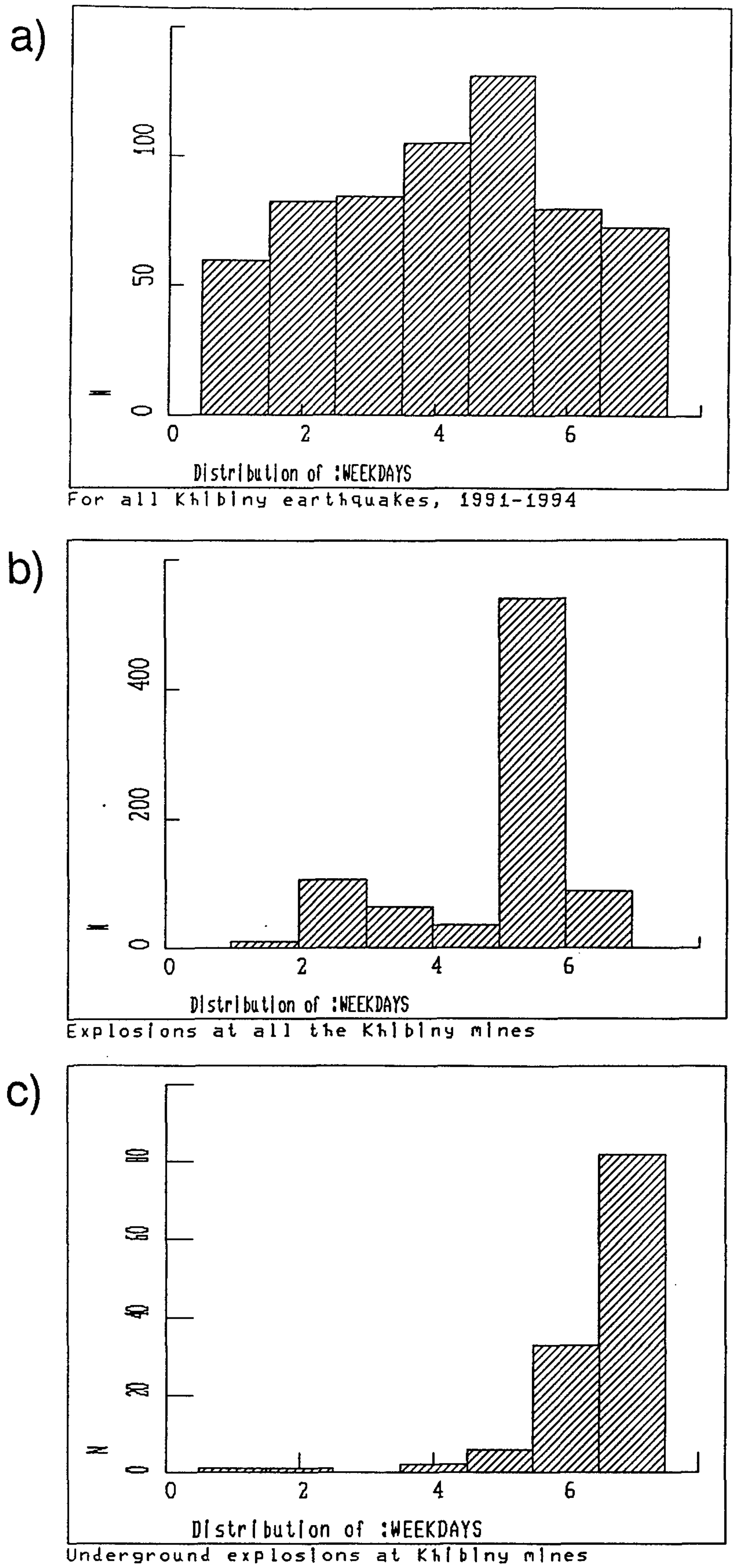
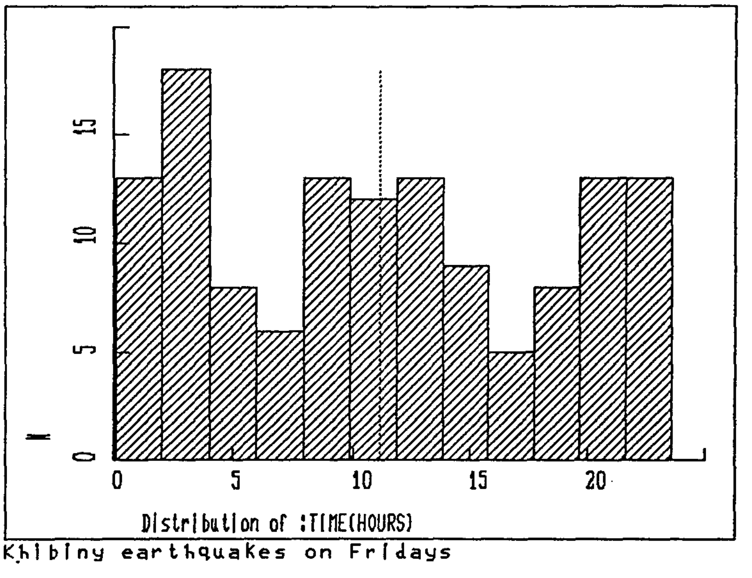



**FIGURE 5.7. Distribution by weekday (1 = Monday) for number of events: a) Khibiny earthquakes, b) all explosions and c) underground explosions. Note the large number of both earthquakes and explosions on Fridays (see Fig. 5.8).**



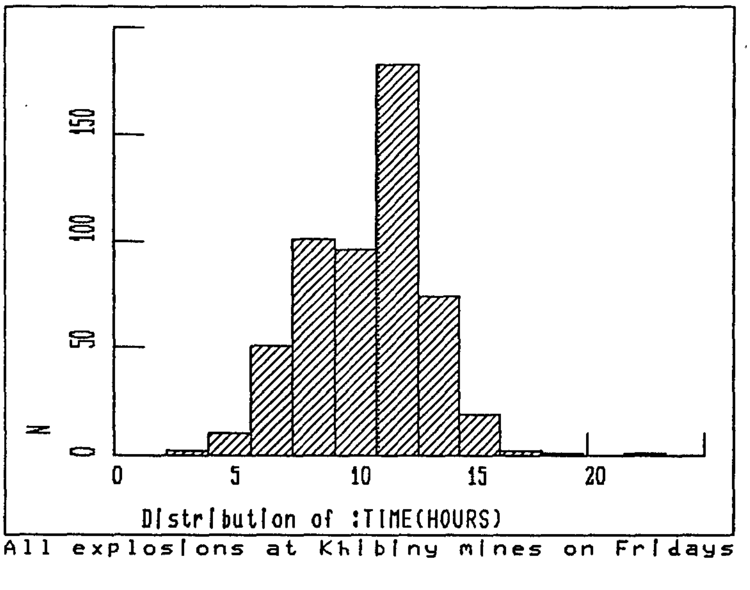




**FIGURE 5.8. Distribution of the number of earthquakes and explosions by hour-of-day on Fridays, which is the weekday with the most seismic events. See text for discussion.**

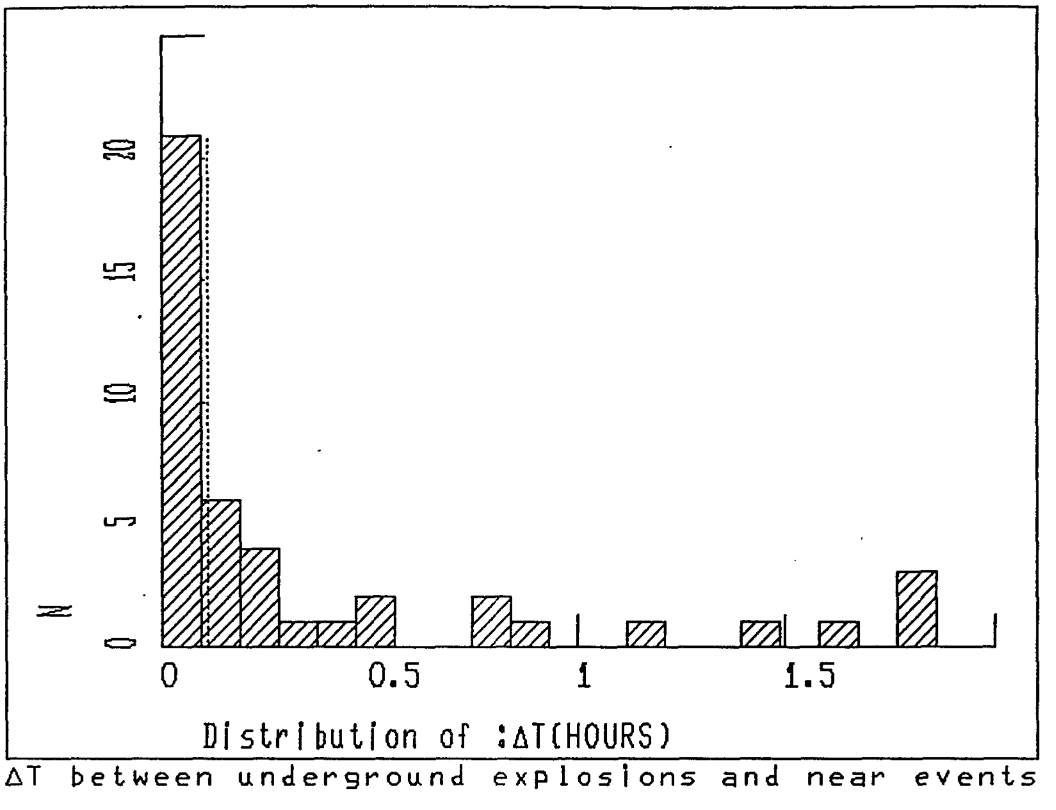



**FIGURE 5.9. Distribution showing the number of earthquakes occurring in 10-minute intervals following underground explosions. The relatively much larger number during the first 10 minutes after explosions indicates a triggering mechanism as discussed in the text.**

## 6.0 Conclusions

The main concludions from this study are summarized in the following:

*1. There is an increased seismic activity associated with the mining activity*

Seismic activity in the Khibiny Massif has shown a significant increase since 1980. During this same time period the annual ore excavation at the Khibiny mines has increased from 19.1 to 46.5 million tons. A geometrical correspondence between the configuration of the mines and the coordinates of Khibiny earthquake epicenters has been detected. While there is some scatter in the earthquake locations in the Khibiny Massif, we believe that more accurate location of these earthquakes will be possible in the future by using the combined data from Apatity stations, Norwegian stations operated by NORSAR and the recently installed IRIS station in Lovozero. This is an important task for future studies.

*2. Underground explosions have been shown to trigger rockbursts*

Triggering effects have been demonstrated to take place at underground mines, when the depth of the mining has exceeded 100 meters. Currently about 30% of all underground explosions have been found to trigger significant rockbursts. By "significant", we mean that they are detectable at a distance of at least 50 km. The triggered rockbursts usually occur within a few tens of seconds after the explosion. Our studies have not revealed any similar triggering effect for open-pit mining explosions in Khibiny.

*3. Magnitude-yield correlation is demonstrated for underground explosions*

We have demonstrated a correlation between the yields of underground explosions and their magnitudes. The overall correlation (using all underground explosions) is about 0.72, but it is as high as 0.89 when considering explosions from Mine 3 only. This mine has deeper underground part and well recorded underground explosions. When considering open-pit explosions, we note that other investigators have been unable to find any correspondence between the (aggregate) yields and the seismic magnitudes. We attribute this difference to the different shot practice for open-pit and underground explosions.

*4. Change in stress field may contribute to the observed seismicity increase*

Some of the increased seismicity in the Khibiny Massif is possibly connected with the open-pit mining, and could be associated with the removal of large volumes of rock, causing a change in the stress regime. In particular, this manifests itself in a gradual displacement of lines of equal seismic energy release in the direction of Mine 4. Our studies have confirmed the conclusions of Kremenetskaya and Trjapitsin (1995) that the rock extraction from a high-stress environment can cause increase in overall seismicity.

## 7.0 Acknowledgement

This research was sponsored by the United States Air Force, European Office of Aerospace Research and Development under Contract No. F61708-94-C0016. The authors would like to acknowledge the contributions from the staff of the Kola Regional Seismological Centre. We also greatly appreciate the cooperation with the NORSAR staff and in particular the NORSAR Director, Dr. Frode Ringdal in carrying out this work.

## 8.0 References

Ahjos, T. and H. Korhonen (1984): On a catalogue of historical earthquakes in Fennoscandian area. 24 pp.

Arzamastsev, A.A. (1994) Unique paleozoic intrusions of the Kola peninsula. Kola Science Centre, Apatity, 79pp (in Russian).

Assinovskaya, B.A. and E.R. Acselevich (1989): Results of studies of seismicity in SE Barents Sea. **In:** *Geophysical Research of the Lithosphere of North European Part of the USSR*. Apatity, pp. 41-48.

Cook, N.G.W. (1976): Seismicity associated with mining. *Eng. Geol.* (Amsterdam), 10, 99-122.

Gibowicz, S.J. (1990): Seismicity induced by mining. In: *Advances in Geophysics*, 32, R. Dmowska and B. Saltzman (eds.), Academic Press, San Diego.

Glowacka, E. and Kijko, A. (1989). Continuous evaluation of seismic hazard induced by the deposit extraction in selected mines in Poland. ESC Proceedings, 21st Gen. Ass. Sofia, Bulgaria, 23-27 August 1988, 444-451.

Johnston, J.C. (1992): Rockbursts from a global perspective. In: Peter Knoll (Ed.): Induced Seismicity, A.A. Balkema, Rotterdam, Netherlands, pp. 63-78.

Kremenetskaya, E.O. (1991): Contemporary seismicity of the NW part of the USSR. In: NORSAR Semiannual Tech. Summ. 1 Apr-30 Sept 1991, NORSAR Sci. Rep. No. 1-91/92, Kjeller, Norway.

Kremenetskaya, E.O. & V. M. Trjapitsin (1995): Induced seismicity in the Khibiny Massif (Kola Peninsula), PAGEOPH Vol 145, No 1 (in press).

Markov, G.A. (1977): Tectonic stress and rock pressure in Khibiny mines. Leningrad, Nauka, 187 pp. (in Russian).

McGarr, A. (1991). On a possible connection between three major earthquakes in California and oil production. *Bull. Seism. Soc. Am.*, 81, 948-970.

Meyer, K. and Ahjos, T. (1985). Temporal variations of energy release by earthquakes in the Baltic Shield. *Geophysica*, Vol. 21, No 1, 51-64.

Mykkeltveit, S. (1992): Mining explosions in the Khibiny Massif (Kola Peninsula of Russia) recorded at the Apatity three-component station. Report PL-TR-92-2253, Phillips Laboratory, Hanscom AFB, MA, USA.

Panasenko, G.D. (1969). Seismic features of the northeast Baltic Shield. Leningrad: Nauka, 184 p (in Russian).

Panasenko, G.D. (1983): Technogenic increase of tectonic activity in the Khibiny Massif, problems and ways to study it. In: Geophysical Investigations in the European North of the USSR, KB AS USSR, pp. 25-38 (in Russian).

Panasenko, G.D. and Yakovlev, V.M. (1983). About the nature of anomalous deformation of a transport tunnel in the mountain Yukspor. In: Geophysical Investigations in the European North of the USSR, KB AS USSR, Apatity, pp. 38-44 (in Russian).

Reasenburg, P.A. and Simpson, R.W. (1992). Response of regional seismicity to the static stress changes produced by Loma Prieta earthquake, *Science*, 255, 1687-1689.

Stein, R.S., King, G.C.P. and Lin, J. (1992). Changes in failure stress on the southern San Andreas fault system caused by the 1992 magnitude = 7.4 Landers earthquake. Science, 258, 1328-1332.

Yakovlev, V.M. (1982). Recent crustal movement in the zone of the southern contact of the Khibiny Massif from data geometric levelling. In: Geophysic and geodynamic investigations of the North-East of the Baltic Shield, KB AS USSR, Apatity, pp. 85-88 (in Russian).

# APPENDIX A

## Empirical modeling of apparent velocities for seismic event location in Khibiny.

Currently the location of seismic events in Khibiny is not accurate enough because of two reasons: incompleteness of source data and absence of a detailed velocity model. To locate more correctly events in the viciniy of Khibiny mines (especially rockbursts or triggered earthquakes) we tried to derive empiric relationships between apparent velocities and distances for Khibiny mines and the closest seismic stations. We have done this study without reference to any particular structural model and we have used data on explosions at Khibiny mines with known coordinates.

At the first stage of this analysis we have considered two stations: AP0 and APA which are situated to the west and south-west from the Khibiny mines.

The geometrical configuration is as follows (R means distance) :

R(APA-AP0) = 19.638 km

**Table A-1: Distance from mines to AP0 and APA**

| MINE | R(MINE-AP0) | R(MINE-APA) | dR |
|---|---|---|---|
| 1 | 31.936 | 17.402 | 14.534 |
| 2 | 32.81 | 16.751 | 16.059 |
| 3 | 35.726 | 18.529 | 17.197 |
| 4 | 38.25 | 20.596 | 17.654 |
| 5 | 43.162 | 25.48 | 17.682 |
| 6 | 49.206 | 32.102 | 17.104 |

For all the mines we determined average time difference between arrivals of P and S waves to these two stations :

**Table A-2: Time differences and calculated velocities**

| MINE | dTp(APO-APA) | dTs(APO-APA) | Vp | Vs |
|---|---|---|---|---|
| 1 | 2.4 | 3.967 | 6.06 | 3.66 |
| 2 | 2.42 | 4.22 | 6.62 | 3.8 |
| 3 | 2.51 | 4.374 | 6.85 | 3.932 |
| 4 | 2.65 | 4.597 | 6.65 | 3.84 |
| 5 | 2.495 | 4.225 | 7.08 | 4.184 |
| 6 | 2.371 | 4.05 | 7.21 | 4.22 |

In Table A-2, Vp and Vs are average apparent velocities calculated by using the time differentials listed.

Next we determined time differences between P and S arrivals for each station and all the mines and compared them with time differences calculated by the average velocities from Table A-2 :

**Table A-3: Comparison of actual and calculated time differences**

| MINE | APO Actual | APA Actual | APO Calculated | APA Calculated |
|---|---|---|---|---|
| 1 | 4 | 2.19 | 3.46 | 1.88 |
| 2 | 4.14 | 2.18 | 3.67 | 1.88 |
| 3 | 4.28 | 2.39 | 3.87 | 2 |
| 4 | 4.71 | 2.52 | 4.21 | 2.27 |
| 5 | 4.8 | 3.2 | 4.22 | 2.49 |
| 6 | 5.77 | 3.95 | 4.87 | 3.15 |

Tp-Ts calculated by average velocities are significantly less than actually observed values. This indicates that a non-uniform velocity model should be used.

Our next step was to check a set of empirical hypotheses about the apparent velocities. The first one was that we have different uniform velocities in Khibiny and outside. From Table A-2 we obtained for this model by the least squares method the following velocities :

**Table A-4: Calculated velocities**

| Type | In Khibiny | Outside |
|---|---|---|
| Vp | 2.22 | 7.41 |
| Vs | 1.72 | 4.3 |

This approximates well the time differences dt(AP0-APA) but after calculation Ts-Tp we obtained :

**Table A-5: Time differences Ts-Tp**

| MINE | AP0(actual) | APA(actual) | AP0(model) | APA(model) |
|---|---|---|---|---|
| 1 | 4 | 2.19 | 3.56 | 1.93 |
| 2 | 4.14 | 2.18 | 3.68 | 1.88 |
| 3 | 4.28 | 2.39 | 4 | 2.08 |
| 4 | 4.71 | 2.52 | 4.24 | 2.29 |
| 5 | 4.8 | 3.2 | 4.7 | 2.77 |
| 6 | 5.77 | 3.95 | 5.27 | 3.4 |

These dt are also significantly less than the observed values so this hypothesis was rejected.

The next hypothesis was that slowness (inverse velocity S=1/V) depends linearly on distance:

$$S = S0 + A*R$$

For this hypothesis we obtained from Table A-2 (by least squares):

SOP=0.1818 AP=-0.0005583

SOS=0.3148 AS=-0.001009

The agreement with Table A-2 is shown below:

**Table A-6: Actual and calculated P and S times**

| MINE | P(actual) | P(model) | S(actual) | S(model) |
|---|---|---|---|---|
| 1 | 2.4 | 2.2424 | 3.97 | 3.8534 |
| 2 | 2.42 | 2.4746 | 4.22 | 4.2523 |
| 3 | 2.51 | 2.6048 | 4.374 | 4.4721 |
| 4 | 2.65 | 2.629 | 4.597 | 4.5096 |
| 5 | 2.495 | 2.5377 | 4.225 | 4.3441 |
| 6 | 2.371 | 2.336 | 4.05 | 3.9874 |

We compared also real (Table A-3) and model Ts-Tp:

**Table A-7: Comparison of actual and computed Ts-Tp**

| MINE | AP0(actual) | APA(actual) | AP0(computed) | APA(computed) |
|---|---|---|---|---|
| 1 | 4 | 2.19 | 3.7885 | 2.1775 |
| 2 | 4.14 | 2.18 | 3.8777 | 2.1 |
| 3 | 4.28 | 2.39 | 4.1741 | 2.3068 |
| 4 | 4.71 | 2.52 | 4.4251 | 2.5445 |
| 5 | 4.8 | 3.2 | 4.8988 | 3.0924 |
| 6 | 5.77 | 3.95 | 5.4541 | 3.8028 |

The agreement is much better then in previous cases. Once the hypothesis is acceptable we calculated the regression parameters using the Tables A-2 and A-3 simultaneously :

SOP = 0.1791 AP = -0.0005394

SOS = 0.3175 AS = -0.001027

A comparison of real and model values of all dt is shown below:

**Table A-8: Comparisons for all models**

| MINE | dTp (AP0-APA) | | dTs (AP0-APA) | | Ts-Tp (AP0) | | Ts-Tp (APA) | |
|---|---|---|---|---|---|---|---|---|
| No | real | model | real | model | real | model | real | model |
| 1 | 2.22 | 2.4 | 3.88 | 3.97 | 3.92 | 4 | 2.26 | 2.19 |
| 2 | 2.45 | 2.42 | 4.28 | 4.22 | 4.01 | 4.14 | 2.18 | 2.18 |
| 3 | 2.57 | 2.51 | 4.50 | 4.37 | 4.32 | 4.28 | 2.39 | 2.39 |
| 4 | 2.60 | 2.65 | 4.54 | 4.59 | 4.58 | 4.71 | 2.64 | 2.52 |
| 5 | 2.51 | 2.50 | 4.37 | 4.23 | 5.06 | 4.8 | 3.20 | 3.20 |
| 6 | 2.32 | 2.37 | 4.01 | 4.05 | 5.63 | 5.77 | 3.94 | 3.95 |

The next stage was concerned with the Lovozero station (LVZ) which is close to Khibiny but situated at another azimuth with respect to the mines. By using P and S waves arrivals to the stations AP0 and APA and the previously described model of apparent velocity we calculated origin times of explosions:

T1 = Tp(APA)-D(APA)*Sp(D(APA));

T2 = Tp(AP0)-D(AP0)*Sp(D(AP0));

(ideally T1=T2) and we obtained apparent velocities for LVZ by:

Vp1 =R(MINE,LVZ)/(Tp(LVZ)-T1)

Vp2 =R(MINE,LVZ)/(Tp(LVZ)-T2)

Vs1 =R(MINE,LVZ)/(Ts(LVZ)-T1)

Vs2 =R(MINE,LVZ)/(Ts(LVZ)-T2)

The velocities Vp1, Vp2 as well as Vs1, Vs2 have the same distribution (which enables us to assume that we have not systematic error in origin times evaluation). Average apparent velocities appeared to be:

Vp = 6.16

Vs = 3.45

(distances from LVZ to the mines are from 33 to 46 km.)

The velocities at the same distances calculated by the previous model are greater:

VpMod(LVZ) = 6.19 - 6.48

VsMod(LVZ) = 3.52 - 3.7

The same procedure was applied with 4 ratios of model and real apparent velocities, i.e., Vp1/VpMod(LVZ), Vp2/VpMod(LVZ), Vs1/VsMod(LVZ), Vs2/VsMod(LVZ). All of them have the same distribution, average value is 0.95. We have drawn the conclusion that it is possible to use the model for the Lovozero station with correction coefficient 0.95.

For the stations located at farther distances the same approach gave us:

**Table A-9: Velocities for distant stations**

| Station | R to mines | Vp | Vs |
|---|---|---|---|
| PLQ | 146-152 | 6.22 | 3.61-3.7 |
| ARC | 392-407 | 7.1 | 4.05-4.06 |
| FIN | 781-790 | 7.48 | 4.21 |
| NRS | 1307-1325 | 7.835 | 4.41 |

This provided a set of different apparent velocity models for different stations: the first one for APA and APO, the second one for Lovozero (analogous to the previous one with correction coefficient 0.95) and the third one for far stations. Also, we used the model for the far stations to extend the other two models to longer distances.

The models were used in the location routines of our SBD software (seismic data base manager). After preliminary testing it has shown to provide more accurate location of explosions than models using standard hodographs for a layered medium. It also seems possible that Khibiny earthquakes and rockbursts are situated more close to the mines than has previously been estimated.

# APPENDIX B

## List of Rockbursts and Earthquakes in the Khibiny Massif 1948-1994

Table B-1 presents the following statistics for 1948-1990:

- Event number
- Date of event
- Origin time of event
- Coordinates (lat-lon); Note that for some events it has not been possible to determine coordinates because of insufficient seismic observations. However, other evidence (e.g., macroseismic) has indicated that they are indeed rockbursts in the Khibiny Massif.
- $M_L$ Local magnitude as reported by the Kola Regional Seismological Centre (for events after 1979, when the station APA came into operation)
- Seismic energy (ergs): Computed from $M_L$ as described by Kremenetskaya and Trjapitsin (1992).

Table B-2 presents similar statistics for 1991-1994, except that coda magnitude $M_C$ has been included together with a comment indicating which rockbursts are considered to be triggered by an immediately preceding explosion.

## Table B-1: Rockbursts in the Khibiny Massif 1948-1990

| No. | Date | Origin time | Coordinates | | | | $M_L$ | Seicmic energy (ergs) | |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 19480923 | 0000 | 67.70 | N | 33.60 | E | | 1.58 | E16 |
| 2 | 19550808 | 172059 | 67.70 | N | 33.60 | E | | 2.24 | E16 |
| 3 | 19550831 | 2115 | 67.70 | N | 33.60 | E | | 2.80 | E15 |
| 4 | 19600209 | 210731 | 67.60 | N | 33.60 | E | | 7.08 | E14 |
| 5 | 19740930 | 091142 | 67.70 | N | 33.70 | E | | 6.31 | E16 |
| 6 | 19791212 | 113452 | | | | | 2.1 | 9.27 | E14 |
| 7 | 19800118 | 001622 | 67.60 | N | 33.70 | E | 2.0 | 6.92 | E14 |
| 8 | 19810108 | 062330 | 67.60 | N | 33.70 | E | 1.9 | 5.16 | E14 |
| 9 | 19810416 | 205634 | | | | | 2.1 | 9.27 | E14 |
| 10 | 19810517 | 033041 | 67.60 | N | 33.97 | E | 1.3 | 8.93 | E13 |
| 11 | 19810517 | 044145 | | | | | 1.9 | 5.16 | E14 |
| 12 | 19810517 | 051951 | | | | | 1.3 | 8.93 | E13 |
| 13 | 19810517 | 072212 | | | | | 1.8 | 3.86 | E14 |
| 14 | 19810517 | 075528 | | | | | 2.2 | 1.20 | E15 |
| 15 | 19810517 | 080247 | | | | | 1.3 | 8.93 | E13 |
| 16 | 19810818 | 000747 | | | | | 2.5 | 2.98 | E15 |
| 17 | 19811116 | 065300 | | | | | 1.9 | 5.16 | E14 |
| 18 | 19820422 | 110258 | | | | | 2.1 | 9.27 | E14 |
| 19 | 19820829 | 053335 | 67.70 | N | 33.70 | E | 3.3 | 3.10 | E16 |
| 20 | 19840619 | 054430 | | | | | 1.4 | 1.20 | E14 |
| 21 | 19840619 | 054731 | 67.33 | N | 33.70 | E | 3.9 | 1.79 | E17 |
| 22 | 19840619 | 062012 | | | | | 0.9 | 2.77 | E13 |
| 23 | 19841030 | 105158 | | | | | 2.2 | 1.20 | E15 |
| 24 | 19841030 | 130400 | | | | | 0.8 | 2.07 | E13 |
| 25 | 19841030 | 142148 | 67.68 | N | 33.72 | E | 2.3 | 1.66 | E15 |
| 26 | 19850424 | 072542 | 67.78 | N | 33.70 | E | 1.7 | 2.88 | E14 |
| 27 | 19850620 | 120640 | 67.69 | N | 33.74 | E | 1.4 | 1.20 | E14 |
| 28 | 19850923 | 093208 | 67.65 | N | 33.72 | E | 1.6 | 2.15 | E14 |
| 29 | 19860306 | 105742 | | | | | 0.9 | 2.77 | E13 |
| 30 | 19860313 | 211626 | 67.71 | N | 33.89 | E | 1.2 | 6.14 | E13 |
| 31 | 19860319 | 113946 | | | | | 1.5 | 1.60 | E14 |
| 32 | 19860515 | 031942 | 67.67 | N | 33.71 | E | 1.4 | 1.20 | E14 |
| 33 | 19860517 | 011338 | 67.69 | N | 33.67 | E | 0.6 | 1.15 | E13 |
| 34 | 19860901 | 211131 | 67.65 | N | 33.78 | E | 0.9 | 2.77 | E13 |
| 35 | 19861104 | 214317 | 67.70 | N | 33.74 | E | 2.0 | 6.90 | E14 |
| 36 | 19870514 | 061824 | 67.63 | N | 33.73 | E | 1.5 | 1.60 | E14 |

## Table B-1: Rockbursts in the Khibiny Massif 1948-1990

| No. | Date | Origin time | Coordinates | | | | $M_L$ | Seicmic energy (ergs) | |
|---|---|---|---|---|---|---|---|---|---|
| 37 | 19870725 | 161339 | 67.66 | N | 33.90 | E | 2.9 | 9.60 | E15 |
| 38 | 19871110 | 172137 | 67.69 | N | 33.76 | E | 1.6 | 2.10 | E14 |
| 39 | 19880113 | 025153 | 67.73 | N | 33.83 | E | 2.6 | 4.00 | E15 |
| 40 | 19880118 | 020948 | 67.65 | N | 33.96 | E | 2.6 | 4.00 | E15 |
| 41 | 19880120 | 121510 | 67.60 | N | 33.50 | E | 2.6 | 4.00 | E15 |
| 42 | 19880211 | 124113 | | | | | 2.2 | 1.20 | E15 |
| 43 | 19880304 | 231701 | 67.70 | N | 33.70 | E | 2.1 | 9.30 | E14 |
| 44 | 19880416 | 115725 | 67.66 | N | 33.75 | E | 2.1 | 9.30 | E14 |
| 45 | 19880507 | 121921 | 67.60 | N | 34.00 | E | 2.0 | 6.90 | E14 |
| 46 | 19880604 | 230507 | 67.54 | N | 33.72 | E | 3.0 | 1.30 | E16 |
| 47 | 19880622 | 013408 | 67.65 | N | 33.47 | E | 2.4 | 2.20 | E15 |
| 48 | 19880903 | 162400 | 67.60 | N | 33.92 | E | 1.8 | 3.80 | E14 |
| 49 | 19881006 | 094741 | 67.61 | N | 34.19 | E | 3.3 | 3.10 | E16 |
| 50 | 19881123 | 211108 | 67.60 | N | 33.80 | E | 2.5 | 3.00 | E15 |
| 51 | 19890203 | 102741 | 67.80 | N | 33.90 | E | 2.2 | 1.20 | E15 |
| 52 | 19890416 | 063442 | 67.61 | N | 33.81 | E | 4.1 | 3.20 | E17 |
| 53 | 19890416 | 064141 | 67.61 | N | 33.81 | E | 1.6 | 2.10 | E14 |
| 54 | 19890707 | 114924 | 67.71 | N | 33.93 | E | 3.4 | 4.10 | E16 |
| 55 | 19890724 | 223234 | 67.60 | N | 33.78 | E | 2.5 | 3.00 | E15 |
| 56 | 19890724 | 233952 | 67.60 | N | 33.69 | E | 2.0 | 6.90 | E14 |
| 57 | 19890801 | 005503 | 67.67 | N | 33.80 | E | 1.9 | 5.20 | E14 |
| 58 | 19890804 | 012618 | 67.60 | N | 33.90 | E | 2.1 | 9.30 | E14 |
| 59 | 19900113 | 120110 | 67.70 | N | 33.90 | E | 2.0 | 6.90 | E14 |
| 60 | 19900113 | 215627 | 67.64 | N | 34.00 | E | 1.8 | 3.80 | E14 |
| 61 | 19900117 | 151722 | 67.70 | N | 33.80 | E | 1.7 | 2.90 | E14 |
| 62 | 19900120 | 121457 | 67.58 | N | 33.92 | E | 2.0 | 6.90 | E14 |
| 63 | 19900122 | 150211 | 67.54 | N | 33.73 | E | 1.8 | 3.80 | E14 |
| 64 | 19900210 | 163907 | 67.89 | N | 33.48 | E | 2.2 | 1.20 | E15 |
| 65 | 19900212 | 005430 | 67.73 | N | 33.69 | E | 1.9 | 5.20 | E14 |
| 66 | 19900213 | 013634 | 67.59 | N | 33.74 | E | 1.1 | 5.00 | E13 |
| 67 | 19900224 | 000635 | 67.67 | N | 33.84 | E | 1.4 | 1.20 | E14 |
| 68 | 19900313 | 074225 | 67.83 | N | 33.21 | E | 1.4 | 1.20 | E14 |
| 69 | 19900313 | 224807 | 67.61 | N | 33.77 | E | 2.0 | 6.90 | E14 |
| 70 | 19900314 | 205921 | 67.68 | N | 33.59 | E | 1.8 | 3.80 | E14 |
| 71 | 19900315 | 120725 | 67.45 | N | 33.21 | E | 0.9 | 2.80 | E13 |
| 72 | 19900322 | 181629 | 67.60 | N | 33.80 | E | 2.0 | 6.90 | E14 |
| 73 | 19900327 | 015434 | 67.70 | N | 33.40 | E | 1.8 | 3.80 | E14 |

## Table B-1: Rockbursts in the Khibiny Massif 1948-1990

| No. | Date | Origin time | Coordinates | | | | $M_L$ | Seicmic energy (ergs) | |
|---|---|---|---|---|---|---|---|---|---|
| 74 | 19900327 | 101115 | 67.70 | N | 34.00 | E | 1.8 | 3.80 | E14 |
| 75 | 19900328 | 111339 | 67.82 | N | 33.42 | E | 2.0 | 6.90 | E14 |
| 76 | 19900403 | 075417 | 67.60 | N | 33.90 | E | 2.1 | 9.30 | E14 |
| 77 | 19900423 | 023140 | | | | | 0.5 | 8.60 | E12 |
| 78 | 19900514 | 121751 | 67.60 | N | 33.70 | E | 1.2 | 6.70 | E13 |
| 79 | 19900514 | 215911 | 67.67 | N | 33.68 | E | 1.0 | 3.70 | E13 |
| 80 | 19900515 | 012248 | 67.70 | N | 33.85 | E | 1.0 | 3.70 | E13 |
| 81 | 19900515 | 120142 | 67.50 | N | 33.92 | E | 0.8 | 2.10 | E13 |
| 82 | 19900515 | 232340 | 67.59 | N | 33.87 | E | 0.7 | 1.50 | E13 |
| 83 | 19900516 | 042529 | 67.56 | N | 33.87 | E | 1.8 | 3.80 | E14 |
| 84 | 19900516 | 221255 | 67.67 | N | 33.93 | E | 0.9 | 2.80 | E13 |
| 85 | 19900521 | 022923 | 67.67 | N | 33.62 | E | 1.1 | 5.00 | E13 |
| 86 | 19900521 | 184943 | 67.68 | N | 33.88 | E | 0.5 | 8.60 | E12 |
| 87 | 19900523 | 190424 | 67.60 | N | 34.00 | E | 1.4 | 1.20 | E14 |
| 88 | 19900524 | 095421 | 67.70 | N | 33.90 | E | 1.3 | 8.93 | E13 |
| 89 | 19900528 | 091715 | 67.80 | N | 33.60 | E | 1.1 | 5.00 | E13 |
| 90 | 19900601 | 183010 | 67.63 | N | 33.82 | E | 2.0 | 6.90 | E14 |
| 91 | 19900603 | 050122 | 67.60 | N | 33.84 | E | 1.3 | 8.90 | E13 |
| 92 | 19900603 | 050134 | 67.60 | N | 33.84 | E | 1.2 | 6.70 | E13 |
| 93 | 19900605 | 104346 | 67.68 | N | 34.26 | E | 2.0 | 6.90 | E14 |
| 94 | 19900605 | 122602 | 67.62 | N | 34.02 | E | 2.0 | 6.90 | E14 |
| 95 | 19900608 | 001941 | 67.62 | N | 33.73 | E | 2.0 | 6.90 | E14 |
| 96 | 19900612 | 113532 | 67.63 | N | 34.29 | E | 2.1 | 9.30 | E14 |
| 97 | 19900612 | 153255 | 67.59 | N | 33.71 | E | 1.8 | 3.80 | E14 |
| 98 | 19900613 | 055353 | 67.61 | N | 33.85 | E | 1.1 | 5.00 | E13 |
| 99 | 19900613 | 215641 | 67.63 | N | 33.85 | E | 2.0 | 6.90 | E14 |
| 100 | 19900615 | 014007 | 67.74 | N | 33.74 | E | 0.9 | 2.80 | E13 |
| 101 | 19900615 | 032523 | 67.66 | N | 33.64 | E | 1.1 | 5.00 | E13 |
| 102 | 19900619 | 005734 | 67.60 | N | 33.92 | E | 0.8 | 2.10 | E13 |
| 103 | 19900621 | 130954 | 67.67 | N | 33.83 | E | 2.3 | 1.70 | E15 |
| 104 | 19900621 | 183048 | 67.69 | N | 33.83 | E | 2.0 | 6.90 | E14 |
| 105 | 19900621 | 231904 | 67.67 | N | 33.66 | E | 2.2 | 1.20 | E15 |
| 106 | 19900622 | 015115 | 67.61 | N | 33.81 | E | 2.4 | 2.20 | E15 |
| 107 | 19900624 | 065848 | 67.61 | N | 33.88 | E | 2.4 | 2.20 | E15 |
| 108 | 19900625 | 062215 | 67.56 | N | 33.82 | E | 2.3 | 1.70 | E15 |
| 109 | 19900625 | 113116 | 67.61 | N | 33.80 | E | 2.2 | 1.20 | E15 |
| 110 | 19900625 | 215128 | 67.67 | N | 33.66 | E | 2.3 | 1.70 | E15 |

## Table B-1: Rockbursts in the Khibiny Massif 1948-1990

| No. | Date | Origin time | Coordinates | | | | $M_L$ | Seicmic energy (ergs) | |
|---|---|---|---|---|---|---|---|---|---|
| 111 | 19900626 | 052403 | 67.72 | N | 33.30 | E | 2.4 | 2.20 | E15 |
| 112 | 19900627 | 004129 | 67.77 | N | 33.29 | E | 2.3 | 1.70 | E15 |
| 113 | 19900627 | 025428 | 67.67 | N | 33.79 | E | 2.2 | 1.20 | E15 |
| 114 | 19900627 | 051520 | 67.59 | N | 33.99 | E | 2.4 | 2.20 | E15 |
| 115 | 19900627 | 064141 | 67.66 | N | 34.07 | E | 2.8 | 7.20 | E15 |
| 116 | 19900628 | 015919 | 67.74 | N | 33.22 | E | 2.6 | 4.00 | E15 |
| 117 | 19900629 | 041211 | 67.69 | N | 33.75 | E | 2.8 | 7.20 | E15 |
| 118 | 19900630 | 045139 | 67.62 | N | 33.90 | E | 2.4 | 2.20 | E15 |
| 119 | 19900630 | 064224 | 67.64 | N | 34.10 | E | 2.6 | 4.00 | E15 |
| 120 | 19900821 | 223415 | 67.70 | N | 33.80 | E | 0.8 | 2.10 | E13 |
| 121 | 19900829 | 015418 | 67.60 | N | 34.20 | E | 1.7 | 2.90 | E14 |
| 122 | 19900906 | 003000 | 67.60 | N | 33.70 | E | 1.2 | 6.70 | E13 |
| 123 | 19900918 | 002457 | 67.60 | N | 33.60 | E | 1.3 | 8.90 | E13 |
| 124 | 19900918 | 144020 | 67.60 | N | 33.60 | E | 1.7 | 2.90 | E14 |
| 125 | 19901016 | 212007 | 67.70 | N | 33.80 | E | 1.1 | 5.00 | E13 |
| 126 | 19901017 | 053115 | 67.60 | N | 33.80 | E | 1.8 | 3.80 | E14 |
| 127 | 19901113 | 122924 | 67.60 | N | 33.70 | E | 1.8 | 3.80 | E14 |
| 128 | 19901113 | 125440 | 67.60 | N | 33.70 | E | 1.6 | 2.10 | E14 |
| 129 | 19901119 | 131051 | 67.70 | N | 33.50 | E | 1.5 | 1.60 | E14 |
| 130 | 19901127 | 095439 | 67.60 | N | 34.20 | E | 1.5 | 1.60 | E14 |
| 131 | 19901129 | 133258 | 67.70 | N | 33.60 | E | 1.7 | 2.90 | E14 |
| 132 | 19901205 | 000419 | 67.70 | N | 33.70 | E | 1.6 | 2.10 | E14 |
| 133 | 19901205 | 124410 | 67.70 | N | 33.60 | E | 1.2 | 6.70 | E13 |
| 134 | 19901211 | 095257 | 67.70 | N | 33.80 | E | 2.0 | 6.90 | E14 |
| 135 | 19901212 | 165836 | 67.70 | N | 33.70 | E | 1.3 | 8.90 | E13 |

**Table B-2: Earthquakes and Rockbursts in the Khibiny massif 1991-1994**

| DATE | | | TIME | | | COORDINATES | | ML | REMARK |
|---|---|---|---|---|---|---|---|---|---|
| 1991 | 1 | 28 | 1 | 16 | 3.2 | 67.64 | 33.73 | 1.1 | |
| 1991 | 1 | 30 | 0 | 28 | 55.1 | | | | |
| 1991 | 2 | 19 | 15 | 8 | 27 | 67.53 | 33.88 | 1 | |
| 1991 | 2 | 20 | 7 | 35 | 58.7 | 67.74 | 33.51 | | |
| 1991 | 3 | 5 | 0 | 8 | 36.3 | 67.67 | 33.78 | 1.8 | |
| 1991 | 3 | 12 | 20 | 45 | 19.7 | 67.93 | 33.93 | 1.7 | |
| 1991 | 3 | 19 | 22 | 55 | 33.1 | 67.73 | 33.65 | 1.6 | |
| 1991 | 3 | 24 | 4 | 50 | 40.4 | | | | TRIGGERED |
| 1991 | 3 | 24 | 8 | 13 | 41.3 | 67.66 | 33.83 | 1.6 | |
| 1991 | 3 | 26 | 15 | 54 | 20.2 | 67.61 | 33.45 | | |
| 1991 | 3 | 27 | 17 | 20 | 36.9 | 67.57 | 34.17 | 1.3 | |
| 1991 | 3 | 29 | 21 | 11 | 9.3 | 67.66 | 33.94 | | |
| 1991 | 3 | 30 | 17 | 42 | 15 | | | | |
| 1991 | 4 | 4 | 11 | 51 | 44.1 | 67.65 | 33.17 | 1.4 | |
| 1991 | 4 | 4 | 11 | 57 | 51.7 | 67.71 | 33.44 | 0.9 | |
| 1991 | 4 | 4 | 17 | 1 | 57.9 | 67.69 | 34.05 | 1.5 | |
| 1991 | 4 | 8 | 13 | 27 | 13.9 | 67.72 | 33.82 | | |
| 1991 | 4 | 8 | 13 | 28 | 10.5 | 67.70 | 33.9 | 1.3 | |
| 1991 | 4 | 12 | 15 | 35 | 49.6 | 67.67 | 33.92 | | |
| 1991 | 4 | 13 | 11 | 6 | 5.1 | 67.81 | 33.93 | | |
| 1991 | 4 | 13 | 12 | 6 | 0.7 | 67.72 | 33.79 | | |
| 1991 | 4 | 27 | 13 | 15 | 21.5 | 67.6 | 33.9 | | TRIGGERED |
| 1991 | 4 | 28 | 5 | 19 | 6.7 | 67.67 | 33.73 | 1.7 | TRIGGERED |
| 1991 | 4 | 28 | 5 | 24 | 4.4 | 67.67 | 33.73 | | TRIGGERED |
| 1991 | 4 | 28 | 5 | 33 | 19.7 | 67.67 | 33.73 | 0.9 | TRIGGERED |
| 1991 | 4 | 28 | 8 | 14 | 26.7 | 67.67 | 33.73 | | |
| 1991 | 4 | 28 | 22 | 18 | 1.8 | 67.62 | 33.87 | 1.9 | |
| 1991 | 5 | 3 | 7 | 39 | 33.4 | 67.64 | 34.28 | | |
| 1991 | 5 | 4 | 2 | 11 | 43.2 | 67.71 | 33.71 | | |
| 1991 | 5 | 5 | 5 | 48 | 2.2 | 67.65 | 34.07 | 2 | |
| 1991 | 5 | 5 | 21 | 45 | 41.1 | 67.66 | 33.68 | 1.4 | |
| 1991 | 5 | 7 | 0 | 22 | 34.5 | 67.61 | 34.24 | 2 | |
| 1991 | 5 | 7 | 13 | 9 | 8 | 67.85 | 33.95 | 2.5 | |
| 1991 | 5 | 7 | 17 | 24 | 38.1 | 67.639 | 33.74 | 1.3 | |
| 1991 | 5 | 12 | 19 | 59 | 34.7 | 67.58 | 33.99 | 1.4 | |
| 1991 | 5 | 17 | 4 | 42 | 12.8 | 67.65 | 33.8 | 1.5 | |
| 1991 | 5 | 17 | 13 | 13 | 40.1 | 67.61 | 34.14 | 1.5 | |
| 1991 | 5 | 18 | 12 | 37 | 49.6 | 67.71 | 34.06 | 1.6 | |
| 1991 | 5 | 24 | 11 | 20 | 27.8 | 67.71 | 33.87 | | |
| 1991 | 5 | 24 | 18 | 8 | 23.1 | 67.67 | 33.72 | 1.4 | |
| 1991 | 5 | 25 | 0 | 48 | 0 | | | | |
| 1991 | 5 | 25 | 3 | 43 | 31.8 | 67.61 | 33.87 | 2.0 | |
| 1991 | 5 | 27 | 14 | 22 | 5 | | | | |
| 1991 | 5 | 27 | 23 | 46 | 27.4 | | | | |
| 1991 | 5 | 30 | 7 | 45 | 8.8 | 67.49 | 33.35 | | |
| 1991 | 6 | 1 | 9 | 31 | 36.2 | | | | |
| 1991 | 6 | 1 | 9 | 31 | 42.2 | | | | |
| 1991 | 6 | 6 | 0 | 6 | 34.6 | | | | |
| 1991 | 6 | 15 | 11 | 1 | 54 | 67.6 | 33.7 | | |
| 1991 | 6 | 17 | 3 | 7 | 50.3 | 67.58 | 33.87 | | |
| 1991 | 6 | 26 | 4 | 33 | 43.5 | 67.51 | 34.09 | 1.5 | |
| 1991 | 7 | 4 | 10 | 56 | 9.1 | 67.89 | 33.67 | | |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 1991 | 7 | 5 | 9 | 56 | 31.2 | 67.85 | 32.89 | | |
| 1991 | 7 | 17 | 7 | 37 | 38.6 | 67.79 | 33.45 | | |
| 1991 | 7 | 19 | 21 | 18 | 8.8 | | | | |
| 1991 | 7 | 23 | 7 | 53 | 33.5 | 67.73 | 33.85 | 1.8 | |
| 1991 | 7 | 24 | 23 | 2 | 16.5 | 67.72 | 33.91 | 1.6 | |
| 1991 | 7 | 25 | 21 | 6 | 15.5 | | | | |
| 1991 | 7 | 26 | 5 | 12 | 10.5 | | | | |
| 1991 | 7 | 29 | 2 | 47 | 43.2 | 67.65 | 33.83 | 1.4 | |
| 1991 | 8 | 5 | 12 | 54 | 20 | | | | |
| 1991 | 8 | 5 | 15 | 27 | 25.7 | | | | |
| 1991 | 8 | 10 | 18 | 0 | 39 | 67.7 | 33.9 | 1.5 | TRIGGERED |
| 1991 | 8 | 15 | 8 | 35 | 45.3 | 67.68 | 33.80 | 1.4 | |
| 1991 | 8 | 17 | 8 | 40 | 56.7 | 67.6 | 34.03 | 1.6 | |
| 1991 | 8 | 30 | 2 | 44 | 4.3 | 67.68 | 34.01 | 2.0 | |
| 1991 | 8 | 31 | 16 | 9 | 2.8 | 67.63 | 33.83 | 1.4 | TRIGGERED |
| 1991 | 9 | 8 | 12 | 3 | 15.5 | | | | |
| 1991 | 9 | 8 | 12 | 3 | 29.8 | | | | |
| 1991 | 9 | 11 | 12 | 34 | 56.1 | 67.68 | 33.68 | 1.9 | |
| 1991 | 9 | 11 | 16 | 9 | 2.7 | 67.59 | 34.12 | 1.6 | |
| 1991 | 9 | 15 | 5 | 55 | 43.6 | | | | TRIGGERED |
| 1991 | 9 | 18 | 0 | 1 | 21.2 | | | 2 | |
| 1991 | 9 | 21 | 17 | 36 | 53.2 | | | | |
| 1991 | 9 | 25 | 18 | 9 | 18.3 | 67.57 | 33.73 | 1.3 | |
| 1991 | 9 | 25 | 18 | 16 | 29.6 | | | | |
| 1991 | 9 | 30 | 19 | 29 | 24.2 | | | 1.3 | |
| 1991 | 10 | 4 | 13 | 37 | 33.5 | 67.64 | 33.77 | | |
| 1991 | 10 | 17 | 23 | 18 | 58.2 | 67.61 | 33.97 | 1.7 | |
| 1991 | 10 | 25 | 15 | 41 | 43.4 | 67.63 | 33.85 | 1.6 | |
| 1991 | 10 | 25 | 17 | 30 | 17.3 | | | | |
| 1991 | 11 | 1 | 17 | 36 | 53.9 | 67.65 | 33.69 | 1.4 | |
| 1991 | 11 | 2 | 5 | 5 | 30 | 67.65 | 33.82 | 1.5 | |
| 1991 | 11 | 5 | 8 | 22 | 32.1 | 67.77 | 33.73 | 1.6 | |
| 1991 | 11 | 23 | 5 | 53 | 11.9 | 67.9 | 34.19 | 2.1 | |
| 1991 | 11 | 25 | 15 | 20 | 33 | | | | |
| 1991 | 12 | 5 | 13 | 52 | 47.2 | | | | |
| 1991 | 12 | 20 | 5 | 42 | 28.1 | 67.66 | 33.83 | 1.6 | |
| 1991 | 12 | 20 | 13 | 13 | 29.5 | 67.66 | 34.00 | 1.9 | |
| 1991 | 12 | 26 | 3 | 47 | 36.1 | 67.64 | 34.03 | 1.4 | |
| 1991 | 12 | 27 | 13 | 37 | 50.8 | 67.7 | 33.63 | 1.5 | |
| 1991 | 12 | 28 | 15 | 37 | 42.8 | 67.53 | 33.95 | 1.9 | TRIGGERED |
| 1991 | 12 | 28 | 15 | 41 | 21.8 | 67.7 | 33.83 | 1.5 | TRIGGERED |
| 1992 | 1 | 10 | 20 | 32 | 39.9 | 67.58 | 33.91 | 1.2 | |
| 1992 | 1 | 11 | 15 | 54 | 38.3 | 67.63 | 33.74 | 1.5 | |
| 1992 | 1 | 14 | 2 | 32 | 25.3 | 67.63 | 33.88 | 1.6 | |
| 1992 | 1 | 24 | 16 | 30 | 15.8 | 67.67 | 33.97 | 2.2 | |
| 1992 | 2 | 8 | 11 | 26 | 14.2 | 67.69 | 33.79 | 2.0 | TRIGGERED |
| 1992 | 2 | 19 | 18 | 6 | 3.7 | 67.58 | 33.86 | 1.7 | |
| 1992 | 2 | 23 | 5 | 43 | 40.9 | 67.65 | 33.76 | 0.8 | TRIGGERED |
| 1992 | 2 | 25 | 11 | 51 | 35 | 67.75 | 33.82 | 1.9 | |
| 1992 | 3 | 2 | 12 | 32 | 54.7 | 67.76 | 33.5 | | |
| 1992 | 3 | 5 | 17 | 28 | 3.24 | 67.59 | 33.85 | 1.7 | |
| 1992 | 3 | 6 | 12 | 23 | 51.9 | 67.67 | 33.61 | 1.8 | |
| 1992 | 3 | 7 | 11 | 49 | 40.8 | 67.54 | 33.99 | | |
| 1992 | 3 | 10 | 12 | 41 | 15.6 | 67.70 | 33.49 | 1.3 | |
| 1992 | 3 | 16 | 14 | 29 | 57.7 | 67.58 | 33.67 | 1.3 | |
| 1992 | 3 | 17 | 12 | 22 | 18.5 | | | | |
| 1992 | 3 | 22 | 2 | 13 | 4.58 | 67.68 | 33.62 | 1.3 | |
| 1992 | 3 | 23 | 9 | 10 | 18.3 | 67.76 | 33.61 | 1.2 | |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 1992 | 3 | 24 | 3 | 30 | 47.3 | 67.70 | 33.49 | 0.9 | |
| 1992 | 3 | 24 | 5 | 10 | 0.7 | 67.7 | 33.7 | 1.2 | |
| 1992 | 3 | 26 | 11 | 38 | 29.4 | 67.79 | 33.56 | | |
| 1992 | 3 | 26 | 21 | 46 | 46 | | | | |
| 1992 | 3 | 27 | 12 | 14 | 19.8 | 67.66 | 33.81 | 1.6 | |
| 1992 | 3 | 27 | 13 | 10 | 28.7 | 67.49 | 33.79 | 1.7 | |
| 1992 | 3 | 30 | 5 | 28 | 42.2 | 67.61 | 33.71 | 1.1 | |
| 1992 | 3 | 30 | 15 | 30 | 36.9 | 67.74 | 33.68 | 1.8 | |
| 1992 | 3 | 30 | 19 | 23 | 22 | | | | |
| 1992 | 3 | 30 | 21 | 35 | 33 | | | | |
| 1992 | 4 | 1 | 14 | 26 | 0.5 | | | | |
| 1992 | 4 | 3 | 1 | 19 | 2.1 | | | | |
| 1992 | 4 | 3 | 3 | 8 | 46.5 | 67.66 | 33.85 | 1.6 | |
| 1992 | 4 | 3 | 4 | 38 | 22.8 | 67.60 | 33.82 | 1.4 | |
| 1992 | 4 | 3 | 15 | 8 | 17.3 | 67.57 | 33.7 | 1.1 | |
| 1992 | 4 | 3 | 15 | 33 | 20.4 | 67.7 | 34.2 | 1.9 | |
| 1992 | 4 | 3 | 19 | 31 | 18.8 | 67.75 | 33.64 | 1.3 | |
| 1992 | 4 | 3 | 21 | 58 | 12.8 | 67.69 | 33.81 | 1.4 | |
| 1992 | 4 | 7 | 20 | 50 | 27.4 | 67.72 | 33.68 | 1.6 | |
| 1992 | 4 | 8 | 11 | 51 | 40.6 | 67.72 | 33.55 | 1.5 | |
| 1992 | 4 | 8 | 22 | 42 | 19.6 | 67.66 | 33.74 | 0.8 | |
| 1992 | 4 | 10 | 5 | 44 | 16.5 | 67.52 | 33.9 | 1.8 | |
| 1992 | 4 | 14 | 4 | 30 | 16.5 | 67.72 | 33.84 | 2.1 | |
| 1992 | 4 | 15 | 12 | 8 | 11.9 | 67.54 | 33.98 | 1.7 | |
| 1992 | 4 | 17 | 8 | 31 | 12.4 | 67.66 | 33.7 | | |
| 1992 | 4 | 17 | 11 | 22 | 8.4 | 67.72 | 34.01 | 1.7 | |
| 1992 | 4 | 17 | 19 | 46 | 20.2 | 67.52 | 34.23 | 1.4 | |
| 1992 | 4 | 20 | 0 | 27 | 6.02 | 67.63 | 33.66 | 1.0 | |
| 1992 | 4 | 21 | 11 | 56 | 59.5 | 67.63 | 33.78 | 1.6 | |
| 1992 | 4 | 21 | 17 | 53 | 6.7 | 67.7 | 33.81 | 1.7 | |
| 1992 | 4 | 24 | 0 | 12 | 50 | 67.67 | 33.86 | 1.5 | |
| 1992 | 4 | 26 | 4 | 23 | 7.3 | | | | TRIGGERED |
| 1992 | 4 | 26 | 5 | 7 | 35.8 | | | | TRIGGERED |
| 1992 | 4 | 28 | 4 | 31 | 16.3 | 67.6 | 33.79 | 1.3 | |
| 1992 | 4 | 29 | 12 | 9 | 29.1 | 67.6 | 34.05 | 1.9 | |
| 1992 | 4 | 30 | 4 | 22 | 49 | 67.68 | 33.83 | 1.5 | |
| 1992 | 5 | 8 | 12 | 43 | 39.3 | 67.6 | 33.9 | 1.8 | |
| 1992 | 5 | 8 | 12 | 43 | 53.6 | | | | |
| 1992 | 5 | 16 | 0 | 4 | 30.7 | 67.61 | 33.71 | 1.6 | |
| 1992 | 5 | 17 | 12 | 15 | 41.7 | 67.65 | 33.58 | 1 | |
| 1992 | 5 | 18 | 17 | 16 | 29.1 | 67.70 | 33.71 | 1.3 | |
| 1992 | 5 | 19 | 11 | 54 | 7.1 | 67.49 | 33.89 | 1.5 | |
| 1992 | 5 | 20 | 11 | 59 | 44.4 | 67.68 | 33.52 | 1.5 | |
| 1992 | 5 | 22 | 0 | 13 | 49.9 | 67.61 | 34 | 1.6 | |
| 1992 | 5 | 26 | 2 | 49 | 42.8 | 67.60 | 33.83 | 1.8 | |
| 1992 | 5 | 26 | 8 | 25 | 16.7 | 67.67 | 33.69 | 1.3 | |
| 1992 | 6 | 2 | 12 | 18 | 16.2 | 67.64 | 33.83 | 1.6 | |
| 1992 | 6 | 2 | 12 | 18 | 32.8 | 67.6 | 33.8 | 2 | |
| 1992 | 6 | 16 | 23 | 38 | 58.3 | 67.64 | 34.07 | 2.1 | |
| 1992 | 6 | 17 | 8 | 56 | 31.1 | 67.6 | 33.8 | 1.5 | |
| 1992 | 7 | 7 | 19 | 39 | 37.8 | 67.65 | 33.71 | 1.3 | |
| 1992 | 7 | 8 | 18 | 26 | 20.5 | 67.7 | 33.74 | 1.5 | |
| 1992 | 7 | 12 | 3 | 29 | 29.5 | 67.61 | 33.78 | 1.6 | TRIGGERED |
| 1992 | 7 | 15 | 16 | 1 | 2.71 | 67.67 | 33.78 | 1.5 | |
| 1992 | 7 | 16 | 8 | 12 | 51.1 | 67.74 | 33.75 | 1.4 | |
| 1992 | 7 | 18 | 5 | 15 | 34.2 | 67.51 | 33.66 | 1.3 | |
| 1992 | 7 | 20 | 9 | 54 | 25.3 | 67.62 | 33.73 | 1.3 | |
| 1992 | 8 | 4 | 10 | 43 | 46.6 | 67.72 | 34.02 | 1.7 | |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 1992 | 8 | 6 | 6 | 19 | 11.9 | | | | |
| 1992 | 8 | 19 | 2 | 1 | 49.5 | 67.65 | 33.84 | 1.7 | |
| 1992 | 8 | 22 | 10 | 43 | 54.4 | 67.6 | 33.8 | 1 | TRIGGERED |
| 1992 | 8 | 28 | 1 | 29 | 57.1 | 67.53 | 33.18 | 1.3 | |
| 1992 | 8 | 30 | 3 | 21 | 51.2 | 67.67 | 33.73 | 1.0 | TRIGGERED |
| 1992 | 8 | 30 | 15 | 52 | 47.8 | | | | |
| 1992 | 9 | 2 | 9 | 58 | 40.6 | 67.76 | 34 | 2.0 | |
| 1992 | 10 | 3 | 12 | 32 | 31.6 | | | | |
| 1992 | 10 | 9 | 0 | 18 | 18.4 | 67.71 | 33.85 | 2.1 | |
| 1992 | 10 | 18 | 9 | 34 | 2.5 | | | | |
| 1992 | 10 | 20 | 23 | 29 | 44.6 | 67.63 | 33.84 | 1.7 | |
| 1992 | 11 | 4 | 9 | 56 | 24.3 | 67.62 | 33.84 | 1.8 | |
| 1992 | 11 | 19 | 14 | 55 | 29.2 | 67.68 | 33.72 | 1.5 | |
| 1992 | 11 | 22 | 5 | 7 | 48.5 | 67.64 | 33.761 | 0.7 | TRIGGERED |
| 1992 | 11 | 28 | 15 | 19 | 6.6 | 67.65 | 33.85 | 1.1 | |
| 1992 | 11 | 28 | 23 | 8 | 11.6 | 67.76 | 33.72 | 0.8 | |
| 1992 | 11 | 29 | 4 | 31 | 11.8 | | | | TRIGGERED |
| 1992 | 11 | 29 | 5 | 56 | 28.7 | | | | TRIGGERED |
| 1992 | 12 | 3 | 14 | 12 | 9.04 | 67.61 | 33.90 | 1.7 | |
| 1992 | 12 | 4 | 2 | 27 | 45.9 | 67.67 | 33.71 | 1 | |
| 1992 | 12 | 8 | 22 | 23 | 6.4 | 67.72 | 33.7 | 1.2 | |
| 1992 | 12 | 15 | 17 | 38 | 54.6 | 67.75 | 33.86 | 1.1 | |
| 1992 | 12 | 15 | 18 | 50 | 34.1 | 67.68 | 33.63 | 1.3 | |
| 1992 | 12 | 15 | 21 | 46 | 32.5 | 67.71 | 33.72 | 1.2 | |
| 1992 | 12 | 16 | 17 | 21 | 28.2 | 67.71 | 33.53 | 0.6 | |
| 1992 | 12 | 18 | 3 | 46 | 33.9 | 67.7 | 33.75 | 1.7 | |
| 1992 | 12 | 23 | 18 | 38 | 29.3 | 67.669 | 33.78 | 1.6 | |
| 1992 | 12 | 24 | 2 | 1 | 54.8 | 67.68 | 33.53 | 0.8 | |
| 1992 | 12 | 30 | 20 | 26 | 28.1 | 67.71 | 33.3 | 0.7 | |
| 1992 | 12 | 31 | 4 | 36 | 25.1 | 67.64 | 33.76 | 0.7 | TRIGGERED |
| 1992 | 12 | 31 | 4 | 48 | 55.9 | 67.64 | 33.76 | 0.8 | TRIGGERED |
| 1992 | 12 | 31 | 8 | 48 | 40 | | | | |
| 1992 | 12 | 31 | 9 | 17 | 52.6 | 67.69 | 33.73 | 0.9 | |
| 1993 | 1 | 8 | 1 | 21 | 22.5 | 67.63 | 33.33 | | |
| 1993 | 1 | 9 | 7 | 5 | 54.2 | 67.42 | 34.15 | | |
| 1993 | 1 | 11 | 21 | 14 | 45 | 67.66 | 33.84 | | |
| 1993 | 1 | 13 | 23 | 14 | 19.4 | 67.74 | 33.69 | 1.1 | |
| 1993 | 1 | 14 | 14 | 48 | 37.7 | 67.65 | 33.28 | 0.8 | |
| 1993 | 1 | 14 | 15 | 38 | 30.5 | 67.65 | 33.77 | 1.5 | |
| 1993 | 1 | 20 | 10 | 30 | 57.5 | 67.67 | 33.76 | 0.8 | |
| 1993 | 1 | 20 | 19 | 36 | 17.2 | 67.72 | 33.86 | 1.1 | |
| 1993 | 1 | 20 | 22 | 41 | 22.1 | 67.7 | 33.92 | 1.6 | |
| 1993 | 1 | 20 | 23 | 30 | 48.3 | 67.71 | 33.67 | 1.1 | |
| 1993 | 1 | 20 | 23 | 43 | 54.5 | 67.66 | 33.78 | 1 | |
| 1993 | 1 | 21 | 0 | 3 | 29.3 | 67.68 | 33.78 | 1 | |
| 1993 | 1 | 21 | 0 | 38 | 58.4 | 67.71 | 33.92 | 1.2 | |
| 1993 | 1 | 21 | 2 | 17 | 55.3 | 67.75 | 33.64 | 1.8 | |
| 1993 | 1 | 21 | 8 | 54 | 33.3 | 67.66 | 33.73 | 1.4 | |
| 1993 | 1 | 21 | 18 | 11 | 26.3 | 67.74 | 33.77 | 1.1 | |
| 1993 | 1 | 22 | 3 | 12 | 49.8 | 67.69 | 33.85 | 1.2 | |
| 1993 | 1 | 24 | 8 | 7 | 14.7 | 67.65 | 33.76 | 0.7 | TRIGGERED |
| 1993 | 1 | 24 | 8 | 9 | 15.4 | 67.65 | 33.76 | 0.6 | TRIGGERED |
| 1993 | 1 | 24 | 8 | 18 | 8.6 | 67.65 | 33.76 | 0.6 | TRIGGERED |
| 1993 | 1 | 24 | 8 | 37 | 25.9 | 67.65 | 33.76 | 0.8 | TRIGGERED |
| 1993 | 1 | 24 | 8 | 52 | 7.9 | 67.65 | 33.76 | | TRIGGERED |
| 1993 | 1 | 24 | 10 | 16 | 28.8 | | | | |
| 1993 | 1 | 24 | 12 | 22 | 24.3 | | | | |
| 1993 | 1 | 24 | 13 | 10 | 41.2 | 67.65 | 33.75 | 1.3 | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 1993 | 1 | 24 | 15 | 19 | 21.5 | 67.67 | 33.78 | 1.4 |
| 1993 | 1 | 24 | 19 | 8 | 15.8 | | | |
| 1993 | 1 | 24 | 19 | 46 | 26 | | | |
| 1993 | 1 | 25 | 13 | 55 | 26.4 | | | |
| 1993 | 1 | 25 | 13 | 57 | 27.8 | | | |
| 1993 | 1 | 27 | 9 | 46 | 20.8 | | | |
| 1993 | 1 | 27 | 14 | 47 | 10.1 | | | |
| 1993 | 1 | 28 | 11 | 57 | 10.9 | 67.64 | 33.86 | 1.6 |
| 1993 | 1 | 28 | 16 | 18 | 57.3 | 67.66 | 34.07 | 1.5 |
| 1993 | 1 | 28 | 17 | 38 | 20.8 | 67.74 | 33.79 | 1.2 |
| 1993 | 1 | 28 | 18 | 33 | 56.1 | | | |
| 1993 | 1 | 28 | 23 | 18 | 29.8 | 67.7 | 33.71 | 1.9 |
| 1993 | 1 | 28 | 23 | 25 | 12.6 | 67.69 | 33.74 | 1.3 |
| 1993 | 1 | 28 | 23 | 27 | 41.5 | | | |
| 1993 | 1 | 28 | 23 | 31 | 0 | | | |
| 1993 | 1 | 28 | 23 | 39 | 0 | | | |
| 1993 | 1 | 28 | 23 | 47 | 0 | | | |
| 1993 | 1 | 29 | 0 | 6 | 0 | | | |
| 1993 | 1 | 29 | 1 | 34 | 0 | | | |
| 1993 | 1 | 29 | 1 | 47 | 0 | | | |
| 1993 | 1 | 29 | 2 | 28 | 0 | | | |
| 1993 | 1 | 29 | 3 | 31 | 0 | | | |
| 1993 | 1 | 29 | 4 | 34 | 0 | | | |
| 1993 | 1 | 29 | 6 | 10 | 0 | | | |
| 1993 | 1 | 29 | 8 | 53 | 0 | | | |
| 1993 | 1 | 29 | 9 | 41 | 38.4 | 67.69 | 33.74 | 1.4 |
| 1993 | 1 | 29 | 12 | 53 | 1.6 | 67.7 | 33.83 | 1.2 |
| 1993 | 1 | 29 | 21 | 14 | 55.9 | 67.67 | 33.76 | 1.4 |
| 1993 | 1 | 30 | 5 | 24 | 15.2 | 67.69 | 33.80 | 1.5 |
| 1993 | 1 | 30 | 18 | 51 | 55.1 | 67.69 | 33.56 | 1.4 |
| 1993 | 2 | 2 | 11 | 17 | 8.16 | 67.65 | 33.73 | 1.5 |
| 1993 | 2 | 3 | 6 | 31 | 7.9 | 67.64 | 33.73 | 1 |
| 1993 | 2 | 3 | 18 | 33 | 37.5 | 67.64 | 34.03 | 1.2 |
| 1993 | 2 | 4 | 23 | 54 | 47 | 67.72 | 33.68 | 1.3 |
| 1993 | 2 | 5 | 10 | 30 | 12.5 | 67.7 | 33.72 | 1.5 |
| 1993 | 2 | 5 | 23 | 31 | 48.8 | 67.62 | 33.85 | 1.2 |
| 1993 | 2 | 6 | 9 | 45 | 19.1 | 67.62 | 33.79 | 1.5 |
| 1993 | 2 | 6 | 18 | 28 | 25.3 | 67.65 | 33.70 | 1.1 |
| 1993 | 2 | 9 | 18 | 42 | 28.3 | 67.72 | 33.76 | 1.5 |
| 1993 | 2 | 10 | 18 | 23 | 7.98 | 67.68 | 33.67 | 1.3 |
| 1993 | 2 | 11 | 1 | 46 | 36.1 | 67.69 | 33.79 | 1.2 |
| 1993 | 2 | 11 | 10 | 26 | 59.3 | 67.72 | 33.74 | 1.6 |
| 1993 | 2 | 11 | 17 | 36 | 47.7 | 67.67 | 33.67 | 1.1 |
| 1993 | 2 | 11 | 20 | 33 | 22.3 | | | |
| 1993 | 2 | 12 | 2 | 55 | 18.9 | | | |
| 1993 | 2 | 12 | 23 | 34 | 5.44 | 67.73 | 33.70 | 1.3 |
| 1993 | 2 | 13 | 3 | 14 | 45.5 | 67.71 | 33.74 | 1.5 |
| 1993 | 2 | 13 | 17 | 25 | 40.4 | 67.58 | 34.08 | 1.1 |
| 1993 | 2 | 13 | 20 | 12 | 8.9 | 67.65 | 33.85 | 1.3 |
| 1993 | 2 | 14 | 18 | 4 | 11.2 | 67.68 | 33.67 | 1.3 |
| 1993 | 2 | 16 | 2 | 43 | 17.8 | 67.7 | 33.48 | 1 |
| 1993 | 2 | 16 | 17 | 20 | 34.3 | 67.69 | 33.67 | 1.4 |
| 1993 | 2 | 17 | 17 | 57 | 8.58 | 67.7 | 33.76 | 1.5 |
| 1993 | 2 | 18 | 4 | 15 | 35.1 | 67.71 | 33.64 | 1.2 |
| 1993 | 2 | 18 | 6 | 12 | 29.9 | 67.62 | 34.1 | 1.5 |
| 1993 | 2 | 18 | 17 | 42 | 28.3 | 67.7 | 33.51 | 1.1 |
| 1993 | 2 | 18 | 23 | 20 | 3.2 | 67.7 | 33.81 | 1.2 |
| 1993 | 2 | 19 | 23 | 14 | 16.8 | 67.65 | 33.68 | 0.7 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 1993 | 2 | 19 | 23 | 30 | 2.9 | 67.63 | 33.85 | 1.4 | |
| 1993 | 2 | 20 | 15 | 1 | 30.7 | 67.68 | 33.75 | 1.2 | |
| 1993 | 2 | 23 | 18 | 39 | 25.3 | 67.67 | 33.78 | 1.4 | |
| 1993 | 2 | 24 | 1 | 17 | 50 | | | | |
| 1993 | 2 | 25 | 0 | 2 | 11.2 | | | | |
| 1993 | 2 | 25 | 3 | 53 | 7.21 | 67.68 | 33.73 | 1.3 | |
| 1993 | 2 | 25 | 5 | 17 | 41.6 | 67.74 | 33.64 | | |
| 1993 | 2 | 25 | 23 | 8 | 3.54 | 67.63 | 33.85 | 1.4 | |
| 1993 | 2 | 26 | 14 | 12 | 58.6 | 67.7 | 33.82 | 1.3 | |
| 1993 | 2 | 27 | 10 | 43 | 48.7 | 67.69 | 33.77 | 1.2 | |
| 1993 | 3 | 1 | 0 | 20 | 52.5 | 67.7 | 33.74 | 1.5 | |
| 1993 | 3 | 1 | 3 | 45 | 31.5 | 67.68 | 33.72 | 1.2 | |
| 1993 | 3 | 1 | 8 | 0 | 50.2 | 67.67 | 33.52 | 0.7 | |
| 1993 | 3 | 2 | 4 | 52 | 6.14 | 67.68 | 33.73 | 1.2 | |
| 1993 | 3 | 2 | 7 | 31 | 9.3 | 67.84 | 32.94 | 1.4 | |
| 1993 | 3 | 2 | 20 | 48 | 28.8 | 67.69 | 33.77 | 1.3 | |
| 1993 | 3 | 4 | 2 | 32 | 44.2 | 67.6 | 33.92 | 1.1 | |
| 1993 | 3 | 6 | 7 | 56 | 7.5 | 67.7 | 33.62 | 1.1 | |
| 1993 | 3 | 6 | 11 | 0 | 47.5 | | | | TRIGGERED |
| 1993 | 3 | 6 | 11 | 0 | 49.5 | | | | TRIGGERED |
| 1993 | 3 | 6 | 11 | 29 | 39.3 | 67.64 | 33.9 | 2 | TRIGGERED |
| 1993 | 3 | 6 | 20 | 53 | 24 | 67.65 | 33.82 | 1.4 | |
| 1993 | 3 | 7 | 6 | 43 | 40.5 | 67.51 | 33.89 | 0.9 | |
| 1993 | 3 | 9 | 5 | 11 | 33.5 | 67.7 | 33.65 | 1.3 | |
| 1993 | 3 | 9 | 20 | 30 | 14.9 | 67.65 | 33.93 | 1.3 | |
| 1993 | 3 | 10 | 10 | 0 | 28.2 | 67.72 | 33.73 | 1.3 | |
| 1993 | 3 | 10 | 22 | 57 | 58.8 | 67.69 | 33.65 | 1.4 | |
| 1993 | 3 | 12 | 0 | 17 | 53.7 | 67.66 | 33.60 | 1.1 | |
| 1993 | 3 | 12 | 1 | 3 | 41.4 | 67.68 | 33.83 | | |
| 1993 | 3 | 12 | 8 | 49 | 48.2 | 67.7 | 33.81 | 1.4 | |
| 1993 | 3 | 12 | 22 | 22 | 19.3 | 67.68 | 33.67 | 1.5 | |
| 1993 | 3 | 14 | 8 | 36 | 19 | 67.68 | 33.76 | 1.3 | |
| 1993 | 3 | 16 | 17 | 26 | 32 | 67.67 | 33.67 | 1.4 | |
| 1993 | 3 | 17 | 11 | 36 | 43.5 | 67.65 | 33.87 | 1.5 | |
| 1993 | 3 | 17 | 20 | 9 | 2.89 | 67.68 | 33.73 | 1.2 | |
| 1993 | 3 | 18 | 0 | 20 | 7.3 | 67.7 | 33.79 | 1.4 | |
| 1993 | 3 | 19 | 3 | 46 | 19.7 | 67.7 | 33.60 | 1.1 | |
| 1993 | 3 | 19 | 15 | 16 | 46.7 | 67.69 | 33.67 | 1.2 | |
| 1993 | 3 | 19 | 17 | 21 | 1.3 | 67.71 | 33.78 | 1.3 | |
| 1993 | 3 | 20 | 4 | 54 | 17.2 | 67.7 | 33.60 | 1.2 | |
| 1993 | 3 | 21 | 1 | 43 | 33.8 | 67.68 | 33.67 | 1.0 | |
| 1993 | 3 | 22 | 15 | 21 | 42.6 | 67.69 | 33.58 | 1.3 | |
| 1993 | 3 | 22 | 18 | 25 | 22.6 | 67.72 | 33.67 | 1.1 | |
| 1993 | 3 | 23 | 14 | 10 | 32.1 | 67.68 | 33.79 | 1.4 | |
| 1993 | 3 | 24 | 1 | 20 | 45.8 | 67.7 | 33.8 | 1.3 | |
| 1993 | 3 | 24 | 19 | 44 | 48.3 | 67.63 | 33.74 | 1.3 | |
| 1993 | 3 | 25 | 15 | 15 | 32.3 | 67.69 | 33.63 | 1.3 | |
| 1993 | 3 | 26 | 7 | 13 | 51.2 | 67.69 | 33.82 | 1.3 | |
| 1993 | 3 | 26 | 23 | 36 | 52.6 | 67.69 | 33.82 | 1.3 | |
| 1993 | 3 | 28 | 23 | 28 | 57.8 | 67.7 | 33.67 | 1.5 | |
| 1993 | 3 | 30 | 1 | 52 | 20 | 67.68 | 33.73 | 2.5 | |
| 1993 | 3 | 30 | 18 | 9 | 47.6 | 67.68 | 33.60 | 1.3 | |
| 1993 | 3 | 30 | 20 | 34 | 40.8 | 67.69 | 33.60 | 1.4 | |
| 1993 | 3 | 31 | 5 | 9 | 50 | 67.66 | 33.60 | 1.0 | |
| 1993 | 3 | 31 | 21 | 26 | 41.3 | 67.68 | 33.88 | 1.4 | |
| 1993 | 3 | 31 | 23 | 24 | 21.8 | 67.72 | 34.01 | 1 | |
| 1993 | 4 | 1 | 15 | 41 | 53.3 | 67.7 | 33.64 | 1.3 | |
| 1993 | 4 | 2 | 10 | 2 | 22.3 | 67.7 | 33.8 | 1.5 | |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 1993 | 4 | 3 | 6 | 47 | 18.8 | 67.67 | 33.64 | 1.3 | |
| 1993 | 4 | 3 | 7 | 2 | 28.8 | 67.66 | 33.69 | 0.7 | |
| 1993 | 4 | 3 | 8 | 29 | 26.7 | 67.62 | 33.87 | 2 | TRIGGERED |
| 1993 | 4 | 4 | 5 | 14 | 5.9 | 67.57 | 33.75 | 1.2 | TRIGGERED |
| 1993 | 4 | 8 | 7 | 8 | 13.3 | 67.64 | 33.9 | 1.5 | |
| 1993 | 4 | 8 | 20 | 48 | 2.31 | 67.68 | 33.71 | 1.2 | |
| 1993 | 4 | 10 | 16 | 28 | 52.3 | 67.71 | 33.87 | 1.1 | |
| 1993 | 4 | 10 | 17 | 42 | 7.59 | 67.67 | 33.75 | 1.4 | |
| 1993 | 4 | 10 | 20 | 45 | 21.7 | 67.71 | 33.75 | 1.3 | |
| 1993 | 4 | 10 | 22 | 38 | 45.5 | 67.64 | 33.77 | 1.2 | |
| 1993 | 4 | 11 | 1 | 49 | 43 | 67.72 | 33.81 | 0.8 | |
| 1993 | 4 | 11 | 3 | 45 | 58.4 | 67.65 | 33.76 | 1.2 | TRIGGERED |
| 1993 | 4 | 12 | 7 | 32 | 53.1 | 67.70 | 33.62 | 2.0 | |
| 1993 | 4 | 13 | 0 | 0 | 45.8 | 67.74 | 33.79 | 0.9 | |
| 1993 | 4 | 13 | 19 | 25 | 3.63 | 67.66 | 33.62 | 1.0 | |
| 1993 | 4 | 13 | 19 | 28 | 17.4 | 67.67 | 33.94 | 1.4 | |
| 1993 | 4 | 14 | 12 | 12 | 34.6 | 67.65 | 33.8 | 1.3 | |
| 1993 | 4 | 16 | 2 | 47 | 45.3 | 67.70 | 33.65 | 1.5 | |
| 1993 | 4 | 16 | 23 | 7 | 9.3 | 67.71 | 33.83 | 1.3 | |
| 1993 | 4 | 21 | 20 | 51 | 0 | 67.63 | 33.67 | 0.8 | |
| 1993 | 4 | 26 | 12 | 17 | 53.6 | 67.67 | 33.77 | 1.2 | |
| 1993 | 4 | 30 | 19 | 28 | 17.3 | 67.68 | 33.63 | 1.5 | |
| 1993 | 4 | 30 | 20 | 0 | 56.2 | 67.64 | 33.72 | 1.5 | |
| 1993 | 5 | 2 | 23 | 43 | 31.5 | 67.69 | 33.76 | 1.3 | |
| 1993 | 5 | 3 | 3 | 26 | 53.2 | 67.67 | 33.70 | 1.1 | |
| 1993 | 5 | 5 | 20 | 45 | 19.4 | 67.70 | 33.65 | 1.4 | |
| 1993 | 5 | 6 | 0 | 54 | 31.5 | 67.76 | 33.96 | 1.2 | |
| 1993 | 5 | 7 | 1 | 9 | 21.1 | 67.7 | 33.66 | 1.2 | |
| 1993 | 5 | 7 | 8 | 44 | 29.8 | 67.71 | 33.74 | 1.3 | |
| 1993 | 5 | 9 | 4 | 4 | 26.4 | 67.67 | 33.71 | 1.1 | TRIGGERED |
| 1993 | 5 | 10 | 1 | 5 | 19.7 | 67.69 | 33.73 | 1.2 | |
| 1993 | 5 | 12 | 14 | 28 | 36.7 | 67.71 | 33.67 | 1.4 | |
| 1993 | 5 | 19 | 2 | 8 | 7.2 | 67.69 | 33.64 | 1.4 | |
| 1993 | 5 | 23 | 16 | 57 | 19.3 | 67.67 | 33.8 | 1.2 | |
| 1993 | 5 | 24 | 16 | 53 | 19.5 | 67.65 | 34.24 | 1.7 | |
| 1993 | 5 | 24 | 21 | 18 | 18.8 | 67.71 | 33.63 | 1.6 | |
| 1993 | 5 | 27 | 1 | 33 | 11 | 67.63 | 33.88 | 1.6 | |
| 1993 | 5 | 27 | 21 | 43 | 8 | 67.66 | 33.88 | 1.5 | |
| 1993 | 5 | 29 | 23 | 3 | 36.5 | 67.59 | 33.94 | 1.3 | |
| 1993 | 6 | 10 | 3 | 1 | 56.9 | 67.72 | 33.56 | 1.2 | |
| 1993 | 6 | 10 | 20 | 38 | 28.1 | 67.72 | 33.74 | 1.5 | |
| 1993 | 6 | 10 | 21 | 3 | 16 | 67.69 | 33.67 | 1.1 | |
| 1993 | 6 | 10 | 21 | 58 | 23.1 | 67.64 | 33.64 | 1.2 | |
| 1993 | 6 | 11 | 11 | 22 | 30.5 | 67.70 | 33.62 | 1.5 | |
| 1993 | 6 | 21 | 21 | 20 | 9.79 | 67.64 | 33.81 | 1.4 | |
| 1993 | 6 | 23 | 3 | 24 | 18.7 | 67.66 | 33.74 | 1.2 | |
| 1993 | 6 | 25 | 2 | 30 | 49.3 | 67.61 | 33.80 | 1.1 | |
| 1993 | 6 | 26 | 15 | 35 | 32.2 | 67.72 | 33.6 | 1.2 | |
| 1993 | 7 | 2 | 22 | 10 | 52.6 | 67.66 | 33.86 | 1.2 | |
| 1993 | 7 | 15 | 5 | 22 | 0.7 | 67.64 | 33.75 | 1.1 | |
| 1993 | 7 | 18 | 2 | 59 | 14.8 | | | | TRIGGERED |
| 1993 | 8 | 4 | 0 | 33 | 43 | 67.6 | 33.8 | 1.3 | |
| 1993 | 8 | 8 | 2 | 23 | 25.5 | 67.60 | 33.85 | 1.2 | |
| 1993 | 8 | 8 | 2 | 29 | 37.9 | 67.6 | 33.7 | 1.3 | |
| 1993 | 8 | 9 | 17 | 39 | 54.3 | 67.60 | 33.80 | 2.0 | |
| 1993 | 8 | 10 | 18 | 44 | 32.2 | 67.71 | 33.8 | 1.4 | |
| 1993 | 8 | 12 | 3 | 24 | 36.5 | 67.72 | 33.73 | 1.5 | |
| 1993 | 8 | 17 | 3 | 35 | 36.6 | 67.69 | 33.77 | 0.6 | |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 1993 | 8 | 17 | 5 | 28 | 52.6 | 67.67 | 33.77 | 1.2 | |
| 1993 | 8 | 19 | 8 | 59 | 15.9 | 67.66 | 33.92 | 1.4 | |
| 1993 | 8 | 20 | 7 | 57 | 54.3 | 67.65 | 33.93 | 1.4 | |
| 1993 | 8 | 21 | 6 | 33 | 33.6 | 67.64 | 33.76 | 1.0 | |
| 1993 | 8 | 22 | 12 | 46 | 28.2 | 67.71 | 33.8 | 1.5 | |
| 1993 | 8 | 23 | 10 | 35 | 44.6 | 67.67 | 33.74 | 1.6 | |
| 1993 | 8 | 24 | 2 | 54 | 15.9 | 67.68 | 34.18 | 1.6 | |
| 1993 | 8 | 26 | 1 | 33 | 9.8 | 67.64 | 33.96 | 1.8 | |
| 1993 | 8 | 28 | 14 | 45 | 12.9 | 67.68 | 34.06 | 1.6 | |
| 1993 | 8 | 28 | 18 | 28 | 41.6 | 67.64 | 33.94 | 1.4 | |
| 1993 | 9 | 2 | 9 | 51 | 14.3 | 67.66 | 33.86 | 1.3 | |
| 1993 | 9 | 2 | 20 | 49 | 53 | 67.72 | 33.74 | 1.3 | |
| 1993 | 9 | 5 | 2 | 21 | 31.5 | 67.68 | 34.24 | 1.8 | |
| 1993 | 9 | 5 | 8 | 56 | 21.2 | 67.75 | 33.99 | 1.6 | |
| 1993 | 9 | 5 | 10 | 10 | 0.7 | 67.74 | 34.03 | 1.6 | |
| 1993 | 9 | 7 | 6 | 27 | 56.3 | 67.7 | 34.22 | 1.8 | |
| 1993 | 9 | 8 | 21 | 13 | 49.4 | 67.66 | 33.77 | 1.6 | |
| 1993 | 9 | 10 | 12 | 9 | 7.7 | 67.68 | 34.13 | 1.7 | |
| 1993 | 9 | 14 | 13 | 41 | 52.9 | 67.7 | 33.65 | 1 | |
| 1993 | 9 | 15 | 21 | 2 | 5.69 | 67.67 | 33.65 | 1.1 | |
| 1993 | 9 | 15 | 21 | 39 | 40.6 | 67.7 | 33.69 | 1.2 | |
| 1993 | 9 | 17 | 9 | 25 | 43.4 | 67.66 | 33.69 | 1.3 | |
| 1993 | 9 | 17 | 21 | 8 | 28.1 | 67.69 | 33.76 | 1.2 | |
| 1993 | 9 | 20 | 20 | 20 | 28.7 | 67.68 | 33.55 | 0.9 | |
| 1993 | 10 | 8 | 7 | 27 | 37.1 | 67.62 | 34.35 | 2.4 | |
| 1993 | 11 | 13 | 10 | 59 | 6.21 | 67.68 | 33.78 | 1.7 | |
| 1993 | 11 | 16 | 16 | 34 | 12.9 | 67.71 | 33.25 | 1.7 | |
| 1993 | 11 | 17 | 7 | 45 | 12.5 | 67.67 | 33.73 | 3.0 | |
| 1993 | 11 | 17 | 8 | 8 | 43.9 | 67.67 | 33.84 | 1.5 | |
| 1993 | 11 | 17 | 8 | 15 | 5.2 | 67.67 | 33.72 | 1.2 | |
| 1993 | 12 | 5 | 6 | 50 | 41.5 | | | | TRIGGERED |
| 1993 | 12 | 5 | 6 | 59 | 0.6 | 67.67 | 33.72 | 1.3 | TRIGGERED |
| 1993 | 12 | 5 | 8 | 16 | 17.4 | 67.67 | 33.72 | 1.1 | TRIGGERED |
| 1993 | 12 | 9 | 4 | 21 | 18.4 | 67.67 | 33.88 | 1.6 | |
| 1993 | 12 | 12 | 8 | 50 | 3.2 | 67.61 | 33.89 | 3.2 | |
| 1993 | 12 | 16 | 19 | 33 | 1.3 | 67.66 | 33.82 | 2.2 | |
| 1994 | 1 | 2 | 17 | 26 | 50.4 | 67.67 | 33.74 | 1.1 | |
| 1994 | 1 | 13 | 17 | 38 | 7.5 | 67.59 | 33.74 | 1.5 | |
| 1994 | 1 | 17 | 16 | 39 | 11.1 | 67.68 | 33.74 | 1.6 | |
| 1994 | 1 | 18 | 21 | 29 | 3.4 | 67.64 | 33.59 | 1.0 | |
| 1994 | 1 | 19 | 4 | 24 | 47.1 | 67.62 | 33.7 | 0.5 | |
| 1994 | 1 | 19 | 11 | 1 | 9.94 | 67.68 | 33.67 | 1.3 | |
| 1994 | 1 | 28 | 18 | 15 | 35.7 | 67.69 | 33.73 | | |
| 1994 | 1 | 28 | 18 | 24 | 22.5 | 67.67 | 33.74 | 1.5 | |
| 1994 | 1 | 28 | 19 | 19 | 39 | 67.75 | 34.7 | 1.8 | |
| 1994 | 1 | 30 | 4 | 19 | 41.4 | 67.67 | 33.74 | 1.7 | TRIGGERED |
| 1994 | 2 | 5 | 5 | 56 | 45.7 | 67.67 | 33.87 | | |
| 1994 | 2 | 7 | 14 | 25 | 37.9 | 67.61 | 33.74 | | |
| 1994 | 2 | 11 | 22 | 45 | 2.9 | 67.61 | 33.69 | | |
| 1994 | 2 | 12 | 21 | 40 | 47.1 | 67.68 | 33.77 | 1.1 | |
| 1994 | 2 | 13 | 23 | 49 | 58.2 | | | 1.1 | |
| 1994 | 2 | 16 | 9 | 51 | 52.1 | 67.68 | 33.68 | | |
| 1994 | 2 | 17 | 20 | 45 | 55.9 | 67.69 | 34.02 | | |
| 1994 | 2 | 18 | 6 | 7 | 50.9 | 67.67 | 33.79 | | |
| 1994 | 2 | 23 | 18 | 23 | 51.2 | 67.69 | 33.69 | | |
| 1994 | 2 | 28 | 20 | 6 | 59.5 | 67.67 | 33.77 | | |
| 1994 | 3 | 4 | 0 | 5 | 34.8 | 67.64 | 34.04 | 1 | |
| 1994 | 3 | 4 | 12 | 57 | 48.3 | 67.64 | 33.80 | 2.0 | |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 1994 | 3 | 7 | 5 | 8 | 48.2 | | | | TRIGGERED |
| 1994 | 3 | 7 | 5 | 8 | 50.6 | | | | TRIGGERED |
| 1994 | 3 | 9 | 15 | 39 | 35.8 | 67.68 | 33.68 | 1.2 | |
| 1994 | 3 | 11 | 15 | 25 | 3.48 | 67.7 | 33.73 | 1.3 | |
| 1994 | 3 | 16 | 21 | 44 | 21.3 | 67.75 | 34.7 | 1.6 | |
| 1994 | 3 | 17 | 8 | 55 | 58.5 | 67.7 | 33.7 | 1.5 | |
| 1994 | 3 | 29 | 6 | 30 | 29.9 | 67.9 | 33.05 | 1.9 | |
| 1994 | 4 | 4 | 16 | 26 | 18.9 | 67.63 | 34 | 1.3 | |
| 1994 | 4 | 4 | 23 | 3 | 46.7 | 67.7 | 33.91 | 1.2 | |
| 1994 | 4 | 8 | 13 | 44 | 55.1 | 67.68 | 33.72 | 1.4 | |
| 1994 | 4 | 12 | 7 | 48 | 6.4 | 67.68 | 33.7 | 0.8 | |
| 1994 | 4 | 16 | 15 | 59 | 30.5 | 67.7 | 33.83 | 1.6 | |
| 1994 | 4 | 20 | 0 | 25 | 54.6 | 67.67 | 33.71 | 1.2 | |
| 1994 | 4 | 21 | 15 | 35 | 11.3 | 67.71 | 33.67 | 0.6 | |
| 1994 | 5 | 6 | 17 | 34 | 59.4 | 67.67 | 33.741 | 1.2 | |
| 1994 | 5 | 11 | 7 | 37 | 9.6 | 67.67 | 33.72 | 1 | |
| 1994 | 5 | 12 | 12 | 12 | 37.5 | 67.66 | 33.741 | 1.5 | |
| 1994 | 5 | 15 | 13 | 12 | 40.7 | 67.61 | 33.86 | 1.4 | |
| 1994 | 5 | 19 | 2 | 38 | 38.1 | 67.69 | 33.74 | 1.5 | |
| 1994 | 5 | 20 | 2 | 26 | 41.3 | 67.69 | 33.76 | 1.1 | |
| 1994 | 5 | 20 | 2 | 26 | 42 | 67.68 | 33.71 | | |
| 1994 | 5 | 21 | 6 | 2 | 21 | 67.67 | 33.72 | 1.6 | |
| 1994 | 5 | 27 | 20 | 24 | 45.2 | 67.69 | 33.76 | 1.1 | |
| 1994 | 5 | 30 | 11 | 2 | 25.8 | 67.67 | 33.68 | 1.2 | |
| 1994 | 6 | 1 | 14 | 35 | 24.3 | 67.62 | 33.79 | 0.5 | |
| 1994 | 6 | 4 | 1 | 7 | 20 | 67.62 | 33.9 | 1.6 | |
| 1994 | 6 | 5 | 18 | 18 | 58.1 | 67.65 | 33.9 | 1 | |
| 1994 | 6 | 5 | 20 | 56 | 16.8 | 67.69 | 33.74 | | |
| 1994 | 6 | 6 | 0 | 24 | 7.8 | 67.75 | 33.65 | 1.0 | |
| 1994 | 6 | 7 | 2 | 1 | 55.8 | 67.65 | 33.64 | | |
| 1994 | 6 | 8 | 22 | 24 | 13.3 | 67.66 | 33.81 | 0.8 | |
| 1994 | 6 | 10 | 21 | 44 | 22.1 | 67.6 | 33.56 | | |
| 1994 | 6 | 11 | 5 | 15 | 8.8 | 67.65 | 33.71 | 1.9 | |
| 1994 | 6 | 12 | 15 | 14 | 28.1 | 67.6 | 33.8 | | |
| 1994 | 6 | 12 | 18 | 56 | 28.9 | 67.66 | 33.79 | 1.4 | |
| 1994 | 6 | 13 | 18 | 22 | 35.8 | 67.75 | 34.15 | 2.1 | |
| 1994 | 6 | 14 | 18 | 56 | 28.9 | 67.66 | 33.79 | 1.4 | |
| 1994 | 6 | 16 | 17 | 6 | 26.3 | 67.67 | 33.76 | 0.9 | |
| 1994 | 6 | 16 | 23 | 43 | 18.6 | 67.67 | 33.74 | 1.4 | |
| 1994 | 6 | 17 | 8 | 40 | 20.1 | 67.63 | 33.86 | 1.2 | |
| 1994 | 6 | 20 | 19 | 54 | 15.3 | 67.67 | 33.72 | 2.0 | |
| 1994 | 6 | 23 | 18 | 24 | 52.1 | 67.69 | 33.78 | 1.5 | |
| 1994 | 6 | 25 | 11 | 33 | 38.1 | 67.65 | 33.79 | 1.2 | |
| 1994 | 6 | 28 | 1 | 30 | 22.6 | 67.64 | 33.90 | 1.0 | |
| 1994 | 6 | 30 | 7 | 19 | 41.7 | 67.65 | 33.72 | 0.8 | |
| 1994 | 6 | 30 | 22 | 0 | 44.6 | 67.68 | 33.67 | 1.0 | |
| 1994 | 6 | 30 | 22 | 31 | 27.1 | 67.67 | 33.81 | 1.4 | |
| 1994 | 7 | 1 | 9 | 30 | 0 | 67.61 | 33.83 | 1.7 | |
| 1994 | 7 | 1 | 9 | 39 | 39.1 | 67.61 | 33.83 | 1.5 | |
| 1994 | 7 | 8 | 22 | 11 | 35.2 | 67.65 | 33.75 | 1.1 | |
| 1994 | 7 | 12 | 9 | 10 | 53.7 | 67.68 | 33.75 | 1.3 | |
| 1994 | 7 | 12 | 19 | 30 | 23.3 | 67.69 | 33.75 | 1.2 | |
| 1994 | 7 | 30 | 1 | 24 | 8.8 | 67.68 | 33.68 | 1.2 | |
| 1994 | 7 | 30 | 8 | 8 | 19.3 | | | | |
| 1994 | 7 | 30 | 11 | 32 | 40.5 | 67.67 | 33.83 | 1.3 | |
| 1994 | 7 | 31 | 12 | 41 | 51.1 | 67.67 | 33.83 | 1.3 | |
| 1994 | 8 | 3 | 7 | 23 | 22.8 | 67.6 | 34.19 | 1.7 | |
| 1994 | 8 | 19 | 10 | 7 | 16 | 67.61 | 33.89 | 1.3 | |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 1994 | 8 | 20 | 0 | 59 | 14.3 | | | | |
| 1994 | 8 | 23 | 0 | 16 | 26.1 | 67.63 | 34.01 | 0.9 | |
| 1994 | 8 | 23 | 17 | 44 | 47.2 | 67.69 | 33.71 | 0.8 | |
| 1994 | 8 | 26 | 3 | 57 | 11.6 | 67.72 | 33.79 | 1.5 | |
| 1994 | 8 | 26 | 9 | 32 | 14.8 | 67.61 | 33.95 | 1.2 | |
| 1994 | 8 | 26 | 10 | 21 | 42.8 | 67.65 | 33.93 | 1.6 | |
| 1994 | 8 | 26 | 10 | 27 | 11.7 | 67.65 | 33.79 | | |
| 1994 | 9 | 1 | 8 | 14 | 32 | 67.65 | 33.74 | 1.2 | |
| 1994 | 9 | 5 | 8 | 54 | 8.55 | 67.69 | 33.70 | 1.1 | |
| 1994 | 9 | 6 | 1 | 21 | 36.6 | 67.67 | 33.75 | 1.4 | |
| 1994 | 9 | 6 | 16 | 48 | 40.6 | 67.67 | 33.93 | 2.1 | |
| 1994 | 9 | 6 | 16 | 52 | 4.6 | 67.64 | 33.94 | 1.1 | |
| 1994 | 9 | 6 | 18 | 45 | 44.9 | 67.66 | 33.71 | 1.4 | |
| 1994 | 9 | 6 | 18 | 49 | 0.23 | 67.75 | 33.63 | 1.4 | |
| 1994 | 9 | 6 | 19 | 1 | 14 | 67.69 | 33.75 | 1.0 | |
| 1994 | 9 | 10 | 11 | 1 | 21.6 | 67.66 | 33.73 | 0.7 | |
| 1994 | 9 | 12 | 14 | 59 | 19.6 | 67.67 | 33.73 | 1.2 | |
| 1994 | 9 | 12 | 16 | 53 | 20 | | | 1.5 | |
| 1994 | 9 | 12 | 18 | 13 | 59.1 | 67.69 | 33.68 | 1.3 | |
| 1994 | 9 | 12 | 20 | 34 | 32 | 67.66 | 33.67 | 1.0 | |
| 1994 | 9 | 15 | 17 | 57 | 27.1 | 67.68 | 33.73 | 0.7 | |
| 1994 | 9 | 15 | 18 | 57 | 0 | | | 1.2 | |
| 1994 | 9 | 16 | 10 | 30 | 17.9 | 67.67 | 33.72 | 1.2 | |
| 1994 | 9 | 16 | 10 | 30 | 39.1 | 67.67 | 33.72 | 0.9 | 1' |
| 1994 | 9 | 16 | 17 | 54 | 37.1 | | | 1.3 | |
| 1994 | 9 | 16 | 21 | 12 | 50.6 | | | | |
| 1994 | 9 | 16 | 23 | 7 | 14.4 | | | | |
| 1994 | 9 | 17 | 3 | 32 | 57.6 | 67.67 | 33.75 | 0.8 | |
| 1994 | 10 | 27 | 6 | 29 | 41.1 | 67.60 | 33.68 | 1.3 | |
| 1994 | 10 | 27 | 9 | 5 | 1.97 | 67.74 | 33.56 | 0.9 | |
| 1994 | 10 | 28 | 19 | 28 | 37.8 | 67.64 | 33.31 | 0.7 | |
| 1994 | 10 | 29 | 8 | 15 | 39.2 | 67.65 | 33.83 | 1.2 | |
| 1994 | 11 | 2 | 4 | 21 | 48 | | | 0.9 | |
| 1994 | 11 | 2 | 10 | 23 | 55.2 | | | 1.3 | |
| 1994 | 11 | 2 | 17 | 52 | 11.9 | 67.80 | 33.45 | 1.9 | |
| 1994 | 11 | 4 | 9 | 14 | 42.7 | 67.67 | 33.74 | 1.3 | |
| 1994 | 11 | 4 | 19 | 43 | 37.1 | 67.63 | 34.11 | 0.8 | |
| 1994 | 11 | 4 | 20 | 26 | 51.7 | 67.69 | 33.65 | 0.9 | |
| 1994 | 11 | 5 | 1 | 48 | 8.77 | 67.69 | 33.54 | 1.5 | |
| 1994 | 11 | 8 | 16 | 33 | 5.86 | 67.65 | 33.47 | 0.8 | |
| 1994 | 11 | 8 | 17 | 0 | 7.3 | 67.68 | 33.55 | 0.9 | |
| 1994 | 11 | 9 | 1 | 7 | 53.5 | 67.64 | 33.76 | 0.9 | |
| 1994 | 11 | 10 | 3 | 34 | 45.3 | 67.68 | 33.71 | 0.5 | |
| 1994 | 11 | 11 | 10 | 23 | 30.2 | 67.71 | 33.48 | 0.6 | |
| 1994 | 11 | 12 | 5 | 56 | 34.3 | 67.68 | 33.67 | 1.2 | |
| 1994 | 11 | 12 | 7 | 1 | 47 | 67.68 | 33.64 | 1.2 | |
| 1994 | 11 | 12 | 12 | 40 | 21.8 | 67.68 | 33.66 | 1.0 | |
| 1994 | 11 | 13 | 23 | 54 | 7.08 | 67.67 | 33.71 | 0.8 | |
| 1994 | 11 | 14 | 20 | 53 | 49.7 | 67.68 | 33.74 | 1.7 | |
| 1994 | 11 | 15 | 22 | 26 | 34.2 | 67.68 | 33.71 | 1.3 | |
| 1994 | 11 | 17 | 1 | 23 | 48.8 | 67.68 | 33.71 | 1.4 | |
| 1994 | 11 | 18 | 7 | 29 | 8.61 | 67.75 | 33.68 | 1.5 | |
| 1994 | 11 | 19 | 0 | 26 | 13 | 67.66 | 33.67 | 1.3 | |
| 1994 | 11 | 19 | 6 | 16 | 13.5 | 67.80 | 34.01 | 2.0 | |
| 1994 | 11 | 19 | 8 | 41 | 45 | 67.69 | 33.67 | 1.2 | |
| 1994 | 11 | 22 | 2 | 48 | 38.4 | | | 1.6 | |
| 1994 | 11 | 23 | 16 | 40 | 41.7 | 67.67 | 33.74 | 1.2 | |
| 1994 | 11 | 23 | 18 | 37 | 6 | | | | |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 1994 | 11 | 24 | 6 | 34 | 57.5 | | | 1.6 | |
| 1994 | 11 | 24 | 10 | 8 | 54.1 | 67.68 | 33.76 | 1.6 | |
| 1994 | 11 | 24 | 16 | 25 | 37.6 | 67.59 | 34.11 | 1.3 | |
| 1994 | 11 | 24 | 16 | 25 | 41.3 | | | | |
| 1994 | 11 | 26 | 2 | 35 | 8.1 | 67.68 | 33.7 | 1.5 | |
| 1994 | 11 | 27 | 7 | 13 | 26.1 | 67.67 | 33.72 | 1.0 | |
| 1994 | 11 | 30 | 0 | 54 | 7.72 | 67.68 | 33.63 | 1.2 | |
| 1994 | 12 | 2 | 13 | 57 | 3.6 | 67.66 | 33.71 | 1.4 | |
| 1994 | 12 | 5 | 0 | 54 | 50.5 | 67.66 | 33.57 | 0.8 | |
| 1994 | 12 | 5 | 3 | 42 | 23 | 67.64 | 33.794 | 1.4 | |
| 1994 | 12 | 6 | 3 | 10 | 44.7 | 67.68 | 33.73 | 1.4 | |
| 1994 | 12 | 6 | 8 | 22 | 20.5 | 67.69 | 33.66 | 0.7 | |
| 1994 | 12 | 8 | 18 | 45 | 18.3 | 67.67 | 33.72 | 0.9 | |
| 1994 | 12 | 9 | 2 | 24 | 15.1 | 67.65 | 33.9 | 1.3 | |
| 1994 | 12 | 9 | 2 | 24 | 26.4 | 67.63 | 33.84 | 1.6 | |
| 1994 | 12 | 9 | 5 | 54 | 34.5 | 67.68 | 33.7 | 0.8 | |
| 1994 | 12 | 9 | 5 | 56 | 4.09 | 67.67 | 33.9 | 1.5 | |
| 1994 | 12 | 9 | 9 | 9 | 37 | 67.68 | 33.73 | 1.0 | |
| 1994 | 12 | 9 | 15 | 4 | 4.6 | 67.67 | 33.63 | 1.1 | |
| 1994 | 12 | 9 | 21 | 30 | 30.1 | 67.64 | 33.88 | 1.3 | |
| 1994 | 12 | 14 | 21 | 57 | 18.6 | 67.66 | 33.72 | 1.7 | |
| 1994 | 12 | 15 | 9 | 49 | 40.8 | 67.70 | 33.61 | 1.3 | |
| 1994 | 12 | 15 | 22 | 45 | 9.89 | 67.65 | 33.79 | 1.1 | |
| 1994 | 12 | 18 | 15 | 52 | 49.1 | 67.68 | 33.71 | 1.2 | |
| 1994 | 12 | 19 | 14 | 59 | 45.1 | 67.68 | 33.7 | 0.7 | |
| 1994 | 12 | 20 | 20 | 26 | 54.6 | 67.68 | 33.72 | 1.3 | |
| 1994 | 12 | 21 | 14 | 2 | 37.1 | 67.68 | 33.71 | 0.9 | |
| 1994 | 12 | 23 | 3 | 43 | 55.2 | 67.67 | 33.77 | 1.5 | |
| 1994 | 12 | 23 | 21 | 30 | 56.9 | 67.63 | 33.83 | 1.5 | |
| 1994 | 12 | 25 | 3 | 28 | 38 | 67.67 | 33.72 | 2.3 | TRIGGERED |
| 1994 | 12 | 25 | 3 | 28 | 49 | 67.67 | 33.72 | | TRIGGERED |
| 1994 | 12 | 28 | 0 | 9 | 37.3 | 67.51 | 34.03 | 1.3 | |
| 1994 | 12 | 28 | 9 | 25 | 6.2 | 67.67 | 33.73 | 1.1 | |
| 1994 | 12 | 29 | 6 | 19 | 49.1 | 67.68 | 33.72 | 1.2 | |
| 1994 | 12 | 29 | 10 | 15 | 57.4 | 67.52 | 33.95 | 1.9 | |
| 1994 | 12 | 29 | 16 | 25 | 11.1 | | | 1.5 | |
| 1994 | 12 | 29 | 18 | 29 | 52.5 | 67.64 | 33.83 | 1.8 | |
| 1994 | 12 | 30 | 3 | 46 | 39.8 | 67.66 | 33.84 | 1.0 | |

# APPENDIX C

## Underground explosions at the Khibiny mines, 1991-1994

| MINE | DATE | TIME | Yield(t) | ML | MC | REMARK |
|---|---|---|---|---|---|---|
| 1 | 1991 1 13 | 4 32 35.6 | 130 | 2.5 | 2.4 | |
| 3 | 1991 1 26 | 18 30 34 | 150 | 2.5 | 2.5 | |
| 2 | 1991 2 3 | 4 57 8.1 | 130 | 2.9 | 2.8 | |
| 2 | 1991 2 10 | 3 11 4.8 | 56 | 2.2 | 2.4 | |
| 2 | 1991 2 17 | 3 44 55.2 | 64 | 1.8 | 2.4 | |
| 3 | 1991 2 23 | 12 8 41.5 | 60 | 2.2 | 2.4 | |
| 1 | 1991 2 24 | 8 45 17.1 | 187 | 2.5 | 2.7 | |
| 2 | 1991 2 24 | 11 11 15.9 | 142 | 2.2 | 2.5 | |
| 1 | 1991 3 8 | 4 42 52.5 | 156 | 2.5 | 2.5 | |
| 2 | 1991 3 24 | 4 23 17 | 89 | 2.4 | 2.7 | trigger |
| 2 | 1991 3 24 | 4 48 58.4 | 118 | 2.7 | 2.6 | trigger |
| 2 | 1991 3 31 | 6 29 37.1 | 215.9 | 2.5 | 2.5 | |
| 3 | 1991 4 13 | 17 59 27.4 | 70 | 1.8 | 2.3 | |
| 1 | 1991 4 21 | 6 40 5 | 122 | 2.4 | 2.5 | |
| 3 | 1991 4 27 | 13 14 14.5 | 130 | 2.1 | 2.4 | trigger |
| 1 | 1991 4 28 | 5 18 47.4 | 150 | 2.7 | 2.7 | trigger |
| 3 | 1991 5 18 | 12 43 12.1 | 90 | 2.4 | 2.5 | |
| 1 | 1991 5 19 | 8 47 13 | 236+61 | 2.6 | 2.8 | double |
| 2 | 1991 6 16 | 5 39 49.9 | 112 | 2.4 | 2.6 | |
| 2 | 1991 6 23 | 4 14 0.4 | 82 | 2.3 | 2.4 | |
| 2 | 1991 6 30 | 6 33 0.9 | 117 | 2.5 | 2.6 | |
| 3 | 1991 7 6 | 19 23 58.7 | 94 | 2.3 | 2.3 | |
| 1 | 1991 7 7 | 5 33 35.4 | 155 | 2.4 | 2.5 | |
| 1 | 1991 8 4 | 12 49 52.1 | 125 | 2.7 | 2.7 | |
| 3 | 1991 8 10 | 18 0 2.1 | 50 | 2.0 | 2.2 | trigger |
| 2 | 1991 8 18 | 6 11 44.5 | 99 | 2.3 | 2.5 | |
| 3 | 1991 8 31 | 16 8 20.4 | 100 | 2.0 | 2.1 | trigger |
| 2 | 1991 9 1 | 6 17 16.5 | 178 | 2.3 | 2.5 | |
| 1 | 1991 9 15 | 4 7 42.8 | 57 | 2.3 | 2.5 | trigger |
| 2 | 1991 10 6 | 5 37 17.2 | 114 | 2.9 | 2.8 | |
| 2 | 1991 10 20 | 4 36 59.3 | 112 | 2.1 | 2.4 | |
| 3 | 1991 10 26 | 13 3 13.3 | 30 | 2.0 | 2.4 | |
| 2 | 1991 10 27 | 1 32 32.1 | 15.4 | 1.8 | 2.3 | |
| 3 | 1991 11 16 | 12 35 33.8 | 52 | 1.9 | 2.2 | |
| 1 | 1991 11 17 | 4 59 19 | 150 | 2.4 | 2.4 | |
| 3 | 1991 11 30 | 13 12 52.5 | 70 | 2.1 | 2.2 | |
| 1 | 1991 12 8 | 8 29 30.6 | 182 | 2.2 | 2.6 | |
| 2 | 1991 12 15 | 5 55 41.5 | 70 | 2.3 | 2.4 | |
| 2 | 1991 12 22 | 7 25 35.1 | 246 | 2.6 | 2.6 | |
| 3 | 1991 12 28 | 15 32 0.6 | 171 | 2.5 | 2.8 | trigger |
| 1 | 1991 12 31 | 8 48 48.5 | 208 | 2.4 | 2.5 | |
| 3 | 1992 1 18 | 12 44 42.7 | 71 | 1.9 | 2.3 | |
| 1 | 1992 2 2 | 5 5 0.4 | 107 | 2.7 | 2.7 | |
| 3 | 1992 2 8 | 11 25 24.7 | 16 | 1.6 | 2.1 | trigger |
| 2 | 1992 2 9 | 4 9 40.8 | 116 | 3.0 | 2.6 | |
| 1 | 1992 2 16 | 8 49 49.7 | 180 | 2.3 | 2.7 | |
| 3 | 1992 2 22 | 12 0 19 | 74 | 2.1 | 2.4 | |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 2 | 1992 | 2 | 23 | 5 | 37 | 2.9 | 101 | 2.6 | 2.7 | trigger |
| 2 | 1992 | 4 | 19 | 2 | 33 | 22.1 | 48 | 2.4 | 2.5 | |
| 3 | 1992 | 4 | 25 | 13 | 38 | 59.9 | 150 | 2.7 | 2.7 | |
| 1 | 1992 | 4 | 26 | 3 | 31 | 56.7 | 84 | 2.5 | 2.5 | trigger |
| 3 | 1992 | 5 | 1 | 2 | 14 | 11.7 | 60 | 1.9 | 2.5 | |
| 1 | 1992 | 5 | 1 | 3 | 2 | 56.8 | 150 | 2.9 | 2.7 | |
| 2 | 1992 | 5 | 24 | 4 | 29 | 57.2 | 112 | 1.7 | | |
| 2 | 1992 | 5 | 24 | 4 | 30 | 6.2 | 106 | 1.7 | | |
| 2 | 1992 | 5 | 31 | 2 | 46 | 41.7 | 25 | 1.2 | 2.3 | |
| 1 | 1992 | 5 | 31 | 3 | 41 | 10.1 | 217 | 2.4 | 2.7 | |
| 2 | 1992 | 6 | 7 | 3 | 47 | 36.9 | 103 | 2.4 | 2.7 | |
| 3 | 1992 | 6 | 19 | 11 | 23 | 35.1 | 80 | 2.2 | 2.6 | |
| 2 | 1992 | 7 | 5 | 4 | 1 | 39.1 | 118 | 2.4 | 2.8 | |
| 1 | 1992 | 7 | 12 | 3 | 24 | 46.4 | 103 | 2.2 | 2.7 | trigger |
| 2 | 1992 | 7 | 26 | 3 | 56 | 6.3 | 38 | 2.2 | 2.5 | |
| 3 | 1992 | 8 | 22 | 10 | 33 | 54.9 | 45.5 | 2.2 | | trigger |
| 2 | 1992 | 8 | 23 | 3 | 10 | 43.5 | 60 | 2.5 | 2.8 | |
| 1 | 1992 | 8 | 30 | 3 | 11 | 56.4 | 91 | 2.8 | 2.8 | trigger |
| 2 | 1992 | 9 | 27 | 5 | 22 | 35.8 | 201 | 2.6 | 2.8 | |
| 2 | 1992 | 10 | 18 | 3 | 24 | 8.9 | 25 | 2.2 | 2.4 | |
| 1 | 1992 | 11 | 7 | 6 | 31 | 43.4 | 177 | 2.6 | 2.8 | |
| 3 | 1992 | 11 | 21 | 12 | 29 | 56.6 | 96 | 2.1 | 2.5 | |
| 2 | 1992 | 11 | 22 | 4 | 46 | 44.8 | 99 | 2.7 | 2.8 | trigger |
| 2 | 1992 | 11 | 29 | 4 | 8 | 46.1 | 119 | 2.0 | 2.6 | trigger |
| 3 | 1992 | 12 | 5 | 10 | 42 | 30.8 | 88 | 2.2 | 2.4 | |
| 1 | 1992 | 12 | 20 | 7 | 10 | 46 | 163 | 2.4 | 2.5 | |
| 2 | 1992 | 12 | 31 | 4 | 35 | 17.9 | 89 | 2.5 | 2.5 | trigger |
| 3 | 1993 | 1 | 16 | 9 | 20 | 45 | 15 | | | |
| 2 | 1993 | 1 | 24 | 8 | 4 | 42.9 | 33 | 1.7 | | trigger |
| 3 | 1993 | 1 | 30 | 13 | 7 | 8.9 | 272 | 2.6 | 2.7 | |
| 1 | 1993 | 1 | 31 | 4 | 14 | 5.9 | 148 | 2.3 | 2.4 | |
| 3 | 1993 | 2 | 13 | 12 | 5 | 34.8 | 148 | 2.6 | 2.8 | |
| 1 | 1993 | 2 | 14 | 7 | 39 | 39.7 | 190 | 2.6 | 2.5 | |
| 2 | 1993 | 2 | 28 | 4 | 23 | 56.4 | 27 | 1.6 | 2.2 | |
| 3 | 1993 | 3 | 6 | 11 | 0 | 31 | 134 | 2.3 | | trigger |
| 2 | 1993 | 3 | 7 | 4 | 14 | 31.3 | 57 | 2.2 | 2.4 | |
| 2 | 1993 | 3 | 28 | 4 | 48 | 2.6 | 219 | 2.4 | 2.7 | |
| 3 | 1993 | 4 | 3 | 8 | 29 | 16.6 | 45 | 1.2 | | trigger |
| 2 | 1993 | 4 | 4 | 3 | 22 | 22 | 88 | 2.3 | 2.6 | trigger |
| 3 | 1993 | 4 | 10 | 8 | 28 | 56.8 | 15 | 1.3 | 2.1 | |
| 2 | 1993 | 4 | 11 | 3 | 45 | 44.6 | 30 | 2.2 | 2.3 | trigger |
| 1 | 1993 | 4 | 18 | 3 | 17 | 54.6 | 127 | 2.2 | 2.7 | |
| 1 | 1993 | 4 | 30 | 23 | 21 | 37.2 | 17 | 2.1 | 2.4 | |
| 2 | 1993 | 5 | 9 | 3 | 14 | 45.1 | 98 | 2.3 | 2.7 | trigger |
| 1 | 1993 | 5 | 23 | 2 | 36 | 9.5 | 196 | 2.7 | 2.5 | |
| 1 | 1993 | 6 | 20 | 2 | 28 | 18.1 | 73 | 2.3 | 2.5 | |
| 2 | 1993 | 6 | 27 | 2 | 42 | 7.2 | 71 | 2.6 | 2.5 | trigger |
| 3 | 1993 | 7 | 3 | 10 | 1 | 15.4 | 60.5 | 1.9 | 2.2 | |
| 2 | 1993 | 7 | 18 | 2 | 57 | 12.1 | 117 | 2.6 | 2.5 | trigger |
| 2 | 1993 | 7 | 25 | 6 | 43 | 52.8 | 16 | 1.8 | 2.1 | |
| 1 | 1993 | 8 | 1 | 8 | 57 | 19.2 | 22 | 1.1 | 1.8 | |
| 2 | 1993 | 8 | 5 | 4 | 42 | 11.6 | 22 | 1.9 | | |
| 3 | 1993 | 8 | 21 | 13 | 25 | 16.1 | 40 | 1.9 | 2.1 | |
| 1 | 1993 | 8 | 22 | 2 | 21 | 46.2 | 75 | 2.7 | 2.4 | |
| 2 | 1993 | 9 | 5 | 4 | 29 | 45.2 | 249 | 2.6 | 2.8 | |
| 2 | 1993 | 9 | 19 | 5 | 20 | 34.7 | 140 | 2.9 | 2.7 | |
| 2 | 1993 | 9 | 19 | 7 | 0 | 37.7 | 24 | 1.1 | 1.9 | |
| 2 | 1993 | 10 | 3 | 3 | 52 | 30.8 | 167 | 2.6 | 2.6 | |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 2 | 1993 | 10 | 10 | 3 | 34 | 16.3 | 44 | 2.4 | 2.4 | |
| 1 | 1993 | 10 | 24 | 5 | 34 | 25.4 | 43 | 2.7 | 2.4 | |
| 3 | 1993 | 11 | 20 | 18 | 46 | 54.3 | 13 | 1.4 | 2.1 | |
| 1 | 1993 | 12 | 5 | 6 | 50 | 18.1 | 254 | 2.6 | 2.8 | trigger |
| 2 | 1993 | 12 | 31 | 8 | 1 | 48.3 | 360 | 2.6 | 2.8 | |
| 3 | 1994 | 1 | 22 | 20 | 20 | 48 | 110 | 2.6 | 2.3 | |
| 1 | 1994 | 1 | 23 | 6 | 58 | 34.1 | 170 | 2.7 | | |
| 2 | 1994 | 1 | 30 | 4 | 6 | 11.6 | 115 | 2.1 | 2.3 | trigger |
| 3 | 1994 | 2 | 19 | 11 | 50 | 36.7 | 41 | | 2.0 | |
| 2 | 1994 | 3 | 7 | 5 | 8 | 36.9 | 112 | 1.8 | 2.7 | trigger |
| 1 | 1994 | 4 | 24 | 1 | 28 | 7.4 | 82 | 2.5 | 2.4 | |
| 3 | 1994 | 5 | 28 | 10 | 36 | 55.4 | 115 | 2.2 | 2.3 | |
| 1 | 1994 | 7 | 24 | 4 | 54 | 41.5 | 196 | 2.1 | 2.7 | |
| 2 | 1994 | 9 | 18 | 3 | 14 | 34 | 136 | 2.5 | 2.5 | |
| 3 | 1994 | 10 | 22 | 11 | 56 | 7.6 | 15 | 1.5 | 2.0 | |
| 1 | 1994 | 11 | 6 | 6 | 0 | 13.8 | 120 | 2.6 | 2.5 | |
| 2 | 1994 | 12 | 11 | 5 | 47 | 8 | 82+91 | 2.5 | 2.7 | double |
| 2 | 1994 | 12 | 18 | 4 | 16 | 2.6 | 126 | 2.7 | 2.7 | |
| 1 | 1994 | 12 | 25 | 3 | 28 | 29.5 | 30+35 | 2.2 | | trigger, double |