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Large Mining Blasts from the Kursk Mining Region, Russia

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Large Mining Blasts from the Kursk Mining Region, Russia

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Table of Contents

Introduction: Mining Blasts as Seismic Events under a CTBT

Monitoring the Comprehensive Nuclear Test Ban Treaty (CTBT) by seismic means will require identification of seismic sources at magnitude levels where industrial explosions (primarily, mining blasts) may comprise a significant fraction of the total number of events recorded, and may for some countries dominate the seismicity. Thus, data on blasting practice have both political significance for the negotiation of treaties involving seismic monitoring of nuclear tests, and operational applications in terms of establishing monitoring and inspection needs on a mine-by-mine basis.

While it is generally accepted that mining explosions contribute to seismicity at lower seismic magnitudes (less than about magnitude 3.5), the rate of mining seismicity as a function of seismic magnitude is unknown for most countries outside the U.S. This results in a large uncertainty when estimating the task of discriminating nuclear explosions from chemical explosions and earthquakes, by seismic means, under a comprehensive nuclear test ban. This uncertainty directly affects estimates of seismic network enhancements required to achieve treaty verification requirements at magnitudes less than about 3.5.

Blasting in the Former Soviet Union

Before its breakup in 1991, the former Soviet Union (FSU) conducted most of the largest known chemical explosive blasts (for a review of blasting in the former Soviet Union, see Leith and Bruk, 1995a). While the largest of those blasts (up to 13kt) were rare explosions for excavation projects (principally dam building), the mining industry of the FSU routinely detonated blasts in excess of 1 kt. The FSU is a leading producer of many commodities mined with explosives, including iron ore. The principal mining regions in the FSU are shown on the map of *Figure 1*. The Kursk region was, in 1987, the second largest iron ore producing region in the former Soviet Union (next to Krivoy Rog, Ukraine), and accounted for about 10% of world iron ore production and 20% of Soviet iron ore production.

Table 1 lists the major, non-coal mining districts in the former Soviet Union that conducted very large blasts (those with total charge exceeding 300 tons). The numbers of large blasts are significantly larger than is estimated for the United States (see data for US explosions in 1987 in Richards and others, 1992), including the US coal-mining industry, which detonates the most of the largest blasts in terms of total charge size. Note that the Kursk mining combines (see below) are prominent on this list, reflecting the large production of iron ores from the Kursk region.

Mining in the Kursk Magnetic Anomaly

The city of Kursk is located in the center of a broad belt of banded iron ore deposits in European Russia, some 400 km south of Moscow (*Figure 2*). The region is known geologically as the Kursk Magnetic Anomalies (or KMA), because of the strong magnetic anomaly pattern generated by the magnetized iron ore deposits. While the

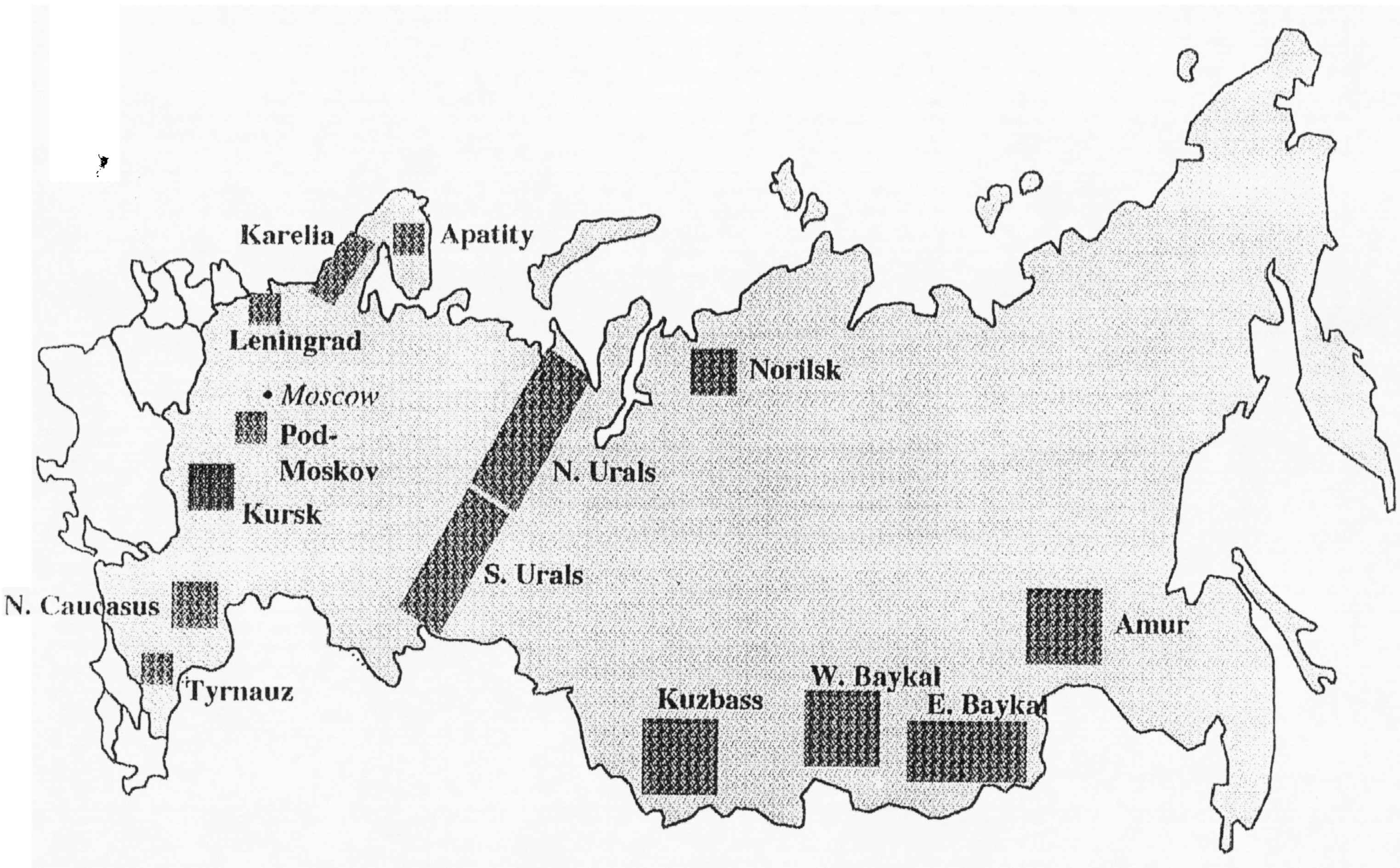

Figure 1. Map of the Russian Federation, showing the principal regions using "strong" more than 300 ton) mining blasts in Russia in 1993. Within each of these regions operate several mining-metallurgical combines, or *GOKs*. Thur Kursk mining region is located south of Moscow, near the Ukranian border.

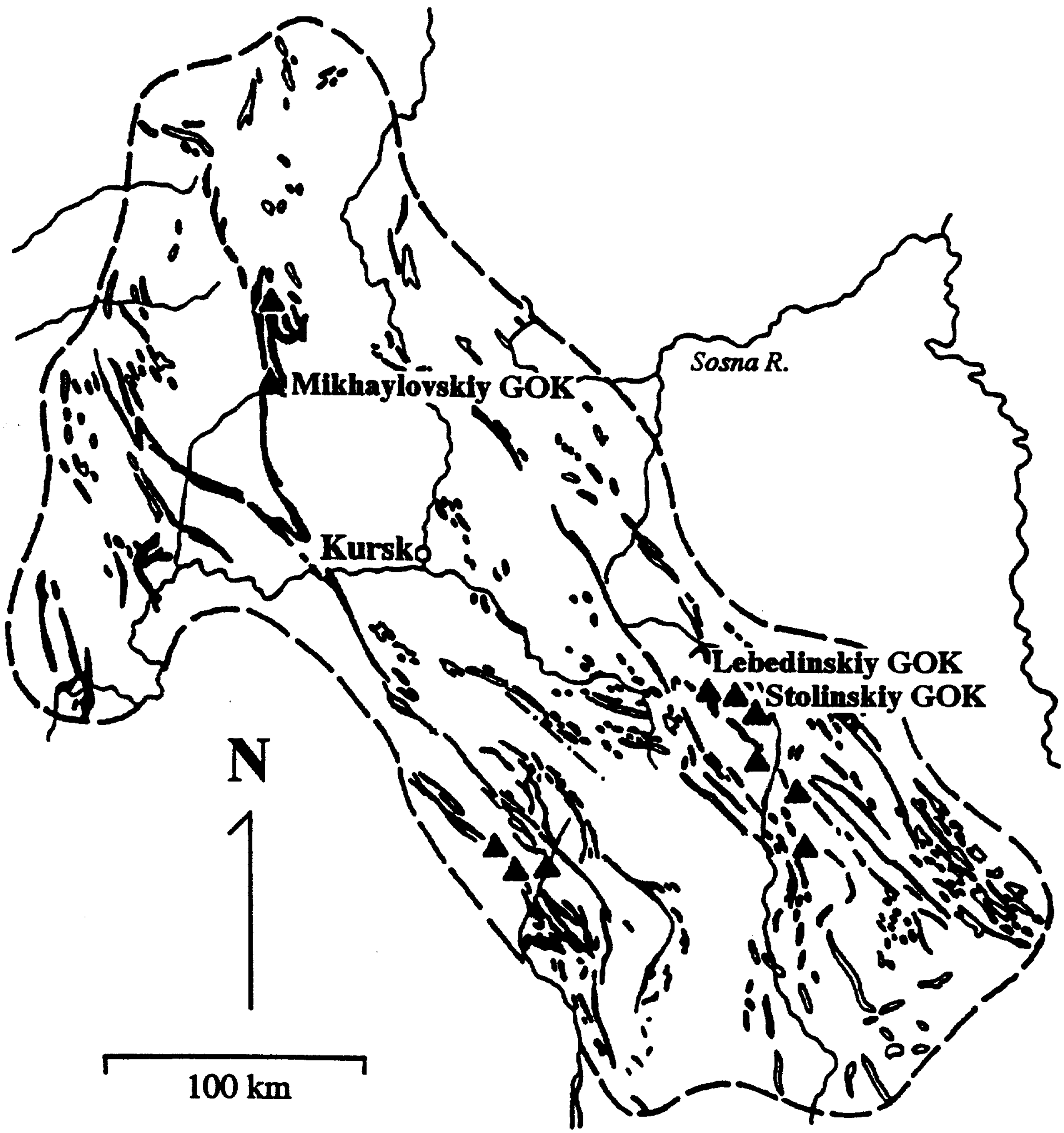

Figure 2. Map of the Kursk region, showing the distribution of banded iron formation (filled bands are higher grade iron ore; unfilled bodies are lower grade ore) and the locations of the principal mining combines (triangles). Note the locations of the Lebedinsky, Mikhaylovsky, and Stolylensky mining/metallurgical combines (GOKs).

KMA were discovered in 1778, the iron ore deposits were completely covered by sediments ranging from 37 to 500 meters thick. Geophysical studies began in 1883, and the first cores of banded iron formation were recovered in 1923 (Alexandrov, 1973).

Table 1. Preliminary Data on Large Mining Blasts in the Former Soviet Union. Data are for the year 1988.

Mining Region	largest group tot. charge size (t)	approximate no. no. per year	commodity (note)
Norilsk	up to 1500	rare	Cu, Ni
Kursk (L)*	300-1500	50	Fe
Udachnaya	> 1000	50	Diamond
Krivoy Rog	> 1000	N/A	Fe
Tyrniauz	< 1000	N/A	Mo
Dzhezkazgan	500-600	50	Cu
Kursk (M)*	100-500	50	Fe
Apatity	> 400	0-10	Apatite
Kursk (S)*	50-500	50	Fe
Aykhal	N/A	25-30	Diamond

* M, Mikhaylovsky combine; L, Lebedinsky combine; S, Stolylensky combine.

The KMA cover an area of about 170,000 square kilometers. There are two principal belts of banded iron formation; one to the southwest of the city of Kursk, the Belgorod belt; the other to the northeast of Kursk, the Oskol' belt. Several of the ore bodies have enormous dimensions: for example, the Yakovlevo deposit, in the Belgorod region, has been traced more than 50 kilometers along strike, ranging in width from 200 to 400 meters in thickness. The reserves of iron in the KMA are estimated to be 13 times that of Krivoy Rog, the next largest iron reserve of the former Soviet Union (in Ukraine), and almost 17 times larger than those of the Lake Superior region in the U.S. and Canada (Alexandrov, 1973).

Mining in the Gubkin Region

Mines conducting "strong" blasts (over 300 tons) in the region of the Kursk Magnetic Anomaly are limited to the surface mines at the Lebedinsky, Mikhaylovsky and Stolylensky Mining and Metallurgical Combines (see *Table 1*). Blasting at these mines is carried out in the open cast method, in deep surface excavations[1]. As seen in *Table 1*, the Lebedinsky and Mikhaylovsky mines have dominated the largest charge sizes of Soviet blasts, and are therefore of interest as targets for seismic monitoring research.

Geologic Setting of the Mines at Gubkin

Iron-bearing quartzites in the region of Gubkin (a.k.a. Stariy Oskol) form an elongated massif, extending up to 3 km in length in a southwest-northeast direction. Within this massif, there are three areas of minerals exploitation, known as Central, Southern and Stoylo-Lebedinsky. The iron ores are reached by removing a cover of sedimentary rocks (as at the Lebedinsky and Stoylensky mines) or by constructing a shaft through the cover rocks (as a Gubkin/Stariy Oskol). A Russian, 1:200,000-scale map of the Gubkin-Stariy Oskol' region is shown in *Figure 3*.

Detailed geologic information is available for the Lebedinsky open-pit mine (see photograph in *Figure 4*). At Lebedinsky, cover rocks are represented by (from top to bottom):

loam and clay	1-20 m
marly-chalky strata	0-60 m
sand layers (Cenomanian-Albian)	25-30 m
sandy-clayey deposits (Jurassic)	2.5-27 m
clays and ore-bearing breccias (Devonian) in depressions in the Precambrian surface	variable

The iron-bearing quartzites consist of quartz, alkaline amphibole, and cummingtonite. The ore-bearing minerals are magnetite and specularite (specular iron); secondary minerals include carbonates, biotite, feldspar, aegerine, garnet, pyrite, and apatite. The amount of non-ore-bearing shales within the layers of iron-quartzites is 1.2%, with thicknesses ranging from 0.1 to 3.0 meters; their vertical thickness can reach 5-10 meters in steeply-dipping beds. Low-iron quartzites comprise 1.85%.

The deposits of iron quartzites are characterized by a complex alternation of rocks of varying petrography and structure; this complexity results in a large water flow into boreholes that are drilled for loading explosives. The hardness of the quartzites in the apex of the folds is more than 20 on the Schmidt scale; the axial compressive strength on laboratory samples exceeds 200 MPa.

A geological cross-section is shown in *Figure 5*.

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[1] Underground mines also exist at throughout the KMA, for instance at Gubkin and Stariy Oskol (see *Figure 3*). Blast data from these mines is also presented in this report.

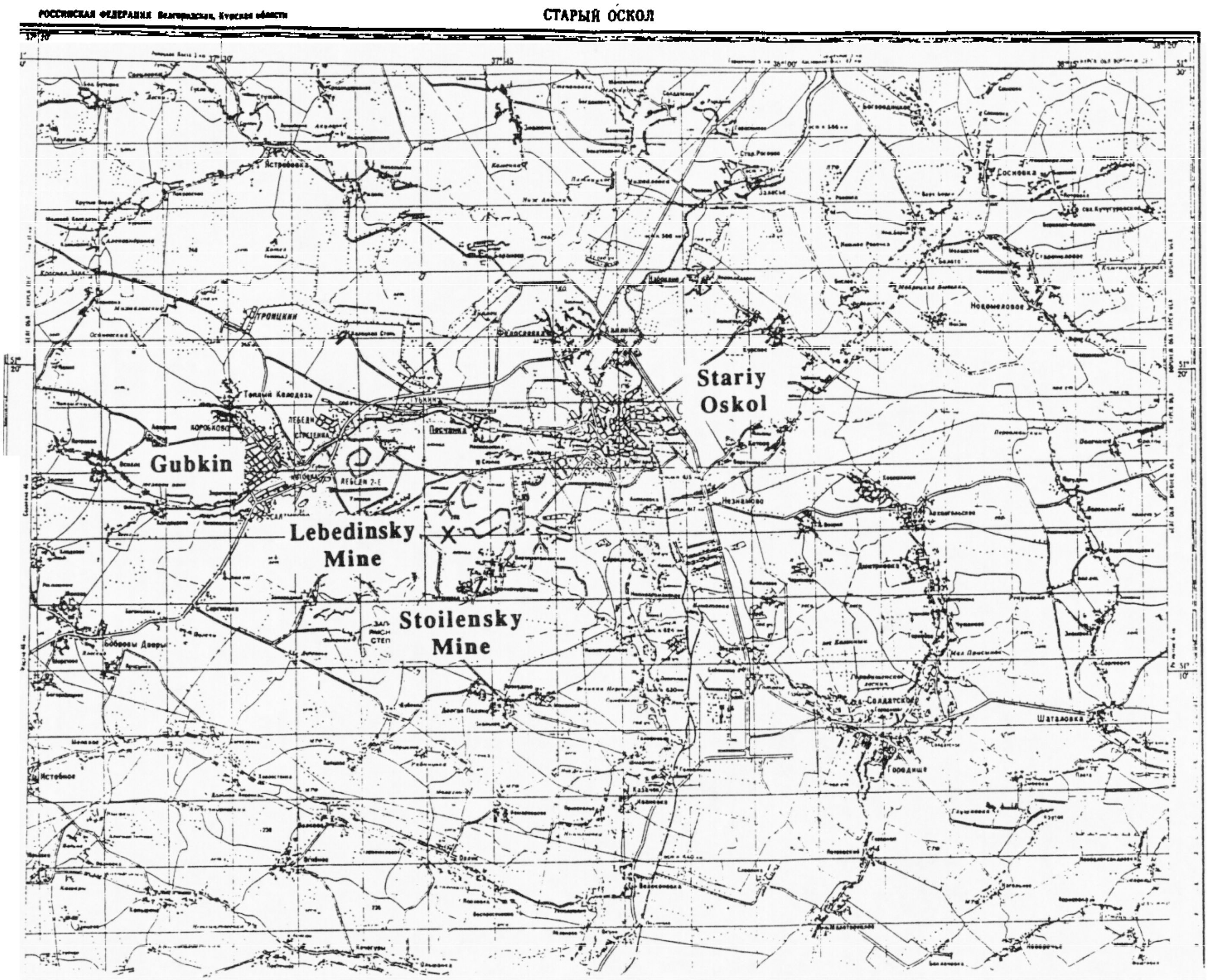

Figure 3. Map of the Gubkin (Stariy Oskol) region (portion of the Russian, 1:200,000 topographic map), showing the locations of the Lebedinsky and Stoylensky open-pit mines and the towns of Gubkin and Stariy Oskol, where underground mining is conducted.

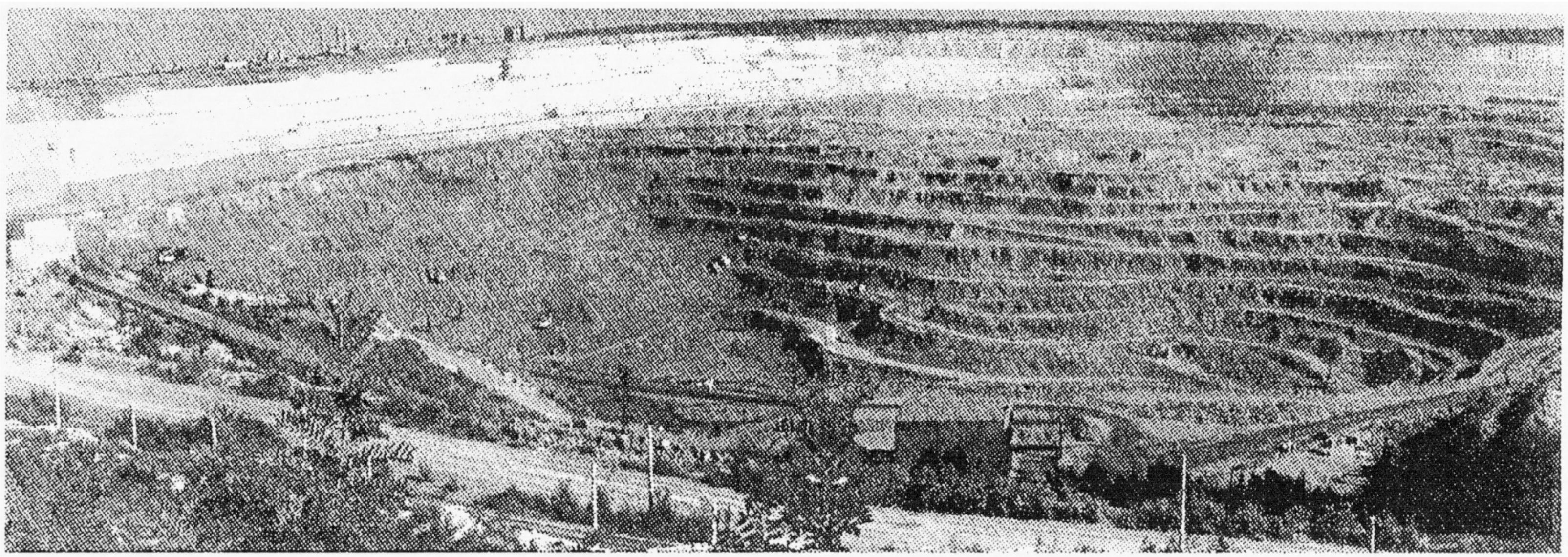

Figure 4. Photo-mosaic of the open pit mine at Lebedinsky. The light-colored, upper layers are a cover of Quaternary and Cretaceous sedimentary rocks (see text), overlying the iron ore-bearing quartzites of banded iron formation. The cover rocks are about 100 meters thick.

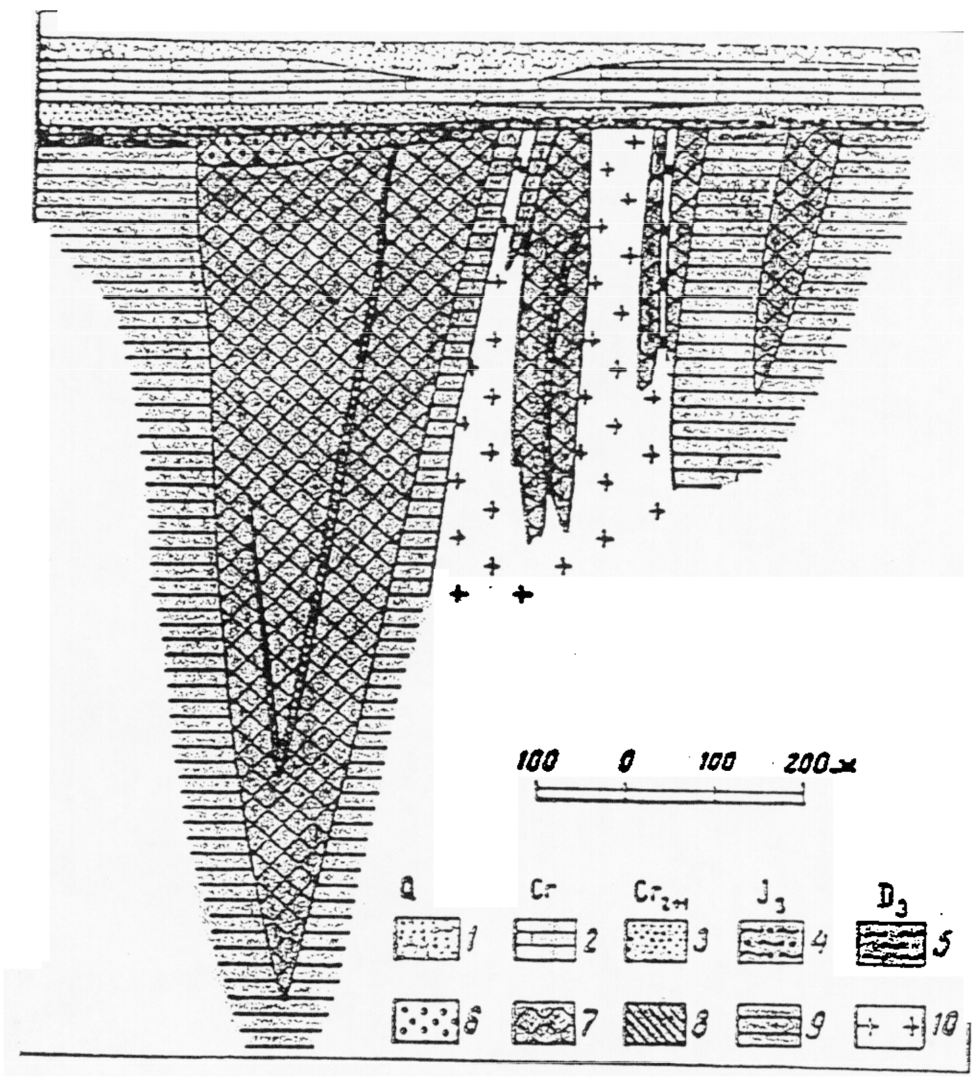

Figure 5. Geological cross-section of the Lebedinsky iron ore deposit, Kursk mining region (from Laznika, 1993). The thick cover layers have been stripped back to expose the iron ores for surface mining. These deposits are also mined nearby in underground workings, at significant depths. Key as follows: 1) soils; 2) marl; 3) sandtone; 4) clay with sandstone interbeds; 5) claystone with sandstone interbeds; 6) iron ores in the weathered layer; 7) banded iron formation (Proterozoic); 8) schists; 9) schist, meta-quartzite and gneiss; 10) diorite porphyrite.

Blasting Practices at the Kursk Mines

Table 2 gives statistics for strong blasts at the Kursk mines in 1993. It is not known how much variability there is in blasting practices at these mines over periods of years, but comparison with *Table 1* indicates that blast size and frequency have dropped since the 1980s. Blasting has been further diminished at Kursk in the last few years as a result of deteriorating economic conditions. This has resulted in both lower total charge sizes and some weeks or months passing without blasts.

Table 2. Total numbers of blasts and "strong" blasts (those with total charges of 300 tons or more) at Kursk in 1993.

mining combine	total charge	total blasts	blasts≥300t
Lebedinsky	250-1400 t	34	30
Mikhaylovsky	200-500 t	50	40
Stolylensky	100-700 t	25	12

Large Blasts at the Lebedinsky Combine in 1992

In recent years, the Lebedinsky combine has detonated the largest blasts in the Kursk region. As noted above, blasting here is conducted in surface mines by the open cast method, in mines cut relatively deep through the surface deposits. Note that this mine is also located in close proximity to active, deep underground mine workings at Gubkin, and is therefore an ideal target for a seismological mine monitoring experiment.

The blasts are composed of a series of blocks, spatially separated across the open pit mine. These blocks are ripple-fired (discussed below), with delays of one or more seconds between them. The principal explosives used are *granulotol* and *grammonite*; a list of explosives commonly used in Russia and the former Soviet Union, and their TNT equivalents, is given in *Appendix 2*. *Figure 6* is a map of the Lebedinsky mine, showing the blocks detonated in series on September 7, 1995. Block maps for other blasts at Gubkin are given in *Appendix 3*. The video/movie of *Appendix 4* shows the detonation of a single block of the blast of September 7, 1995, at the Lebedinsky mine.

Table 3 lists large blasts detonated at the Lebedinsky Combine during the first six months of 1992. Several features of these blasts are worth noting. First, most of the blasts were detonated on alternate Thursdays, and all but two were detonated at 12:00 or 12:30pm, local time. This pattern of regular blast timing at a single mining combine is typical of Russian blasting practice, and has been noted at several of the largest Russian mines (e.g., Apatity, Tyrnauz, Kuzbass, and others).

(*continues*)

Figure 6. Sketch map of the pit at Lebedinsky mine, showing the distribution of charge blocks for the blast of September 7, 1995.

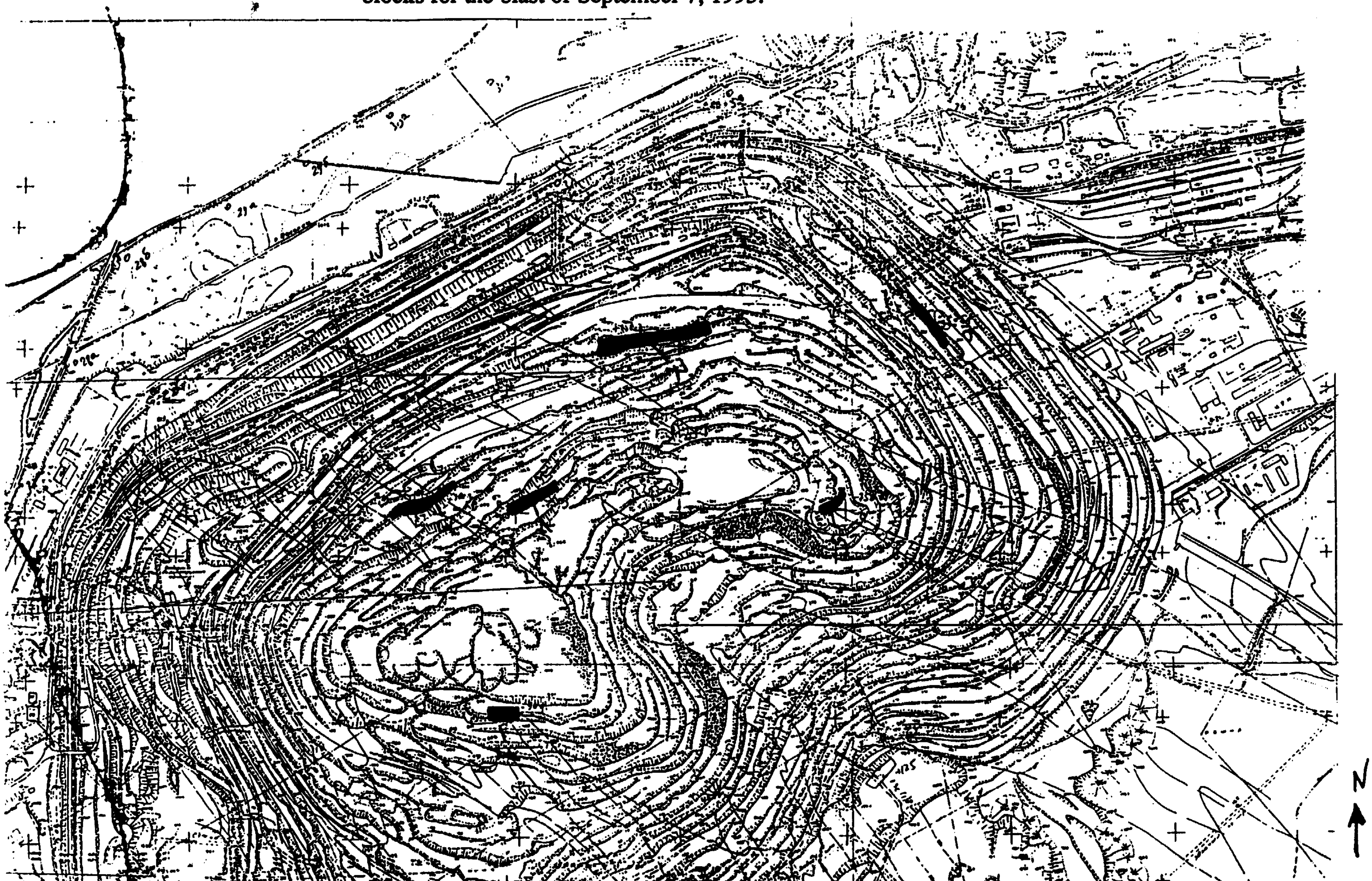

Table 3. Blasts at Lebedinsky mining combine, Feb-Jun, 1992

date	day	time (Mos.)	total.charge(t)
92/02/06	Th	12:00	871.7
92/02/21	Fr	12:00	1248.1
92/03/05	Th	12:30	1110.0
92/03/19	Th	12:00	979.0
92/04/02	Th	12:00	1319.6
92/04/16	Th	12:00	946.6
92/04/30	Th	12:30	786.7
92/05/08	Fr	9:00	290.6
92/05/14	Th	12:00	694.0
92/05/22	Fr	12:00	1221.7
92/06/11	Th	13:22	1568.5
92/06/25	Th	12:00	1273.5

Two types of blasting

Blasts at Kursk have traditionally been conducted using a "conventional" geometry, in which an entire row of spaced charges is detonated at once (*Figure 7a*). This method, which is very efficient at crushing and displacing the rock but results in large amplitude ground motion near the source, has dominated the blasting at Kursk for decades. This type of blasting is now apparently only rarely used in the United States because of damage to structures near mines as a result of the near-source ground motion. Detailed blasting data for mines in the Magadan Oblast' of the Russian Far East, for the years 1989-1992 indicate that this blasting pattern was exclusively used for mining in this region, which includes both coal and metal mining (Leith and Bruk, 1995b).

In the last 1-2 years, the Kursk mines have started to use a second method or geometry, which we will call "reduced-shaking", in which individual rows are blasted in a series of charge-delayed holes. In the Russian application of this method at Kursk, charges are fired so that short, diagonally oriented rows are fired sequentially, each consisting of only a few holes (see *Figure 7b*). This is similar, but not identical to common U.S. "ripple-fire" blasting practices, and results in a much decreased local ground motion. By 1994, both blasting geometries were being used for mining iron ore at the Kursk mining combines.

Detailed Example of a Blast from 1994

Table 4 list the blast parameters from a large, complex blast that was detonated at

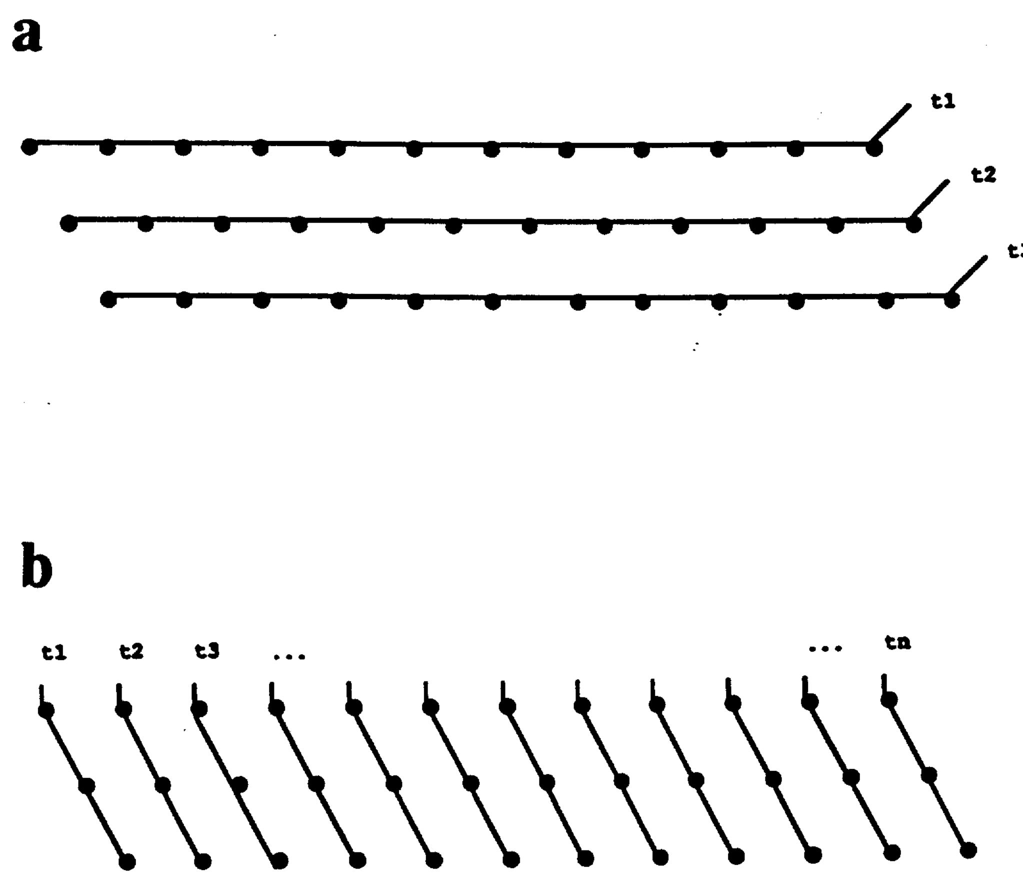

Figure 7. Typical blast geometries: a. Charge/delay geometry of a typical "conventional" mining blast, in which successive charge rows are detonated with no delay along the row. b. Charge/delay geometry of a "reduced shaking" blast, in which charge rows are detonated on the diagonal, down the rock face, with a short (e.g., 10 msec) delay between rows.

the Lebedinsky mining combine in 1994. In this blast, which was detonated at 12:00pm on Tuesday, 16 August, 1994, 318 tons were detonated in five individual "blocks", separated laterally by 500 to 1000 meters. Each block was blasted in a conventional charge geometry (see above), and there was a delay of about 1 second between each block. A diagram of one block's charge geometry is shown in *Figure 8*).

Table 4. Charge geometry for a single block of the 18 Aug. 1994, blast at Lebedinsky combine, KMA mining region.

charge rows	3
hole diameter	250mm
holes per row	~38
charge per hole	560kg
charge per row	~21 t
hole depth	16.5m
charge length	12m
row separation	8m
hole separation	5m
delay interval	35msec
delays per block	3
charge per block	~64 t

Charge-time Data

Surface blasting. Charge-time data for two blasts at Lebedinsky mine are given in *Figures 9 and 10*. As described above, the blasts are detonated as a series of blocks, with groups of holes in each block detonated simultaneously, separated by delays of 20-50 milliseconds. The total charge detonated in a single delay ranges from less than one-half ton to more than 9 tons. The detonation of a single block takes approximately 1-2 seconds, and the entire blast sequence may occur over more than 20 seconds. Data on the total charge per block is available for blasts from July, 1994 through September, 1995, listed in *Appendix 1*.

Underground blasting. Charge-time data for six blasts in the underground mines at Gubkin are given in *Table 5*. The underground blasts are also detonated as groups of holes, separated by delays of 20-25 msec. While the total charge and the charge per delay are smaller, as expected, it is noted that in the majority of these blasts, some 4 tons or more of explosive is detonated simultaneously --similar to the charges per delay in the surface mines. *Figure 11* plots all six underground blasts on the same time scale, so that the variability in their charge-time patterns can be more easily compared.

5-Aug-95

time, msec	charge, kg
0	1634
20	3311
40	2794
60	4342
80	4257
100	4316
125	1979
150	2313
175	163
	25109 kg

12-Aug-95

time, msec	charge, kg
0	413
20	1652
40	2013
60	1248
80	1660
100	1239
125	2082
150	1265
175	1222
200	774
225	1396
	14964 kg

19-Aug-95

time, msec	charge, kg
0	146
20	194
40	1445
60	1771
80	1668
100	1669
125	1136
150	766
175	335
	9130 kg
break of 2-3 minutes	
0	413
20	413
40	413
60	413
	1652 kg

26-Aug-95

time, msec	charge, kg
0	129
20	636
40	2211
60	3020
80	3557
100	4120
125	3483
150	4464
175	4205
200	2548
	28373
break of 25 minutes	
0	3732
25	1118
50	1945
75	731
100	584
125	197
	8307 kg

Table 5. Blasting patterns for six underground blasts conducted at Gubkin in August, 1995
Note that two blasts were conducted on the days of Aug. 19 and Aug. 26

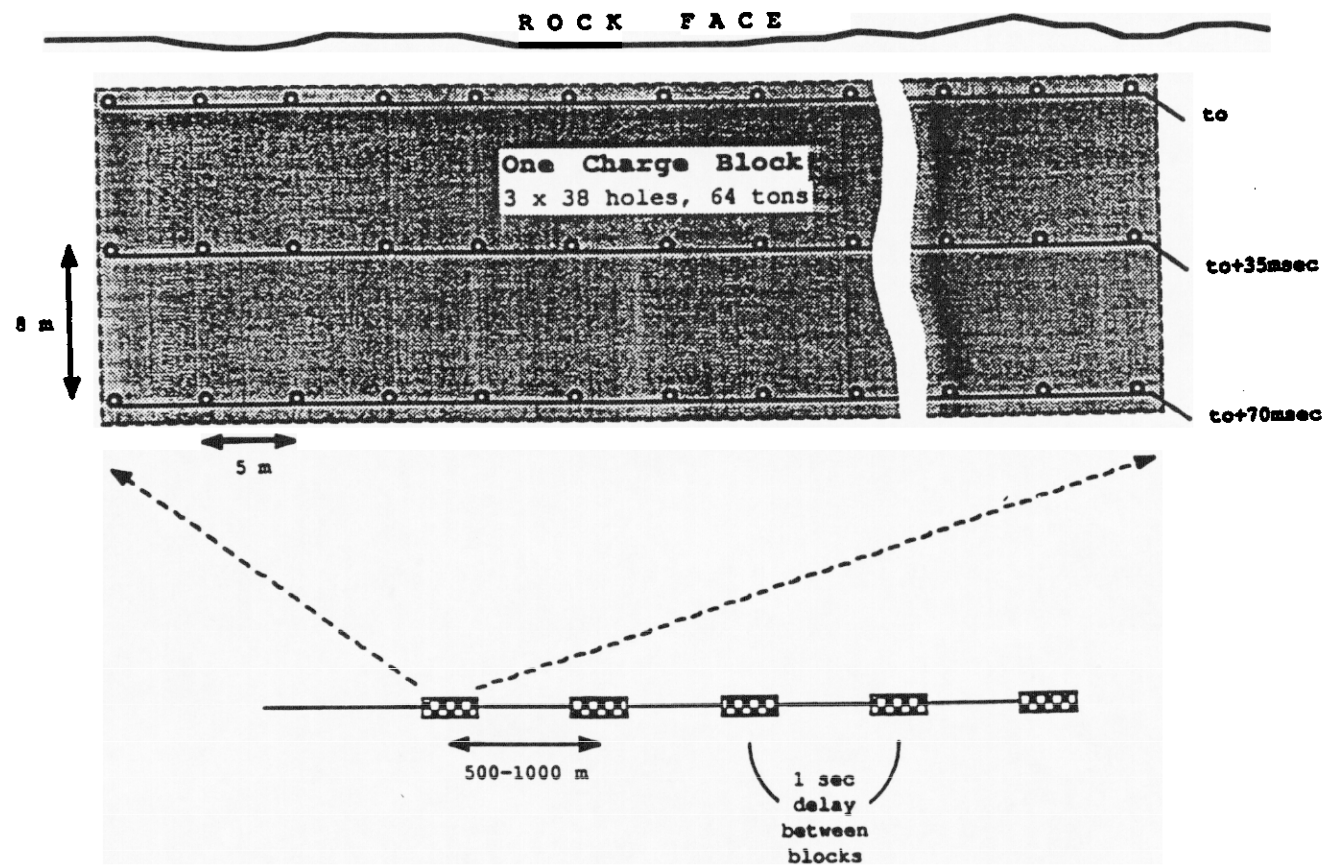

Figure 8. Example of the detailed charge geometry for a single block of the 18 Aug. 1994 blast at Lebedinsky combine, KMA mining region, Russia. This blast was composed of a series of 5 such charge blocks, each separated by 500-1000 meters, and detonated with a delay of about 1 second.

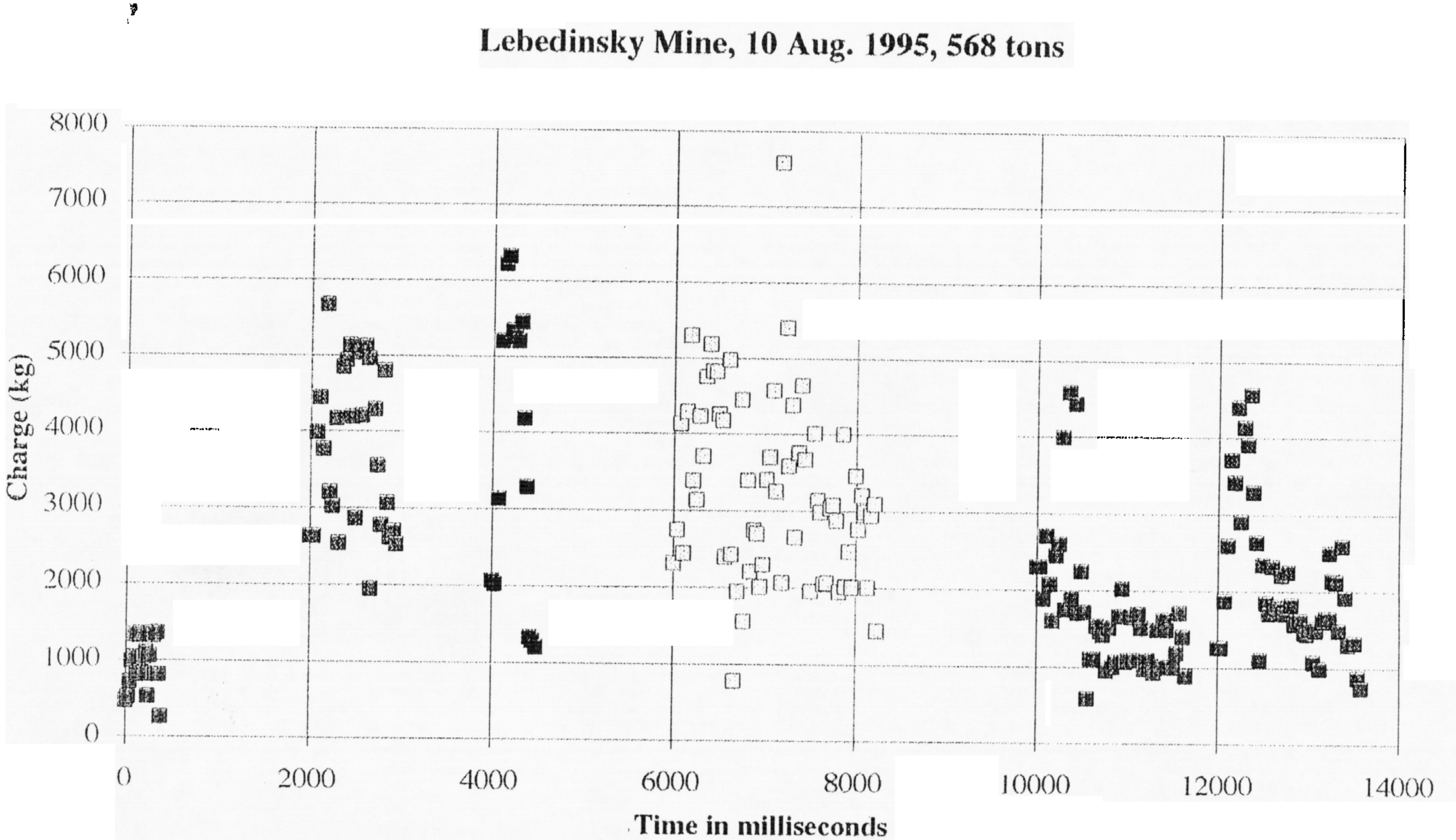

Figure 9. Firing pattern (charge-per-delay) of the blast at Lebedinsky mine on 10 August, 1995.

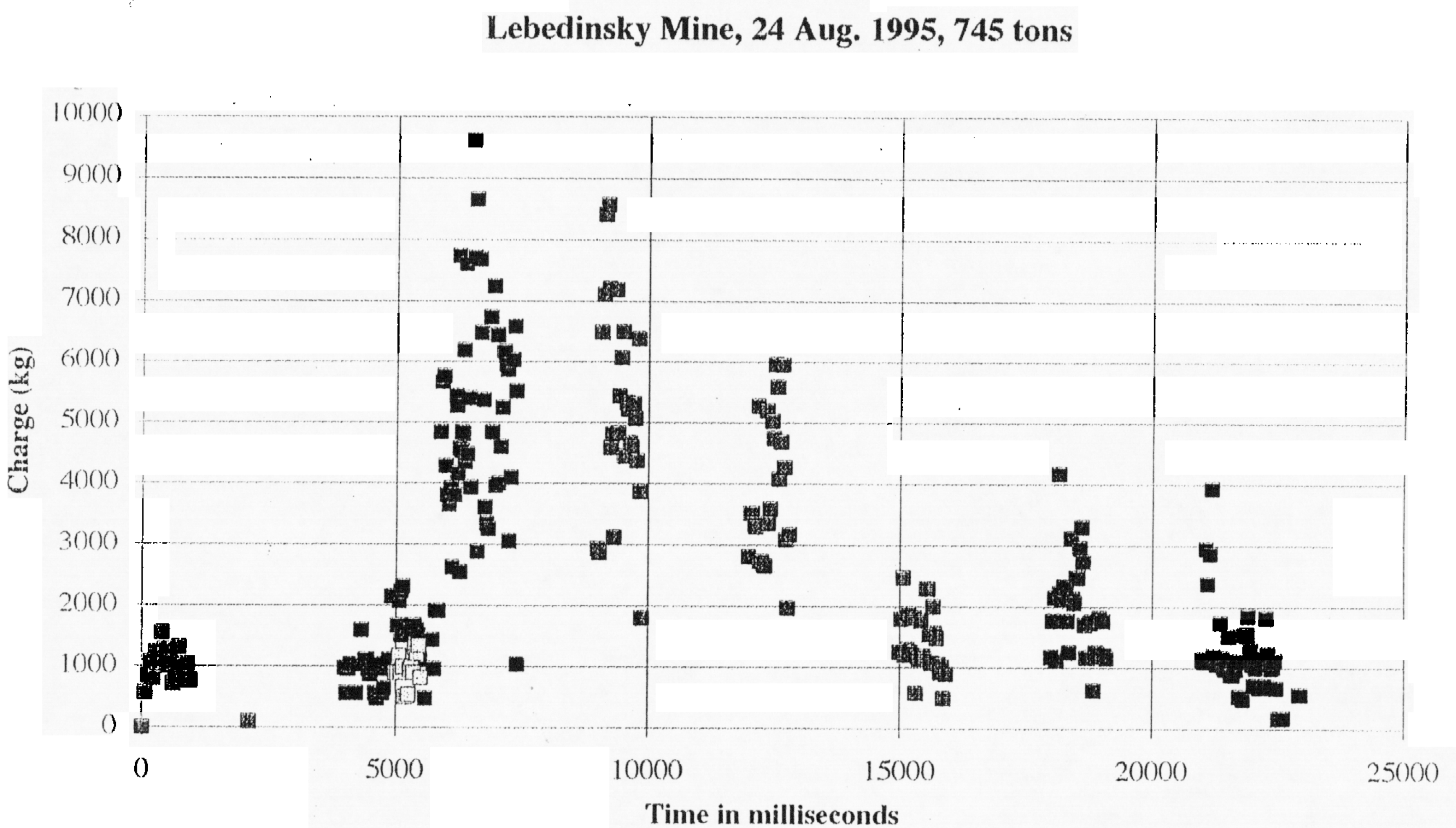

Figure 10. Firing pattern (charge-per-delay) of the blast at Lebedinsky mine on 24 August, 1995.

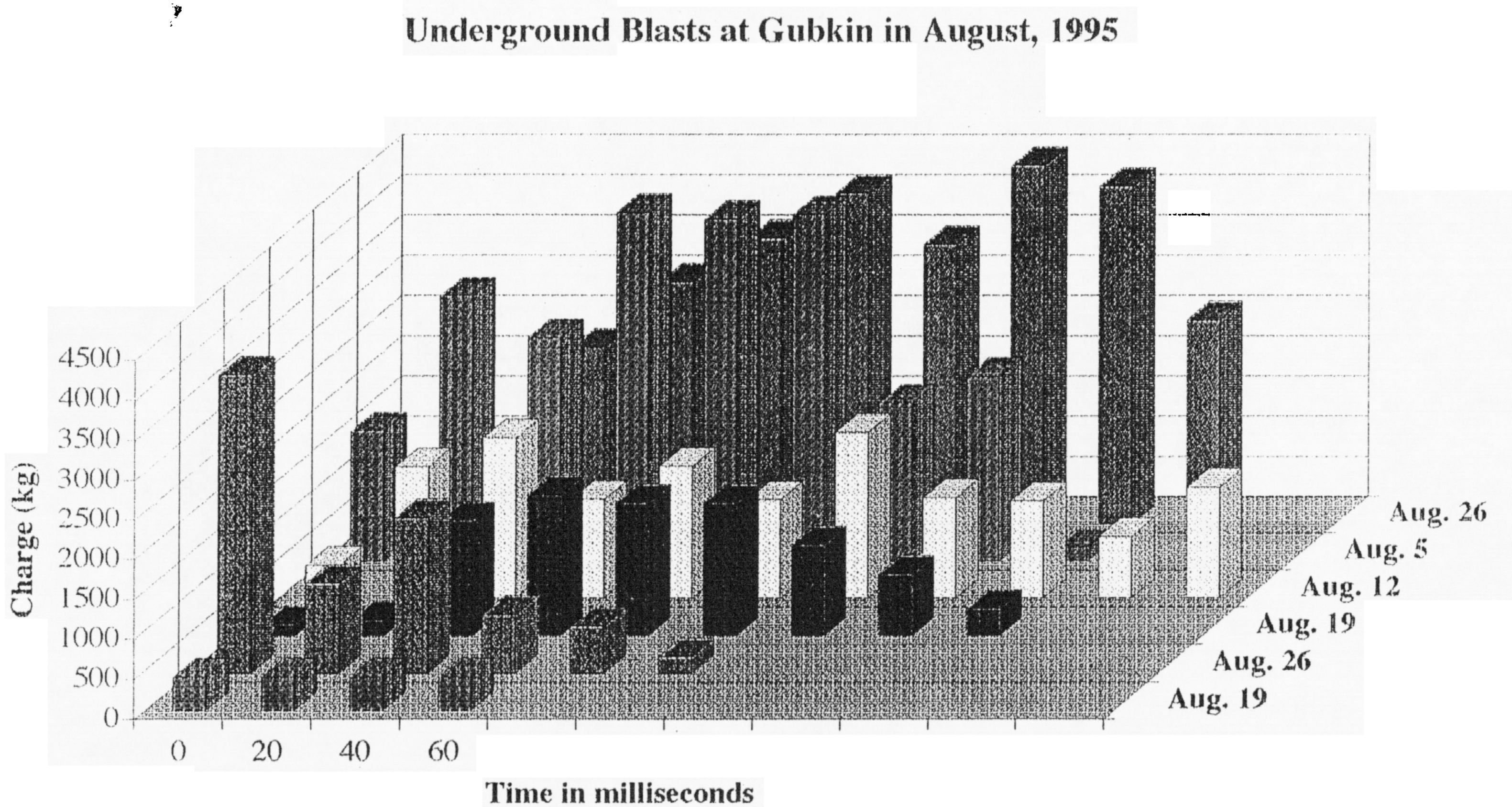

Figure 11. Firing pattern (charge-per-delay) of six blasts detonated at the underground mine at Gubkin. Note that, despite these blasts being detonated underground, there are still trhee to four metric tons of explosives being fired in a single delay, similar to the open pit mines.

Blasting Trends

It is well known that, since the breakup of the former Soviet Union, economic conditions have deteriorated, affecting most of the major industries. This has included the mining industry, where production has fallen dramatically since 1990. Likewise, the consumption of explosives has also fallen: In 1990, approximately 2 million metric tons of explosives were detonated in Russia; by 1994, than number had fallen to about 700,000 metric tons. Economic conditions have affected blasting practices through the unavailability (or high cost) of explosives, and has resulted in both fewer blasts and smaller total charge sizes.

There is also apparently a trend to reduce the local seismic shaking at some mines, as evidenced by the used of the "reduced shaking" blasting geometry for some of the blasts at the Lebedinsky combine. It is not known whether this is becoming more common at other mines, for mining other mineral commodities, and whether its use will soon dominate the mining industry in populated areas of Russia.

Seismic Recordings of Blasts, August-September, 1995

Mine Blast Sources, Stations and Instrumentation

Blasts detonated in August and September, 1995, were recorded from the open pit mines at Mikhaylovsky, Lebedinsky and Stoylensky GOKs, and from the underground mines at Gubkin (see map of *Figure 12* for mine and station locations). These were recorded at the permanent FDSN station at Mykhnevo (MHV), as well as at an array of portable stations at various regional distances from 60 to 250 km from the mines. These included a digital seismic recording station at Svoboda, about mid-way between the Mikhaylovsky mine and the three mines near Gubkin (see Figure 1), and five analog seismic recording sites, at Elets, Turdey, Lamskoe, Bolshoye Ogarevo, and Tim. Coordinates of the mines and seismic recording sites are given in *Table 6,* and plotted on *Figure 12*.

Blasts were recorded on three-component, Russian, short-period seismometers (No. SM-3KV). A photograph of the seismometers is shown in *Figure 13*. Examples of the amplitude-frequency response of four of the instruments are given in *Figures 14 and 15*. Blasts recorded at Svoboda were digitized on a REFTEK Data Acquisition System and recorded to tape. Blasts recorded at the other portable stations were recorded in analog format on TEAC recording systems. Blasts recorded at Mykhnevo were recorded on multiple seismometer and system types, including a broadband digital seismic system operated jointly by the Russian Academy of Sciences and a German institute.

(continues)

Figure 12 (next page). Map of the region between Moscow and Kursk, Russia, showing the locations of the major iron-ore mines (Mikhaylovsky, Lebedinsky and Stoylensky), the permanent seismic stations at Obninsk (OBN) and Mykhnevo (MHV), and the portable seismic station sites used in this study (red triangles, named).

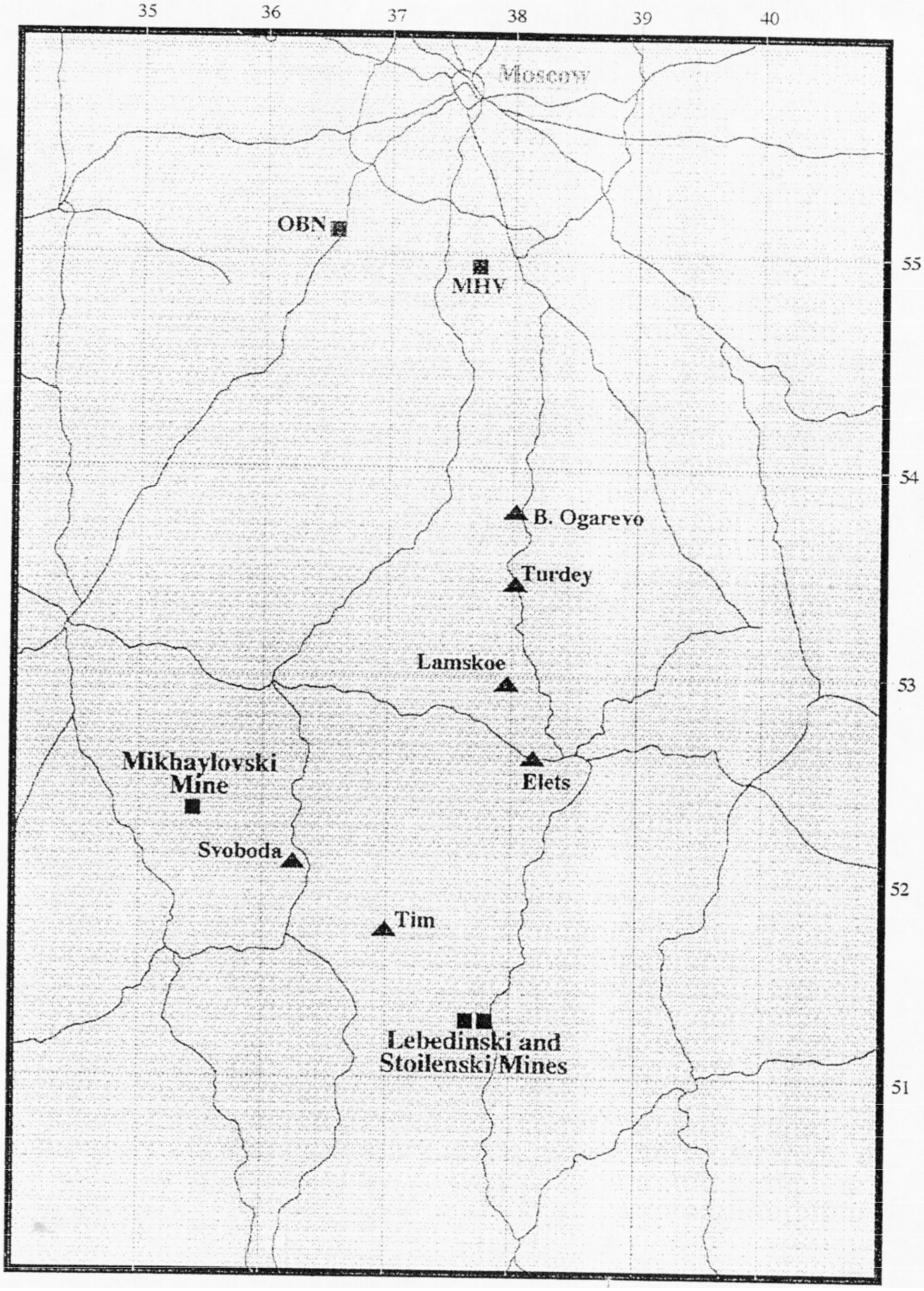

Figure 12 (caption previous page)

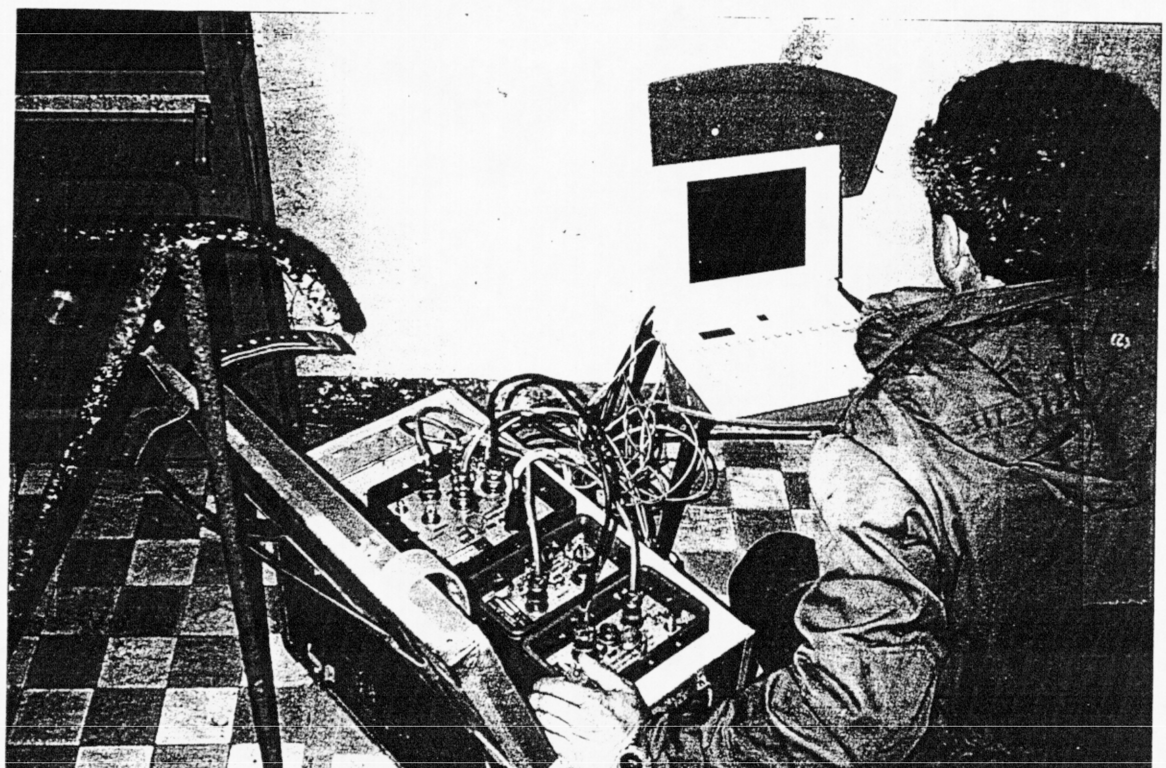

Figure 13. Photograph the REFTEK digital seismic recording system that was deployed at Svoboda, being tested in the vault at Mykhnevo.

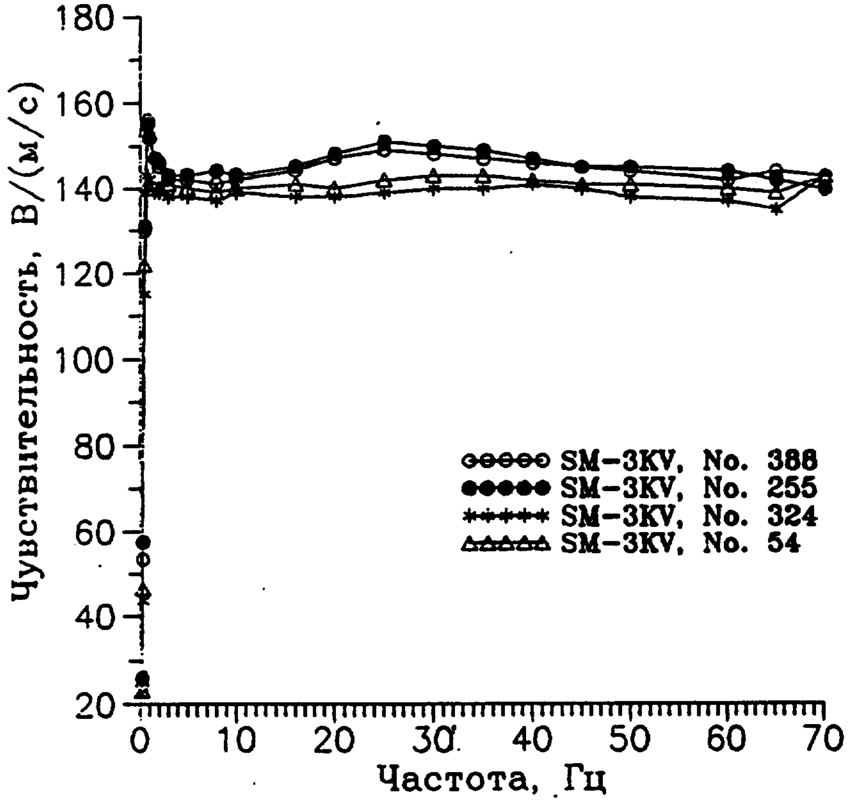

Figure 14. Sample amplitude-frequency characterisitcs of four of the SM3KV seismometers that were deployed at all portable seismic station sites.

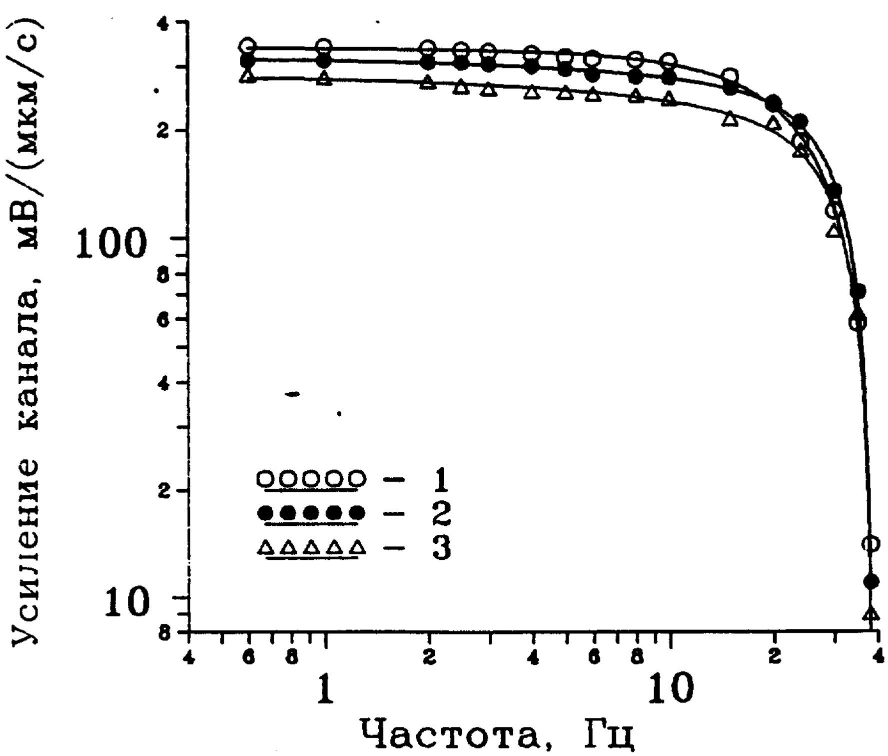

Figure 15. Magnification curves for the for the SM3KV short-period seismometers.

Table 6. Approximate Mine and Station Coordinates

Mine Name	Latitude deg	Latitude min	Longitude deg	Longitude min	Source of Coord.
Mikhaylovsky	52	22	35	27	1:200k map
Lebedinsky	51	15	37	40	1:200k map
Stoylensky	51	15	37	45	1:200k map
Gubkin	51	20	37	50	1:200k map

Code	Station Location	Latitude deg	Latitude min	Longitude deg	Longitude min	Source of coord.
OBN	Obninsk	55	18 20	36	34 12	station book
MHV	Mykhnevo	54	57 49.4	37	45 59.5	GPS
	Elets	52	37	38	30	gazetteer
	Tim	51	37	37	07	gazetteer
	Svoboda	51	58	36	17	gazetteer
	Turdey	53	22	38	00	gazetteer
	Lamskoe	52	57	38	02	gazetteer
	Bol. Ogarevo	53	33	37	43	gazetteer

Blasts Recorded

Table 7 lists the blasts recorded in August and September, 1995, by date, mine location, blast size, recording station, distance and instrument type. Total charge sizes range from about 10 tons to 935 tons; source-receiver distances range from 60 km to 500 km. The column labelled, "other information available" indicates the availability of information related to the details of the blasting deployment, such as the timing of individual charges in the ripple-fired blast, maps of the blocks detonated, and videotapes of the blasts. Detailed charge-time data are given in *Appendix 3*.

Sample Seismograms

Seismograms of all recorded blasts are given in *Appendix 5*. An example of seismograms recorded on the REFTEK at Svoboda for a blast from the Mikhaylovsky mine is shown in *Figure 16*, and an example of a broadband recording of a blast from Lebedinsky mine is shown in *Figure 17*.

Magnitude Determinations

Magnitudes of the blasts from the Kursk mines were determined at the seismic station Mykhnevo (MHV) using the formula:

Table 7. List of blasts from the Kursk mining region recorded during August-September, 1995

date	Julian day	time (GMT)	source location	charge (t)	magnitude ML	recording station	distance (km)	data at USGS paper rec.	data at USGS disk rec.	recording instrument	other info. available
4-Aug-95	216	10:08	Stoilensky	299.4	2.6	Mikhnevo	~500	√	√	REFTEK	firing pattern, block map
10-Aug-95	222	8:15	Lebedinsky	424.2	3.4	Mikhnevo	~500			broadband	firing pattern, block map
18-Aug-95	230	9:57	Stoilensky	195.6	2.2	Svoboda	~130	√	√	REFTEK	firing pattern, block map
24-Aug-95	236	8:10	Lebedinsky	834.6	3.2	Svoboda	~130	√	√	REFTEK	firing pattern
						Elets	~150	√		TEAC	
						Mykhnevo	~500	√		broadband	
						Tim	~65		√	TEAC	
						Turdey	~240		√	TEAC	
26-Aug-95	238	~20:00	Gubkin	36.68	2.0	Svoboda	~120	√	√	REFTEK	firing pattern
1-Sep-95	244	~8:00	Mikhaylovsky	270	2.6	Svoboda	~60	√	√	REFTEK	
						Tim	~130	√		TEAC	
1-Sep-95	244	10:00	Stoilensky	221.3	2.5	Svoboda	~130	√	√	REFTEK	video; block map;
						Tim	~65	√		TEAC	block timing
2-Sep-95	245	20:00	Gubkin	10 ?		Svoboda	~120	√	√	REFTEK	
7-Sep-95	250	8:31	Lebedinsky	633.7	3.0	Svoboda	~130	√	√	REFTEK	video;
						Tim	~65	√		TEAC	block map;
						Bol. Ogarevo	~270	√		TEAC	block timing
						Lamskoe	~180	√	√	TEAC	
8-Sep-95	251	8:00	Mikhaylovsky	320	2.8	Mikhnevo	~340	√	√	broadband	
						Svoboda	~60	√	√	REFTEK	clipped; 2 events
10-Sep-95	253	~8:00	Lebedinsky	N/A		Mikhnevo	~500	√		REFTEK	

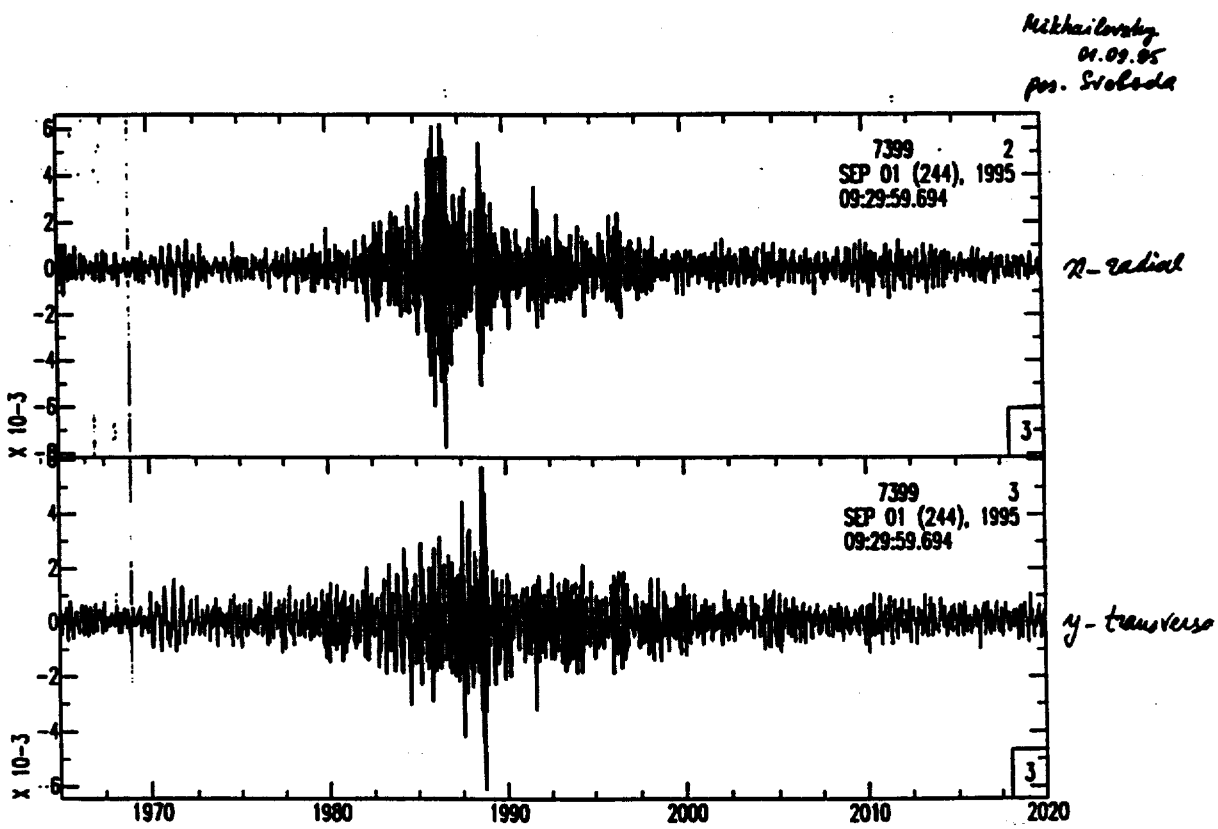

Figure 16. Examples of seismograms recorded on the REFTEK recorder deployed at Svoboda. Shown are the radial and transverse components of records of the blast of September 1, 1995, detonated at the Mikhaylovsky mine. The blast was 270 tons total charge, recorded at a distance of 60 km. A magnitude M_L=2.6 was calculated for this blast.

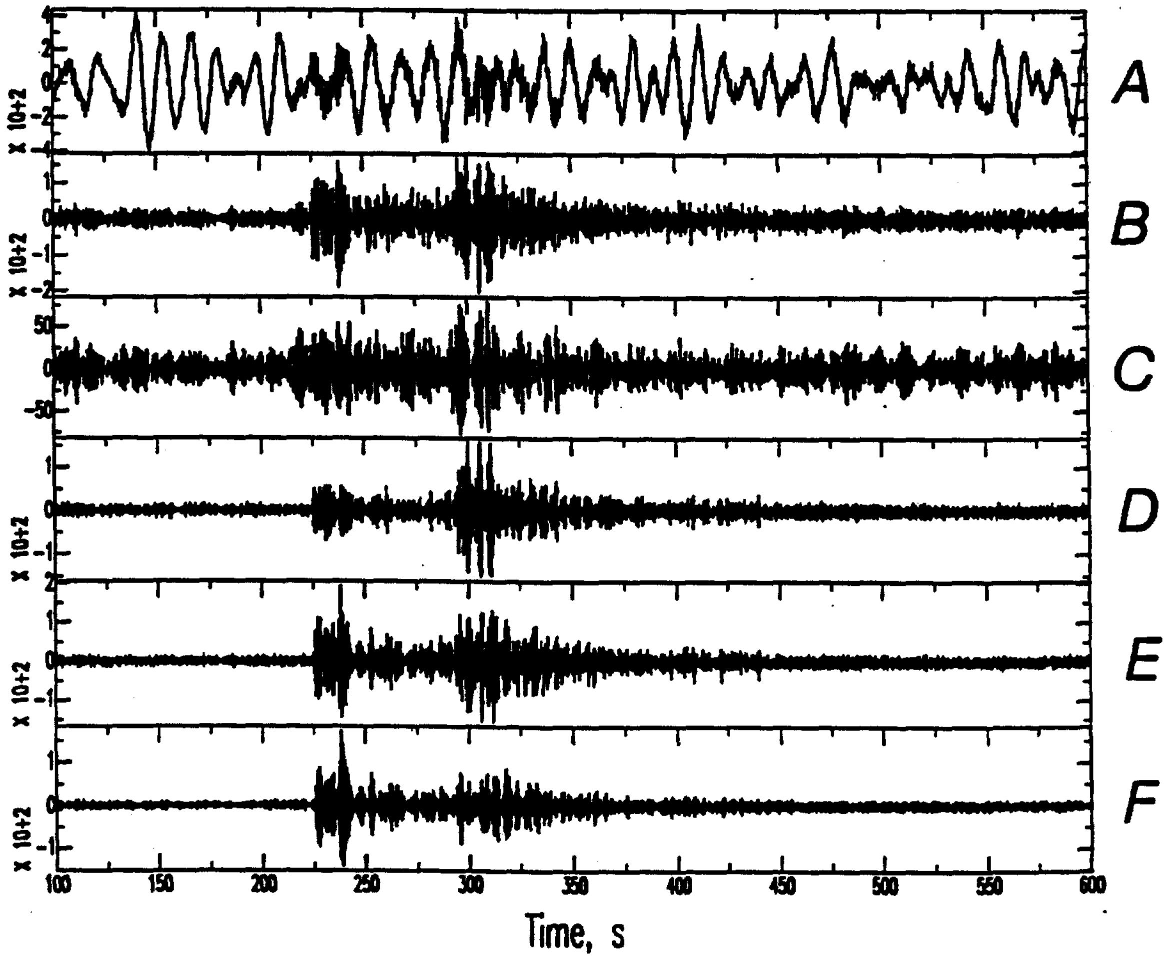

Figure 17. Example of the raw and filtered trace of the broadband recording of the blast of September 8, 1995, recorded at Mykhnevo (MHV), 340 km to the North. Trace *A* is unfiltered. Traces *B-F* are band-passed as follows: *B*, 0.7 Hz to nyquist; *C*, 0.7 - 1.4 Hz; *D*, 1 - 2 Hz; *E*, 1.4 - 2.8 Hz; *F*, 2 Hz to nyquist.

$$M_{PV} = log\ (A_{max} / T) + \sigma(d,h)$$

where A_{max} is the maximum amplitude of the p-wave on the vertical component of the short-period seismogram, T is the visible period, d is the epicentral distance, h is the depth of the event (zero, for mining blasts), and σ is n empirical calibration function for the station (Instruktsiya, 1982). The station was calibrated using earthquakes from the Caucasus region, to the south of Kursk (Solov'ev and others, 19__). In practice, magnitudes were graphically picked from a nomogram, which is given in *Appendix 6*.

In addition, the NORSAR regional bulletins were reviewed to determine if any of the Lebedinsky blasts from 1992-1995 were located events by the Scandinavian seismic arrays. Of the more than 100 blasts listed in *Appendix 1*, only one appears in the regional bulletins. This blast, which occurred on May 22, 1992 and was 1221.7 tons total charge, was detected by three arrays (NORESS, ARCESS and FINESS), and located approximately 100 km SW of the mine. The NORSAR magnitude, m_b=2.9, compares with a Russian-determined M_L=3.6, calculated from the records at Mykhnevo by the method described above.

Spectral Analysis

The visible effects of large, surface mining blasts (cratering, deformation of quarry's sides resulting from rock mass drop, gas dust cloud), as well as their controlled periodicity, can assist in their detection and discrimination from other types of seismic events. However, in most cases, this information will not be available, and a detailed analysis of the seismic signal may allow the determination of distinctive indications of mass industrial explosions. In the case of ripple-fired explosions, the high frequency seismic trace has prominent spectral modulation believed to indicate ripple-firing (Baumgardt, Ziegler, 1988). Spectral modulation parameters are determined by the precise time periods between the explosions of groups of boreholes. For a more detailed description of this effect, see, for example, Hedlin and others (1990).

Spectra and sonograms were calculated for two industrial chemical explosions with yields of 834 and 634 metric tons, conducted at Lebedinsky quarry in 1995, and recorded at distances 150 km and 180 km, respectively, *Figures 18 and 19* show the seismograms of these blasts, along with the corresponding spectra. Spectral modulation is seen distinctly in the accompanying sonograms. Additional evidence that these explosions were ripple-fired comes from a calculation of the cepstrum of the seismogram. If the blasting is conducted with the constant delay times between charges, the consequent multiplicity of sources results in cepstral peaks (Hedlin and others, *op cit.*). This work is incomplete for the blasts recorded at Kursk in 1995.

Discussion

In this study, we have chararcterized the large mining blasts at Kursk, based both a review of blasting at mines in the Gubkin region over the past 5 years and on a sample of seismically-recorded blasts from August-September, 1995. This work has included compiling information on the spatial and temporal distribution of charges for both

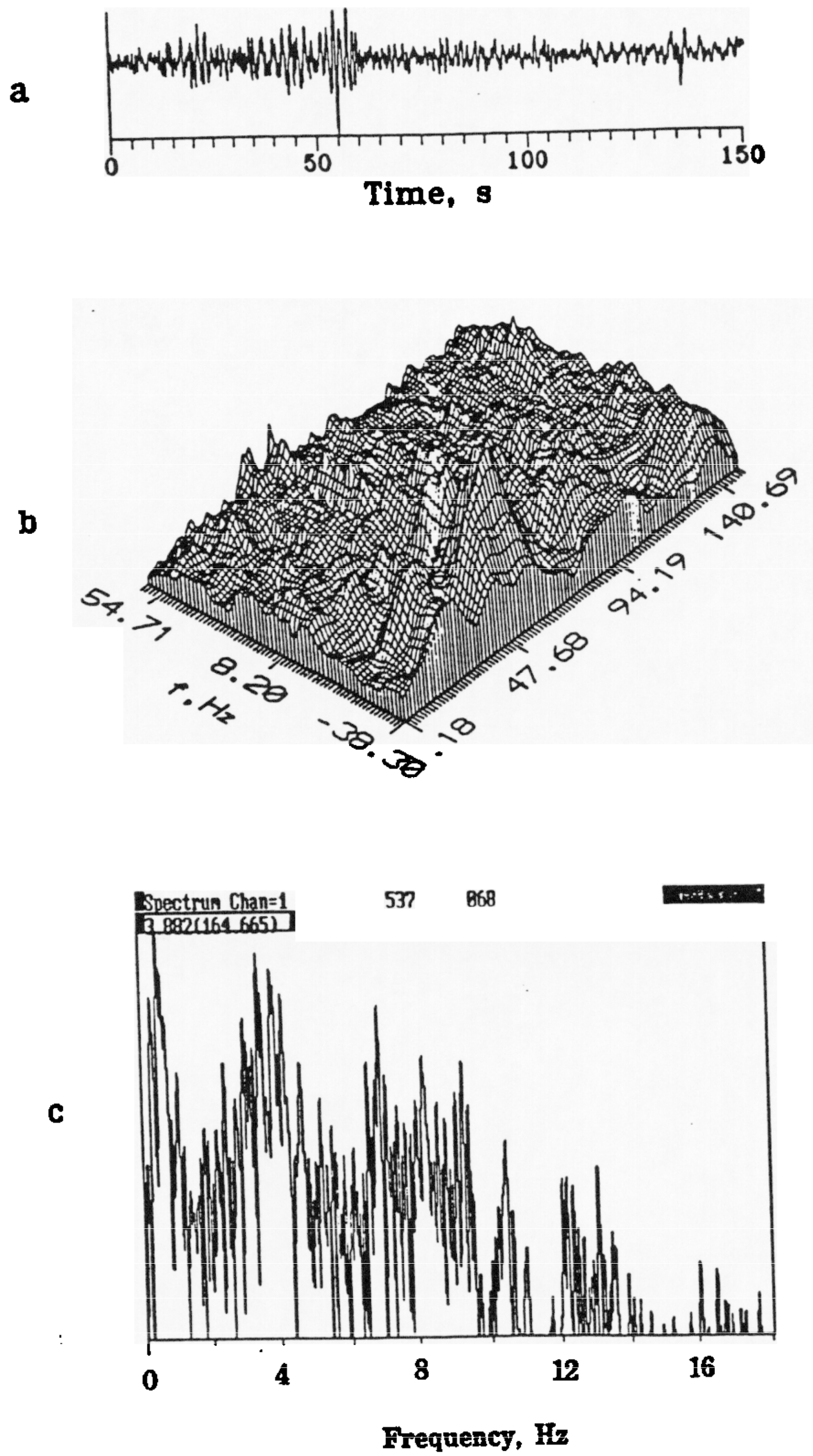

Figure 18. Seismogram, sonogram and log of the spectrum of the blast of August 24, 1995, at Lebedinsky mine (834 tons).

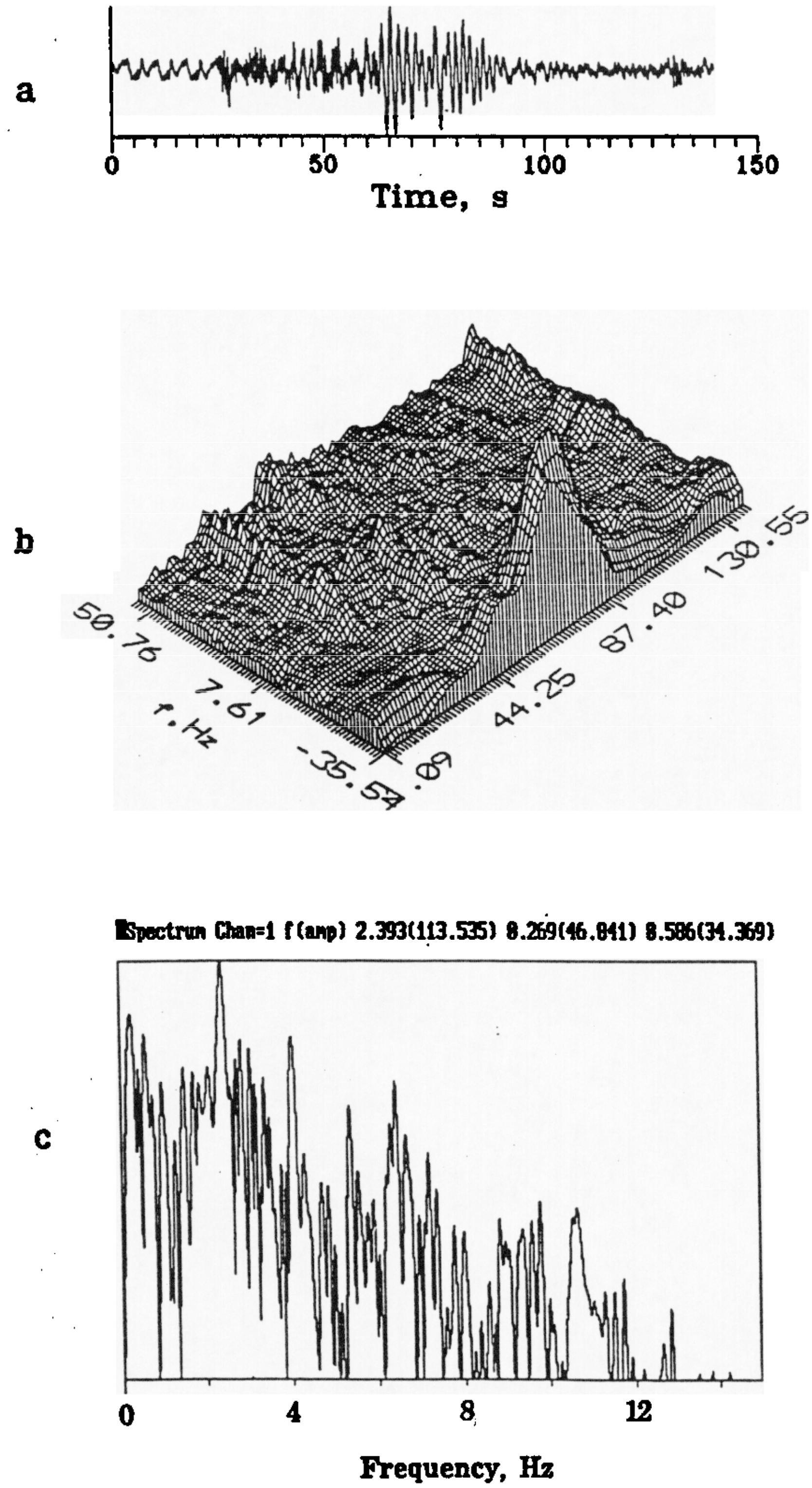

Figure 19. Seismogram, sonogram and log of the spectrum of the blast of Septebmer 7, 1995, at Lebedinsky mine (634 tons).

surface and underground blasts, videotaping of individual blasts, compiling data on explosives, and providing information on the context of these blasts with respect to both Russian, Soviet and U.S. blasting. Twelve blasts from August-September, 1995, were recorded on two permanent and six portable seismic stations at distances ranging from 60 to 500 km from one of four blasting sites.

Based on this work, several features of the blasts at Kursk should be emphasized:

1) Blasting at Kursk is clearly diminished over the levels of only a few years ago; both the total number of blasts has decreased, as well as the average total charge per blast.

2) Blasting practice in the surface mines at Kursk has changed, such that the predominant mode is true ripple firing, in which many delays are used along the rock face (which we have called, "reduced-shaking mode". Nevertheless, this ripple-firing practice does not match that used in major mines in the U.S. in that entire rows of holes are still blasted at once, detonating as much as 10 tons of explosive in a single delay.

3) Data on a limited number of blasts in the underground mines at Kursk indicates that relatively large charge-per-delay are used; over 4 tons in several cases. These amounts are essentially the same as those used in the surface mines.

4) Local magnitudes, M_L, determined at near-regional distances (300-500km), range from about 2.5 to 3.5, for blasts with total charges of about 200 to 850 tons. *Figure 20* shows these magnitudes compared with explosions from the Soviet program of peaceful nuclear explosions and with chemical explosions in Russia and the former Soviet Union that were detonated for non-mining purposes. Note that these magnitudes correlate well with total charge, a feature not observed in ripple-fired miing blasts in other studies. This may reflect particular features of the blasting practice used at Kursk, or it may be related to the method of magnitude determination used.

5) Of over 100 blasts detonated in the years 1992-1995, only one of these blasts was located by the seismic arrays in Scandinavia. This blast, from 1992, had a teleseismic magnitude, m_b, of 2.9, and a regional magnitude, M_L, of 3.6. While this is only one point for comparison, it suggests that there may be a significant discrepancy between the teleseismic magnitude, m_b,, and a regional magnitude, M_L,, as determined at the station MHV. It also suggests that most Kursk mining blasts will have teleseismic magnitudes less than 3.0, and may not be well recorded by the proposed International Monitoring System.

6) The large mining blasts from the surface mines at Gubkin show evidence of spectral scalloping, typical of ripple-fired mining blasts. This feature may aid in discriminating them from earthquakes and other seismic sources.

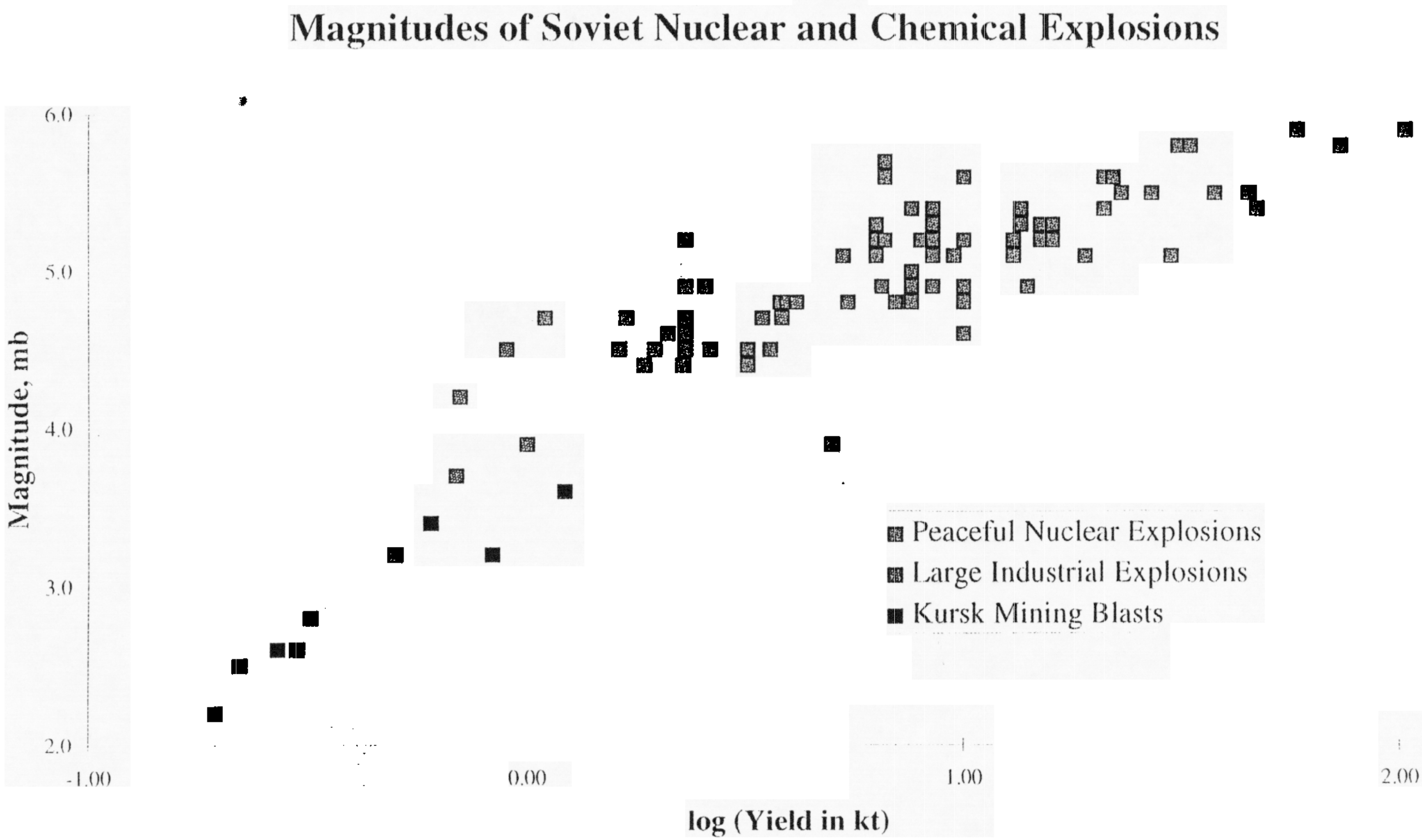

Figure 20. Comparison of the magnitudes of Soviet and Russian explosions: Peaceful nuclear explosions are shown in red; large chemical explosions for military and civilian purposes (but not mining) are shown in green; and the Kursk mining blasts are shown in blue. Note that the magnitudes of the Kursk blasts are not m_b; see text for details.

Acknowledgements

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Appendix I: Catalog of Mining Explosions at Lebedinsky GOK, 1992-1995

[Explosives: *granulotol*, *grammonit*]

1992

Ref. No.	Date da mo yr	Time (Moscow)	Total Charge metric tons	
1	06.02.92	12:00	871.7	
2	21.02.92	12:00	1248.1	
3	05.03.92	12:00	1110.0	
4	19.02.92	12:00	979.0	
5	02.04.92	12:00	1314.6	
6	16.04.92	12:00	996.6	
7	30.04.92	12:00	786.7	
8	08.05.92	9:00	290.6	
9	14.05.92	N/A	694.0	871.7?
10	22.05.92	12:00	1221.7	*m_b=2.9, NORSAR bulletin
11	11.06.92	13:22	1568.5	
12	25.06.92	12:00	1273.5	
13	09.07.92	12:00	867.9	
14	23.07.92	13:00	660.5	
15	11.08.92	13:30	1436.7	
16	25.08.92	12:03	1299.6	
17	17.09.92	12:32	1187.6	
18	08.10.92	14:52	1126.1	
19	15.10.92	12:00	792.4	
20	30.10.92	12:02	776.9	
21	13.11.92	12:00	558.3	
22	19.11.92	12:00	671.8	
23	26.11.92	12:00	356.7	
24	10.12.92	11:58	1475.8	
25	18.12.92	14:20	247.0	
26	28.12.92	12:46	1862.0	

1993

Ref. No.	Date da mo yr	Time (Moscow)	Total Charge metric tons
1	14.01.93	12:00	988.1
2	21.01.93	12:00	474.3
3	04.02.93	12:00	857.0
4	18.02.93	12:00	936.6
5	04.03.93	13:00	911.2
6	25.03.93	12:30	456.6
7	01.04.93	12:00	685.9
8	08.04.93	12:00	1082.2
9	15.04.93	12:00	534.1
10	29.04.93	12:00	407.1
11	07.05.93	12:50	434.3
12	21.05.93	12:35	1082.5
13	24.05.93	15:20	118.0
14	04.06.93	12:00	752.7
15	15.06.93	12:30	1177.2
16	01.07.93	12:00	1413.4
17	15.07.93	12:00	566.5
18	22.07.93	12:00	272.2
19	29.07.93	12:30	1058.3
20	12.08.93	15:35	1192.7
21	09.09.93	13:00	456.9
22	16.09.93	13:00	354.2
23	23.09.93	12:00	401.0
24	30.09.93	12:00	248.2
25	07.10.93	12:05	388.8
26	14.10.93	13:15	350.8
27	21.10.93	12:00	349.5
28	28.10.93	12:00	340.4
29	04.11.93	12:02	355.2
30	18.11.93	12:10	581.5
31	25.11.93	12:00	297.6
32	02.12.93	12:19	301.2
33	16.12.93	12:25	426.3
34	30.12.93	12:12	323.4

1994

date da.mo.yr	time (Mos)	total tons	charge per block metric tons
13.01.94	12:02	424.1	N/A
27.01.94	12:20	285.5	N/A
03.02.94	12:50	649.9	N/A
17.02.94	12:08	379.7	N/A
03.03.94	12:16	592.7	N/A
17.03.94	13:02	673.6	N/A
31.03.94	12:20	419.9	N/A
14.04.94	12:35	360.6	N/A
28.04.94	12:00	445.8	N/A
05.05.94	12:32	264.0	N/A
17.05.94	12:15	435.0	N/A
27.05.94	13:15	509.0	N/A
09.06.94	12:30	662.8	N/A
05.07.94	14.00	385.7	85.8+80.1+2+84+87.9+17.9+1.2+20.9+6.6
14.07.94	12.55	553.1	27.5+106.9+26.3+85.7+111.9+21.3+57.4+9.7+100.16
21.07.94	13.00	481.5	99.7+28.9+68.9+39.6+65.3+39+82.7+50+4.7+2.7
04.08.94	12.58	630.0	39.1+35.3+55.4+68.2+55.8+69.5+38.7+161.4+58.7+47.9
18.08.94	13.35	318.5	47.1+21.8+67.4+73.2+47.7+34.5+20.1+6.8
18.09.94	12.08	516.35	18.6+139.5+81.7+165.5+79.2+17.3 +14.5
15.09.94	12.42	243.55	83.9+90.6+60.9
01.10.94	12.00	768.5	83.5+72.1+78.1+139.6+153.3+121.6+78.6+41.8
06.10.94	12.30	180.8	51+77.6+31.2+21.1
20.10.94	14.15	513.5	80.7+80.1+115.7+105.8+95.1+33.1
27.10.94	12.25	397.2	83.7+65.4+46.8+122.7+23.2+47.5+7.7
03.11.94	13.18	618.96	154.3+53.1+50.5+81.98+163.6+28.5+52.0+35
17.11.94	12.30	839.9	124.9+84.2+79.2+101.3+106.5+15.3+58.6+58.5+89.2+112.3+1.4+8.7
01.12.94	12.53	468.4	74.4+52+99.1+44.3+48.6+122.7+10.4+16.9
15.12.94	13.25	519.6	49.5+30.8+116.1+71.1+163.1+53.6+35.4

1995

date da.mo.yr	time (Mos)	total tons	charge per block metric tons
06.01.95	12.05	663.2	56.2+92.6+81.5+112.8+90.4+213.4+16.3
19.01.95	12.35	1109.5	135.6+140.0+183+121.9+159.3+20.4+98.4+87.6+46.3+116.7
02.02.95	12.32	718.46	45+109.2+89.5+88.2+83+32.8+92.4+125+23.7+23.7
16.02.95	12.03	882.2	34.6+43.5+115.2+72.6+23+153.4+53.3
02.03.95	13.10	1021.7	132.2+77.4+29.3+41.2+109.4+62+92.4+34.4+4.8+12.5+16+8.4+5.8+0.
24.03.95	12.18	1455.1	168.7+138.6+44.4+34.3+160.7+191.9+53.5++300+193.9+90.5+222.7+30.4
06.04.95	12.10	291.4	77.7+42.8+79.4+62.1+48.6+72.3+23.7+152.3+35.7
20.04.95	12.00	560.4	87.1+59.4+96.3+1.9+121.7+114.2+79.6
27.04.95	12.22	101.2	67.6+33+0.6
06.05.95	12.02	729.4	174.+46+72.6+113.3+44.7+121.1+157.6
18.05.95	12.40	868.85	114.4+107.7+27.1+31.7+55.8+27.6+126.6+176.3+85.8+113.9+1.3
08.06.95	12.19	460.6	125.8+76+305.4+125.7+8+98.4
22.06.95	12.15	625.7	89.2+82.2+102.7+127.9+124.6+16.8+30.2+52.4
29.06.95	12.10	430.5	22.5+88+186.9+36.5+48.2
13.07.95	12.03	924.8	59.4+152.9+32+141.2+47.8+164.9+93.3+181.6+38.1+12+4+1.5
27.07.95	12.35	717.2	77.6+130+14.4+6.6+86.2+66.4+80+49.2+76.5+130.5
10.08.95	12.15	603.4	139.8+78.5+98+109.7+67.7+20.2+44.8+2.3+40.6+1.6
24.08.95	12.10	834.6	135.2+18.9+41.5+62.6+92.8+60.7+171.8+65.8+17.4+50+99+13.9+1.7
07.09.95	12.34	633.7	73.36+68.36+196.77+48+117.53+150
21.09.95	12.05	638.6	138.16+162.72+95.48+10.6+161+ 70.66
28.09.95	12.01	235.2	77.87+91.16+61.4+0.38+2.54+1.8

Appendix 2: List of Explosives
Commonly Used in Russia and the former Soviet Union

No.	Explosive name	Energy, kCal/kg.
1	Akvatol AV	830.
2	Akvatol AVM	1050.
3	Akvatol MG	1080.
4	Akvatol V-15	1320.
5	Akvatol 65/35 (with water)	910.
6	Alumotol	1240.
7	Ammonal	1110.
8	Ammonit *okal'ny*	1240.
9	Ammonit 6 ZhV	1000.
10	V-5	1000.
11	Hexogen	1380.
12	Grammoamonal A-45 (water)	1250.
13	Grammoamonal A-8	1250.
14	Grammoamonal A-50	930.
15	Granulit AS	1020.
16	Granulit AS-4	1020.
17	Granulit AS-8	1120.
18	Granulit M	880.
19	Granulit S	900.
20	Granulotol (with water)	840.
21	GNDS	1020.
22	Detonit M	1210.
23	Dinaftalit	930.
24	Zernogranulit 30/70 V(s)	940.
25	Zernogranulit 79/21	1000.
26	Zernogranulit 50/50 V(s)	880.
27	Zernogranulit 80/20	1000.
28	Igdanit	930.
29	Ifzanit T-60	910.
30	Ifzanit T-80	930.
31	Ifzanit T-20	830.
32	Carbotol 15T	700.
33	LT-4	1010.
34	Nitroglicerin liquid	1485.
35	NFTA	1010.
36	Octogen	1380.
37	Termol	890.
38	Tetril	1100.
39	Trotil (TNT)	1000.
40	Ten	1400.
41	TNB	1000.

Appendix 3: Sketch maps of the locations of charge blocks for blasts at the Lebedinsky and Stoylensky open pit mines.

A.3.1- August 4, 1995, Stoylensky mine, 299.4 tons

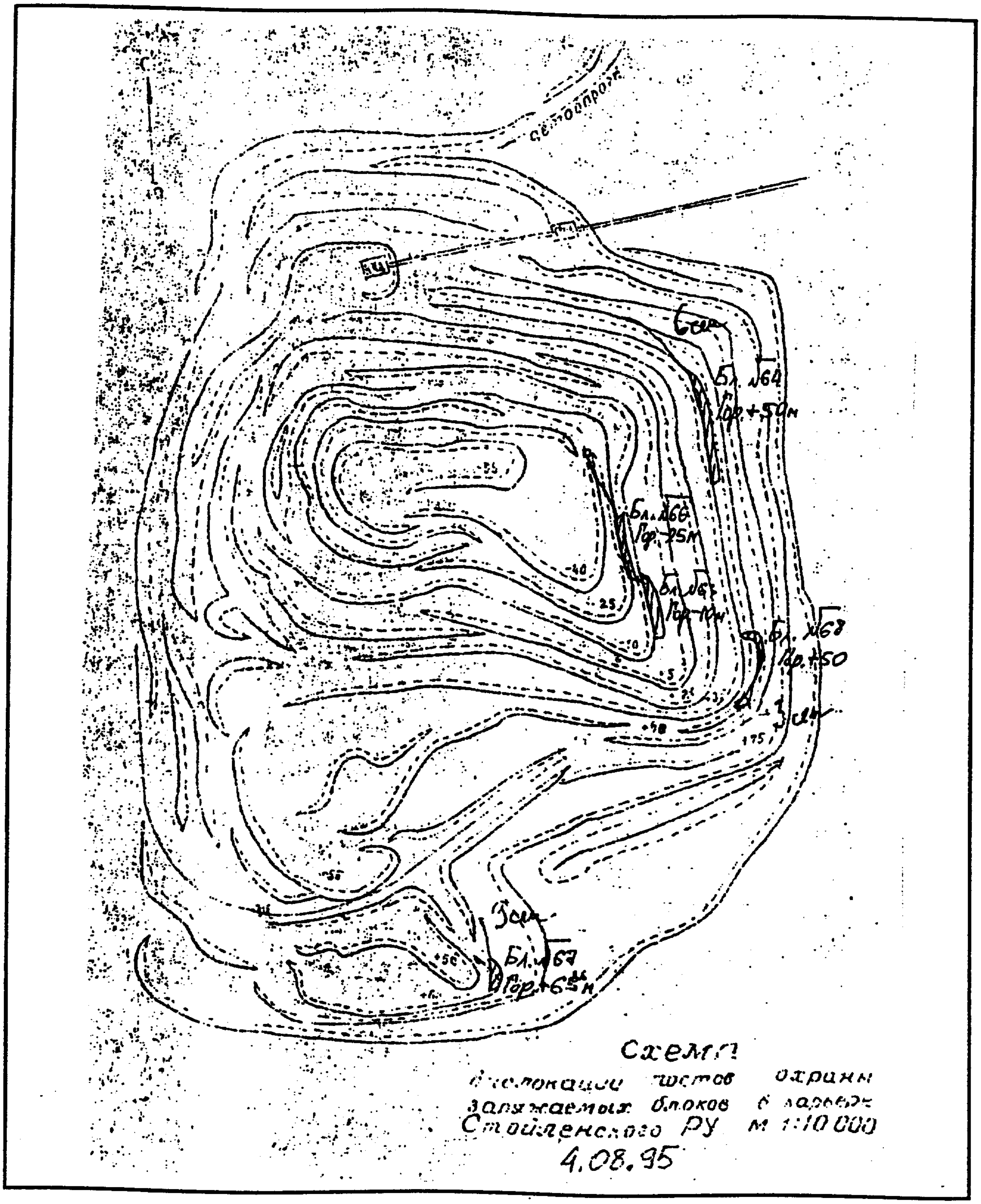
A.3.2- August 10, 1995, Lebedinsky mine, 424.2 tons

A.3.3- August 18, 1995, Stoylensky mine, 195.6 tons

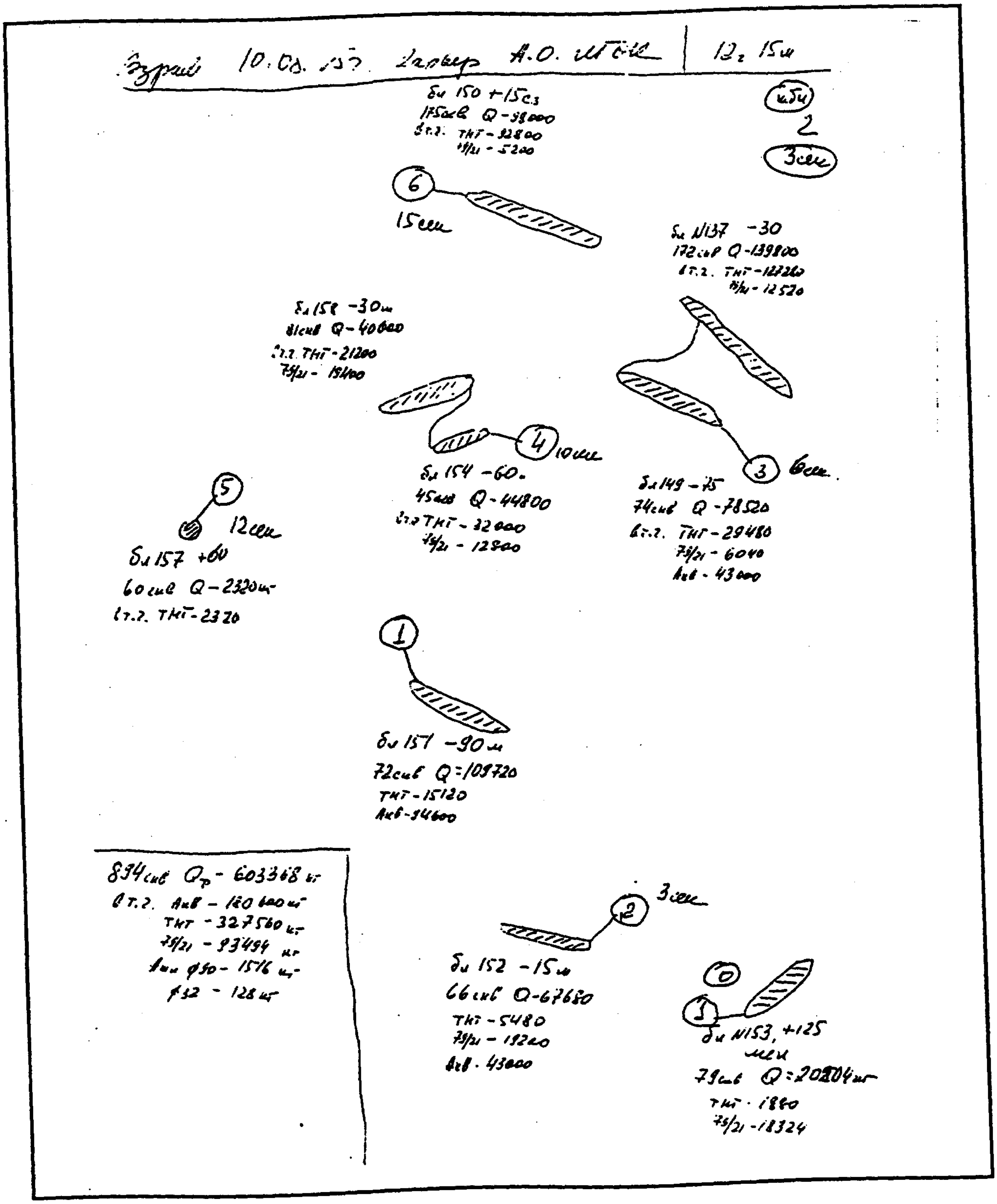
A.3.4- September 1, 1995, Stoylensky mine, 221.3 tons

A.3.5- September 1, 1995, Stoylensky mine, 221.3 tons

A.3.6- September 7, 1995, Lebedinsky mine, 633.7 tons

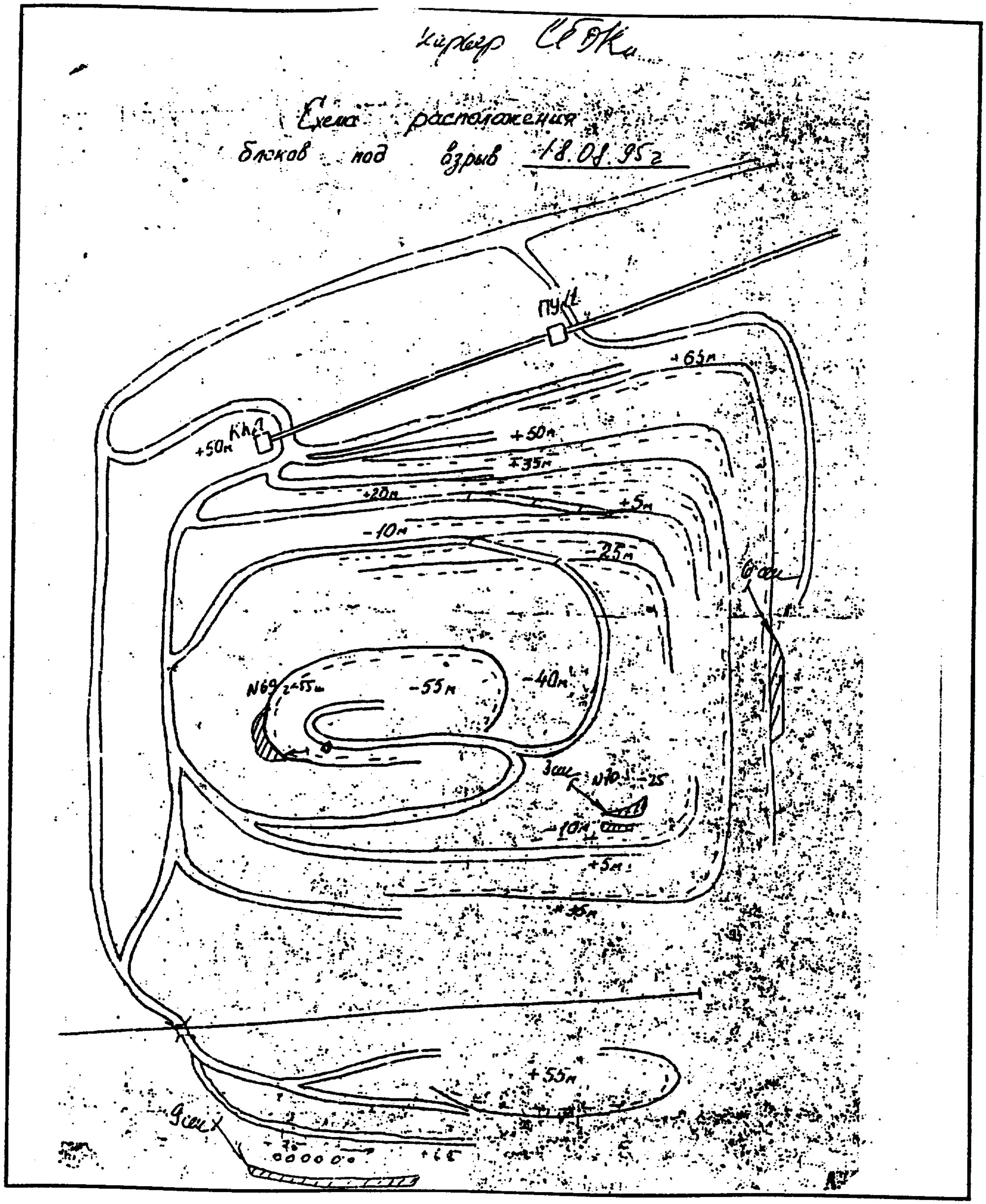


A.3.1.

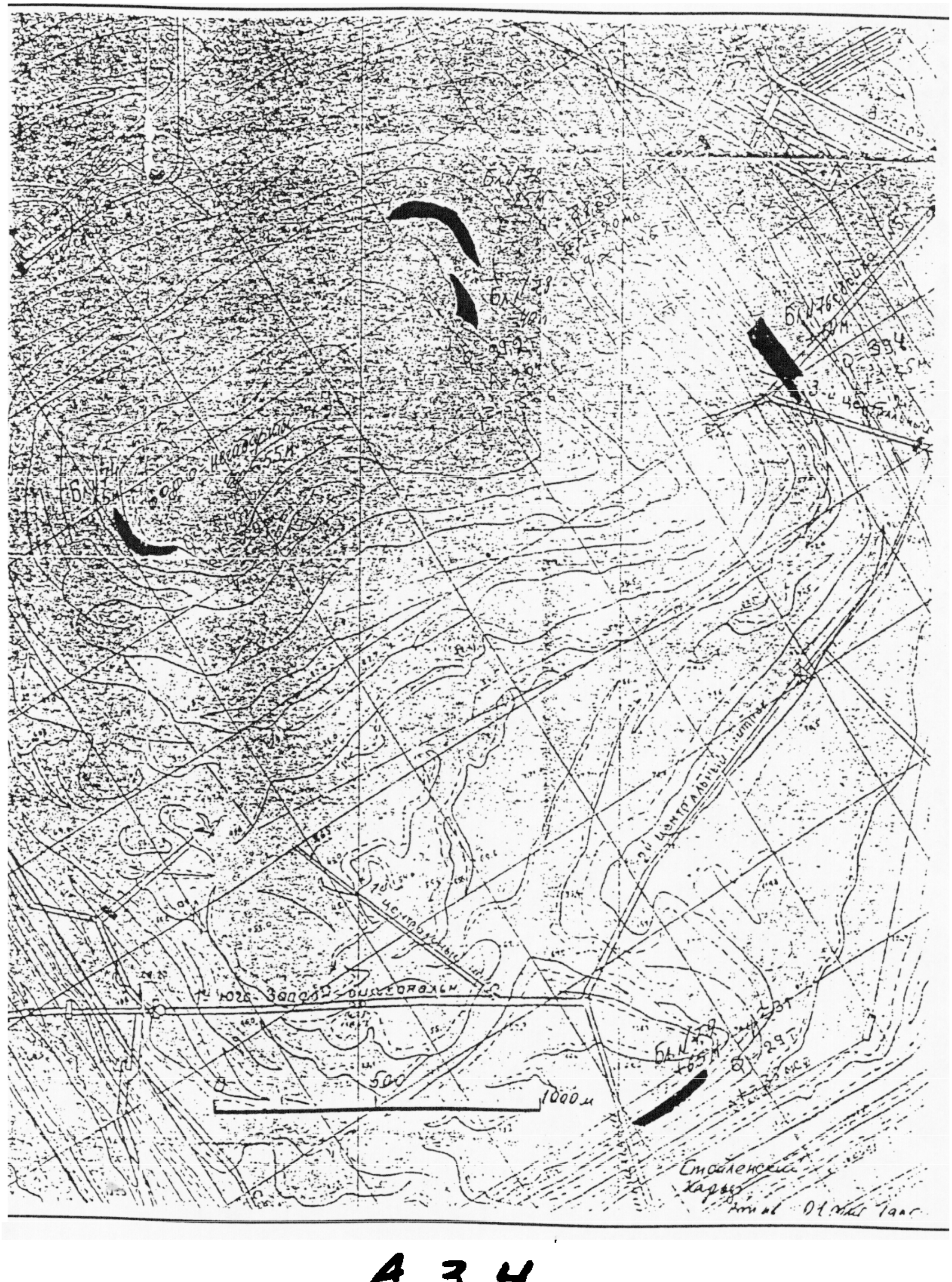


10.08.137
12 15м
Бл 150 +15 сз
175куб Q-38000
ТНТ-32800
79/21-5200
15см
Бл N137 -30
172куб Q-139800
ТНТ-127280
79/21-12520
Бл 158 -30м
81куб Q-40600
ТНТ-21200
79/21-19400
10см
Бл 154 -60
45куб Q-44800
ТНТ-32000
79/21-12800
6см
Бл 149 -75
74куб Q-78520
ТНТ-29480
79/21-6040
Акв-43000
12см
Бл 157 +60
60куб Q-2320кг
ТНТ-2320
Бл 151 -90м
72куб Q=109720
ТНТ-15120
Акв-94600
894куб Qр-603368 кг
Акв-120600 кг
ТНТ-327560 кг
79/21-93494 кг
ф30-1576 кг
ф32-128 кг
3см
Бл 152 -15м
66куб Q-67680
ТНТ-5480
79/21-19200
Акв-43000
Бл N153, +125
79куб Q=20204кг
ТНТ-1880
79/21-18324

A.3.2.

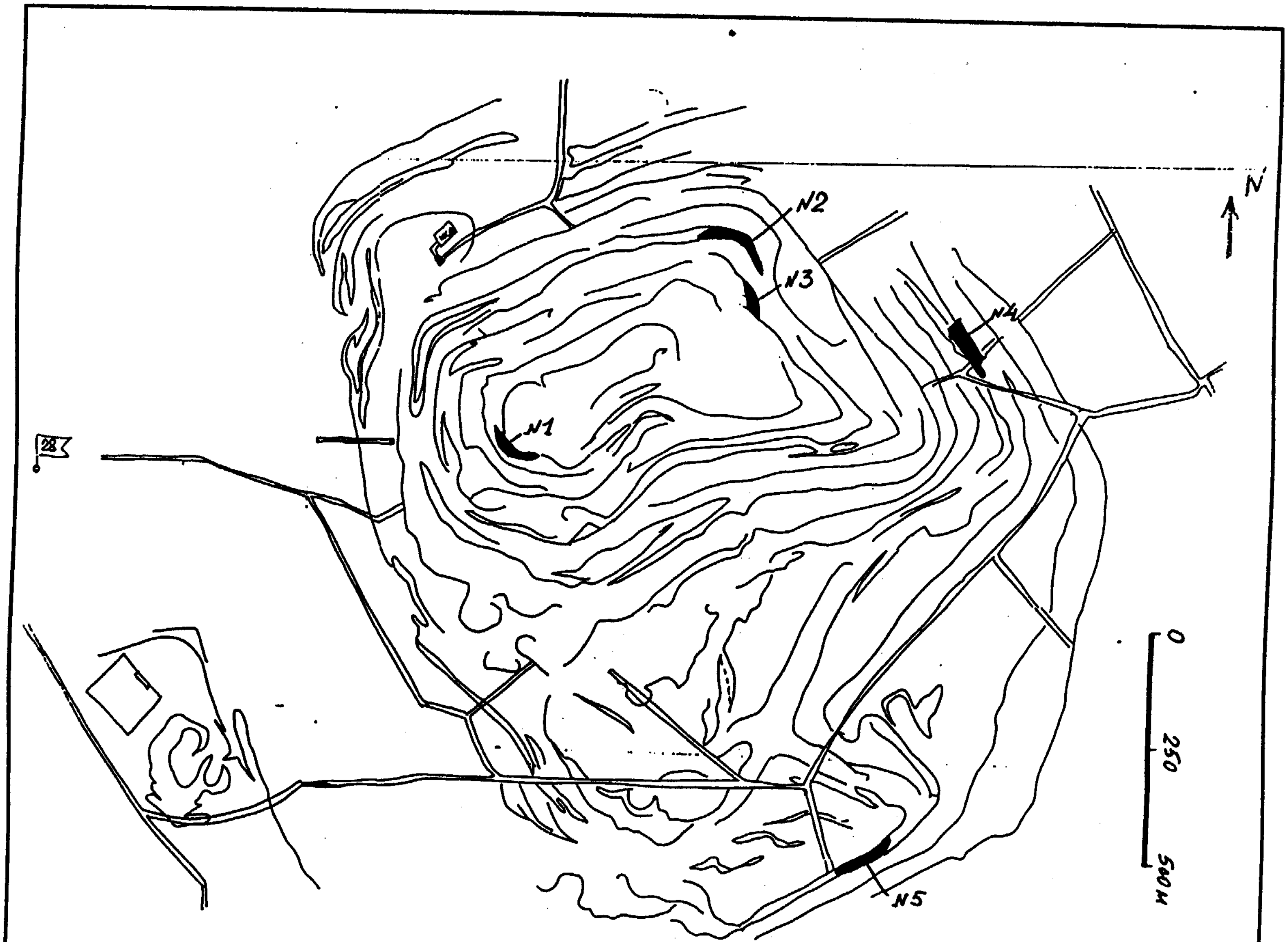

Карьер СГОКа
Схема расположения
блоков под взрыв 18.08.95г
ПУ
КП
+50м
+65м
+50м
+35м
+20м
+5м
-10м
-25м
-40м
-55м
+55м

А.3.3.



A.3.4.

А.3.5.

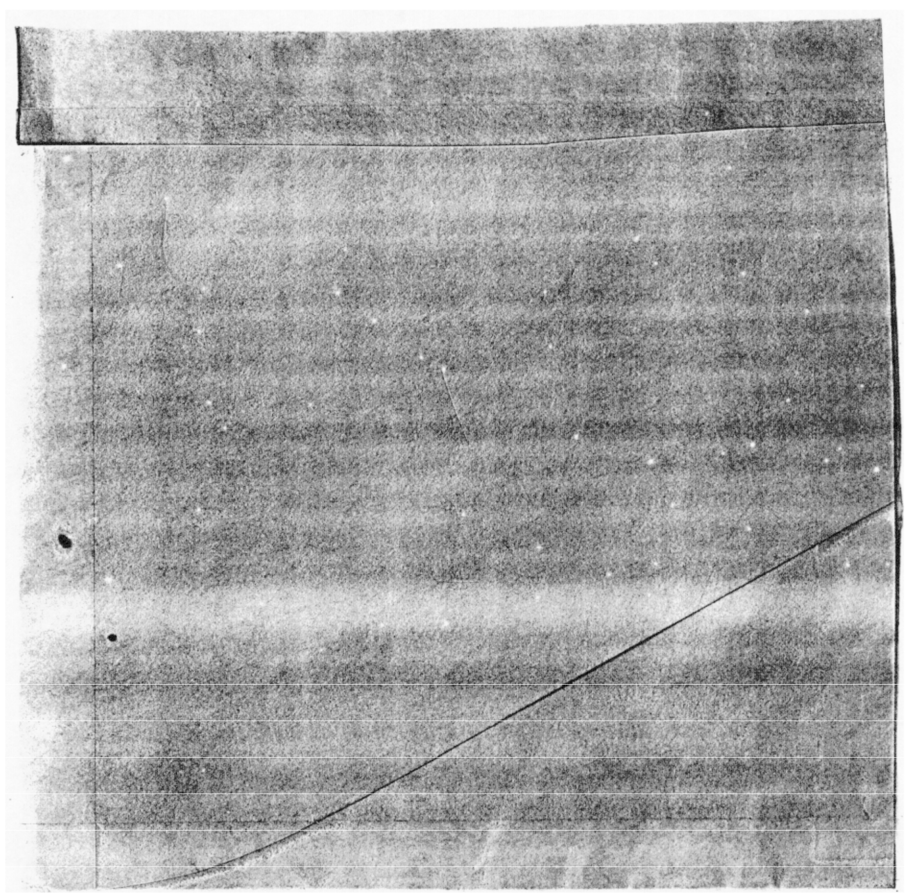


Карьер Стойленского ГОКа

A.3.6.

Appendix 4: Video/movie of the detonation of a single block from the blast of September 7, 1995, at Lebedinsky GOK.

Quicktime movie of ....

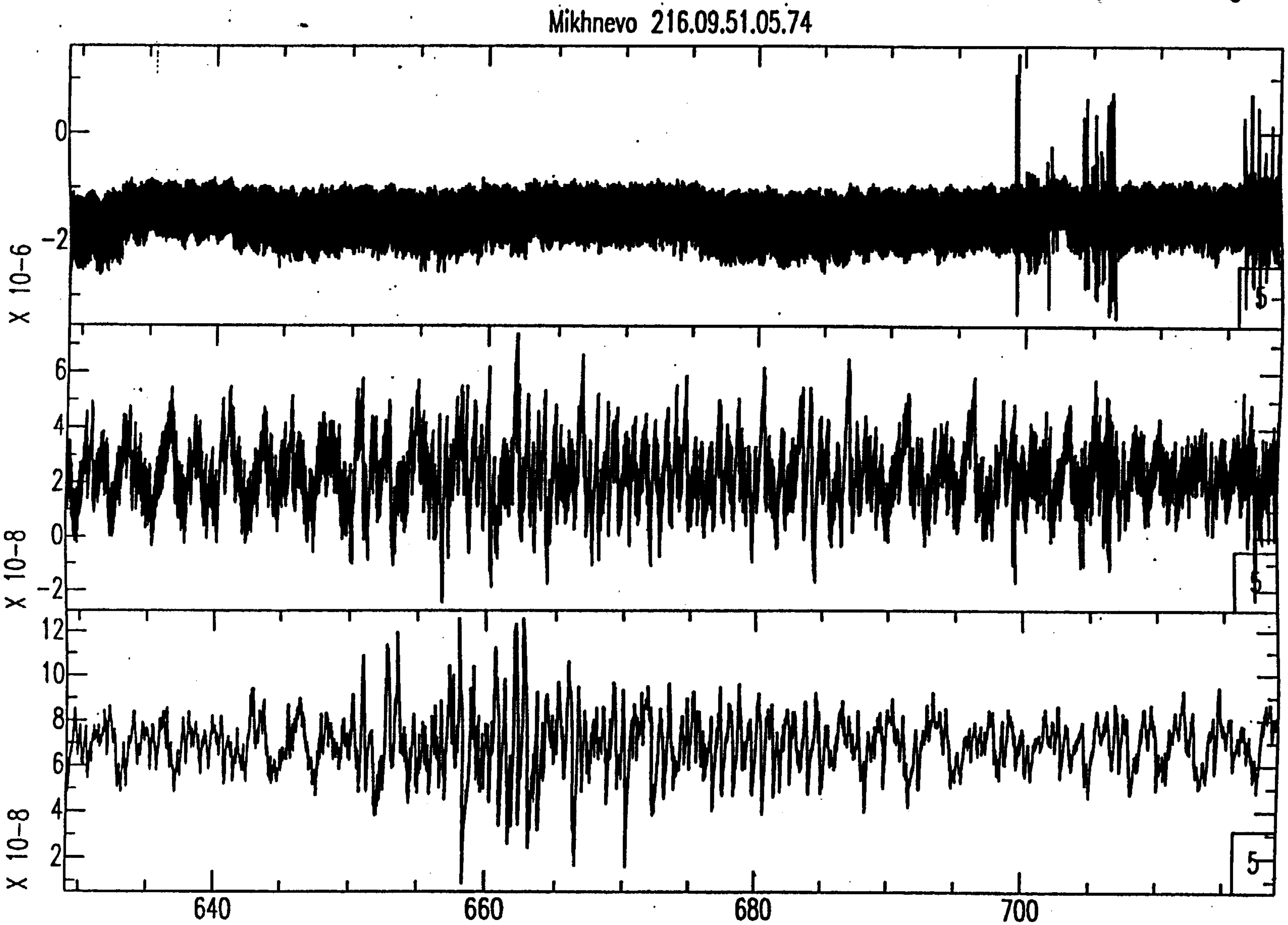


Appendix 5: Seismograms for blasts recorded in Aug.-Sep., 1995.

Events are identified by the year and Julian day on which they occurred. To obtain blast information, compare with *Table 7*.

Stoilensky 6^k
04.08.95
Registrpoint → Mikhnevo

REFTEK



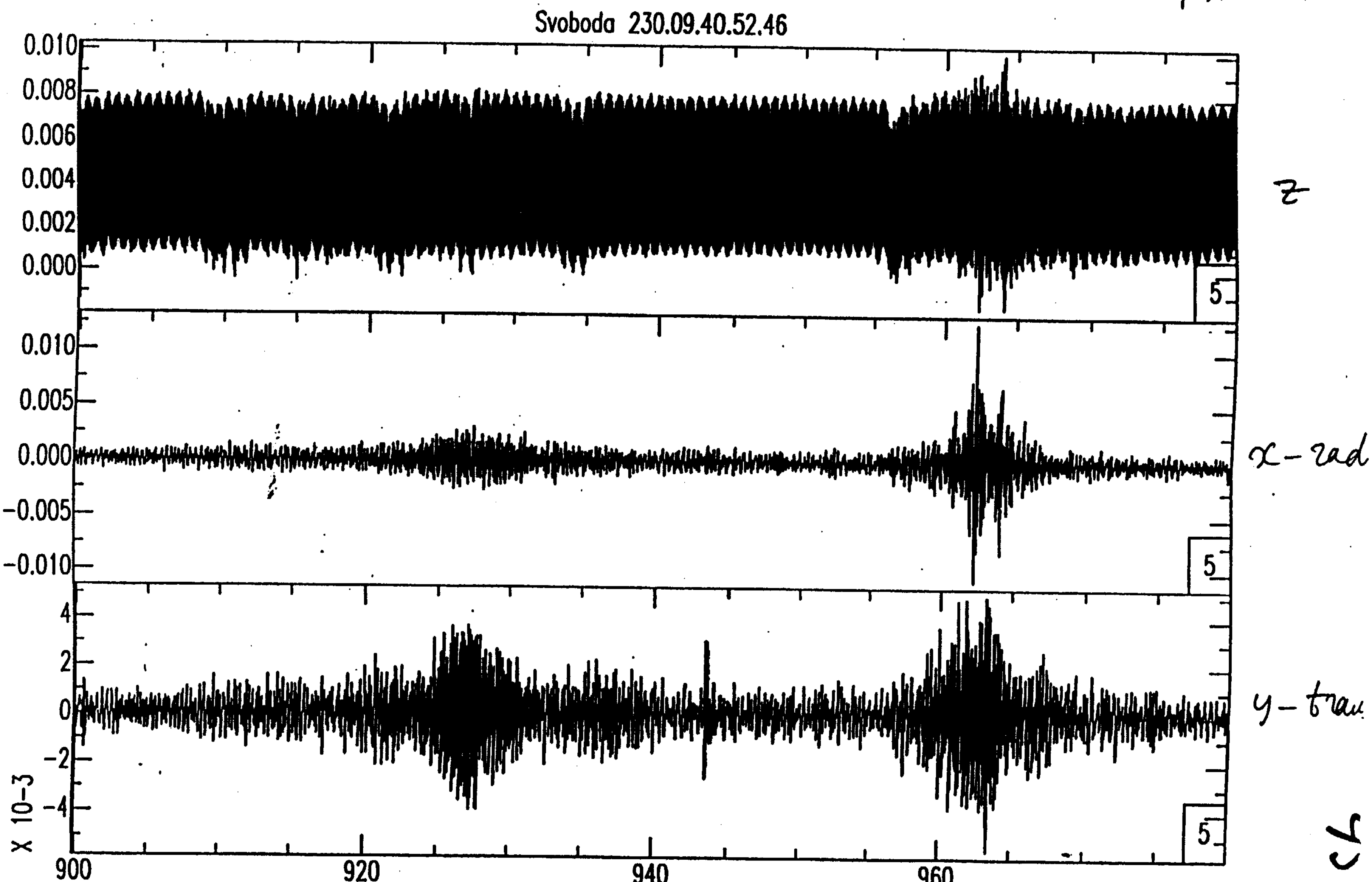
Z-vertical

N-S

W-O

95-216

Str. Bušky 6
18.08.9?
pos. Svoboda

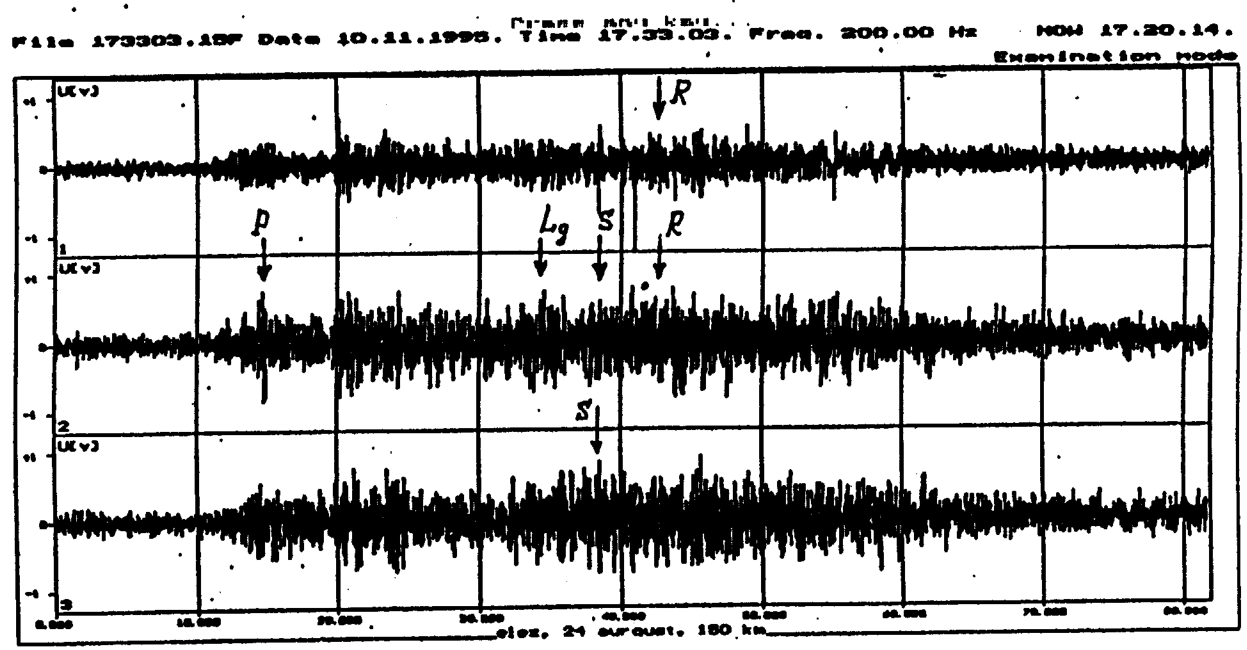


92-230

Вертикальная

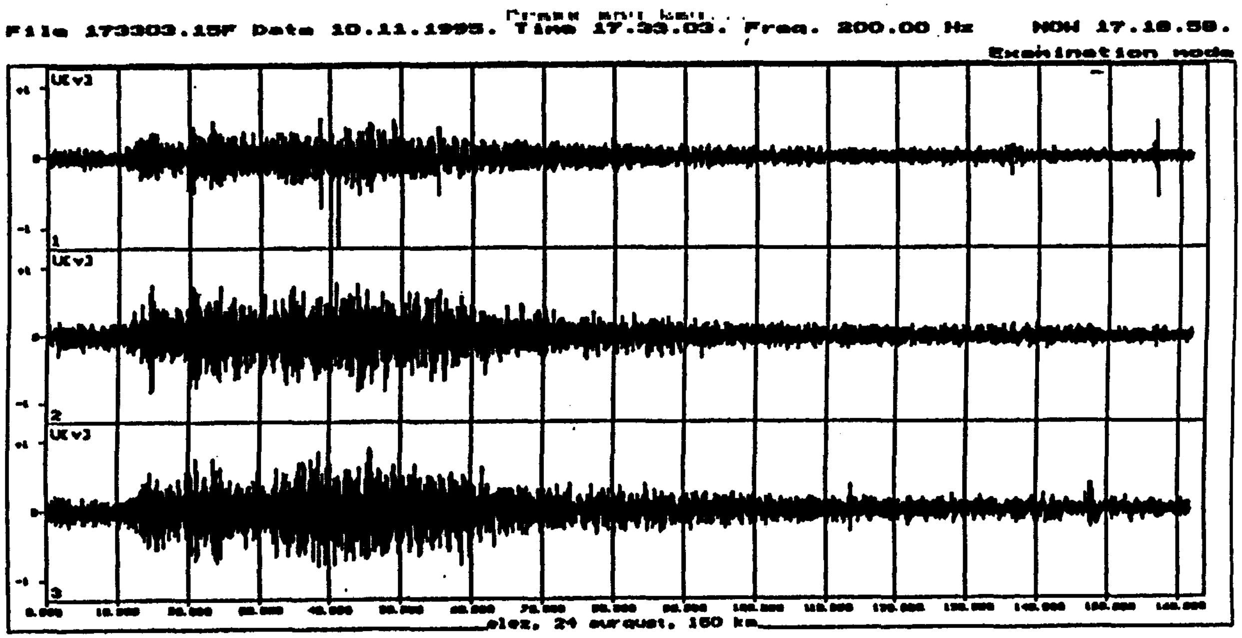
Радиальная

Тангенциальная



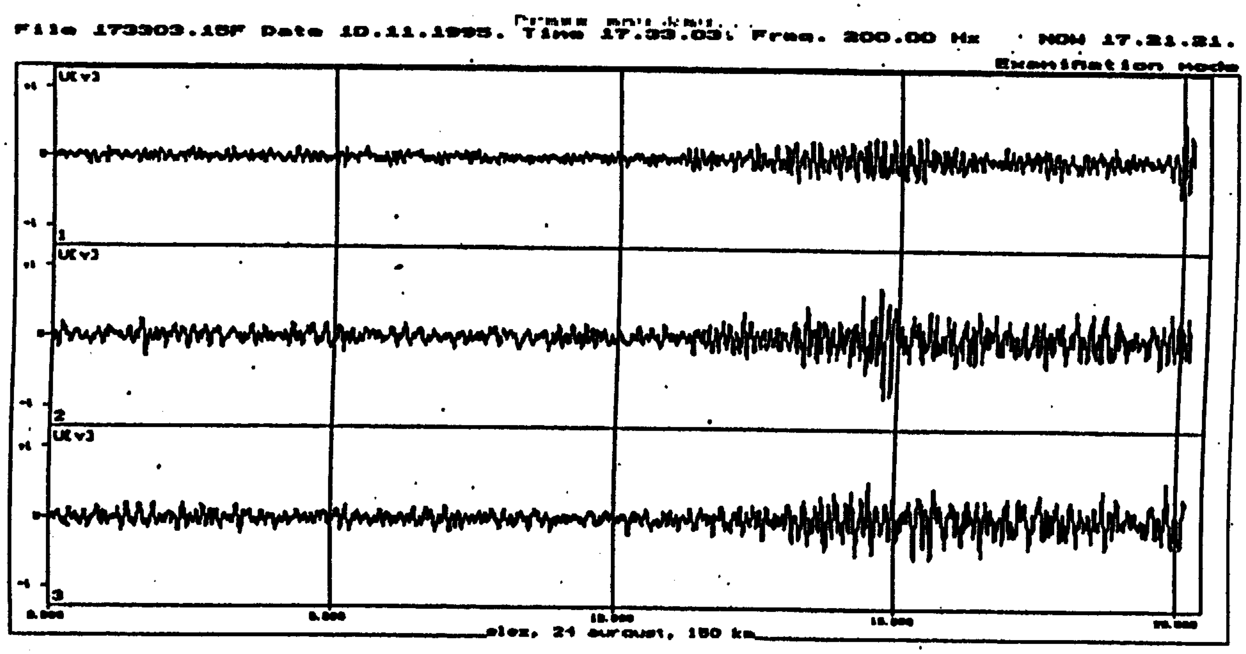
0 – 80 сек

Взрыв на Лебединском ГОКе
24 августа I995г.
Сейсмопункт в г.Елец, эпицентральное расстояние №I50 км
Амплитуды волн: P_x =7,8 мкм/с , L_{gx} =6,9 мкм/с , S_y =8,I мкм/с



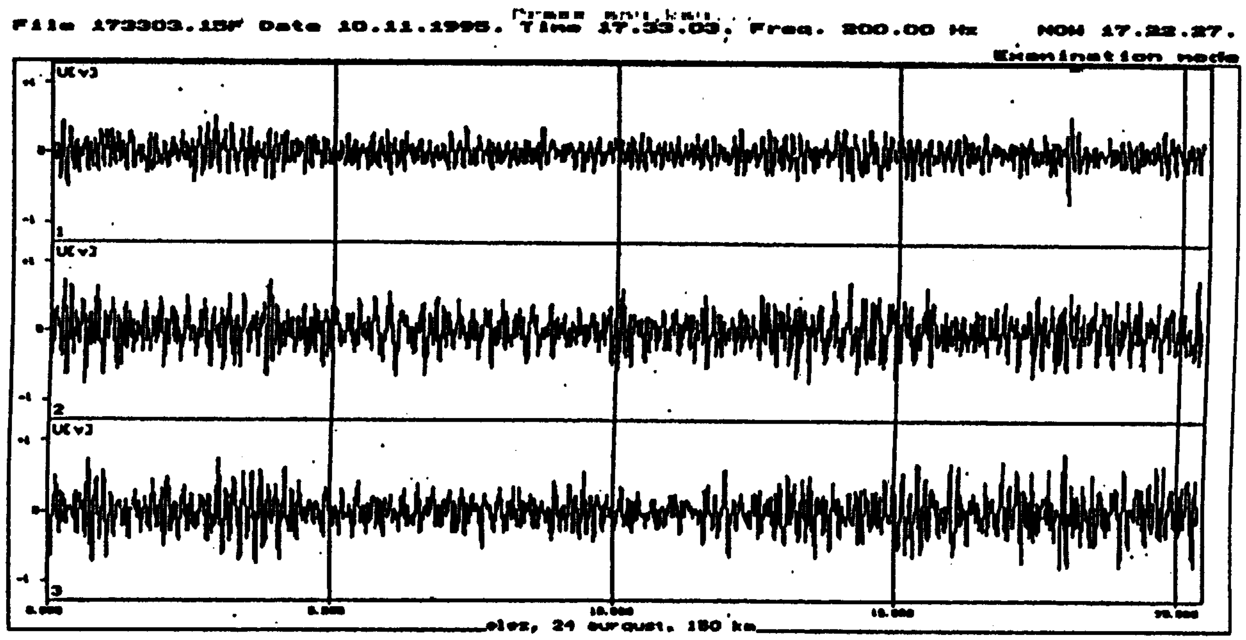
0 – I60 сек

95-2318

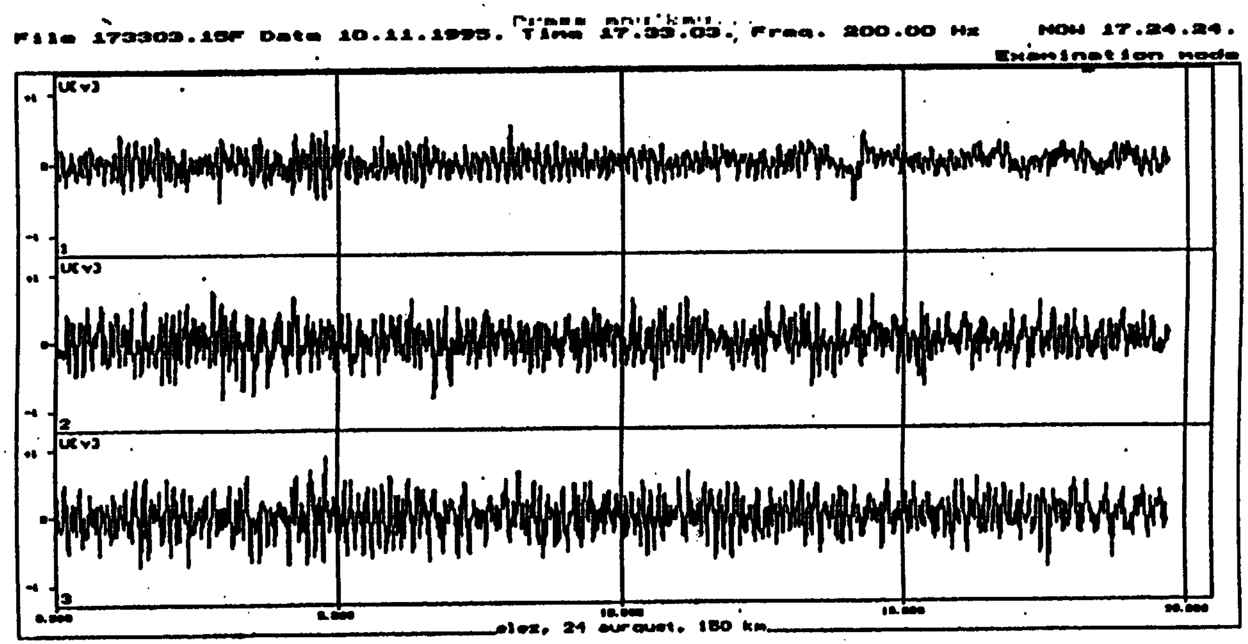


0 – 20 сек

95-236

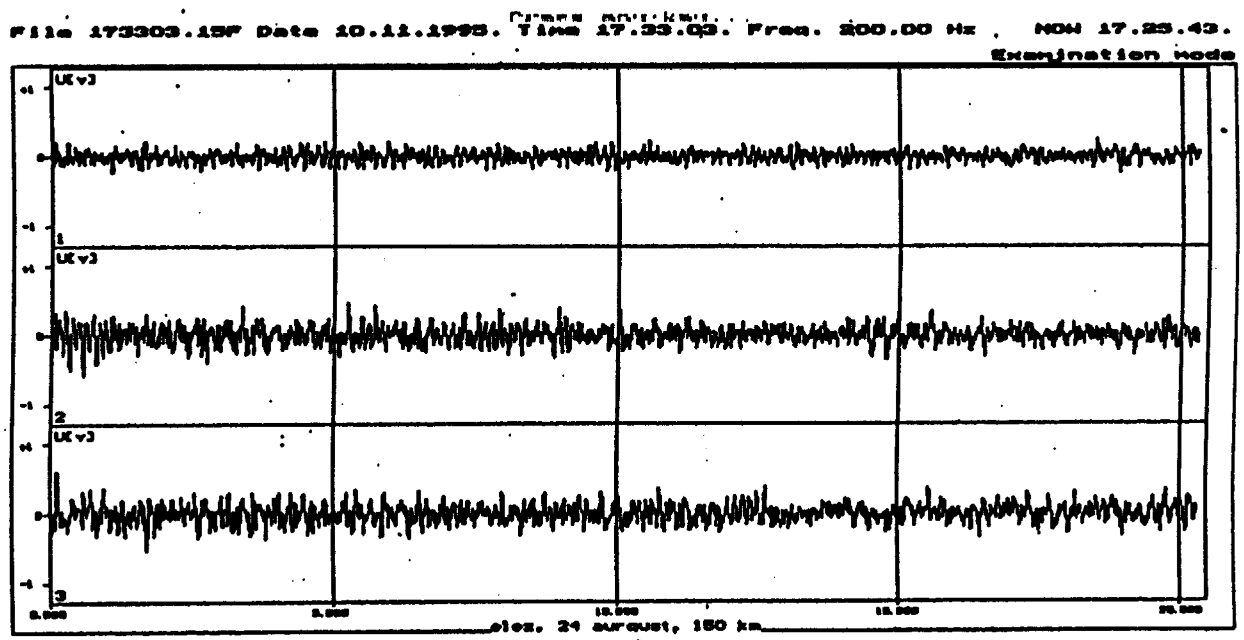

File 173303.15F Date 10.11.1995. Time 17.33.03. Freq. 200.00 Hz NOW 17.22.27.
Examination mode
U(v)
U(v)
U(v)

20 – 40 сек



40 – 60 сек

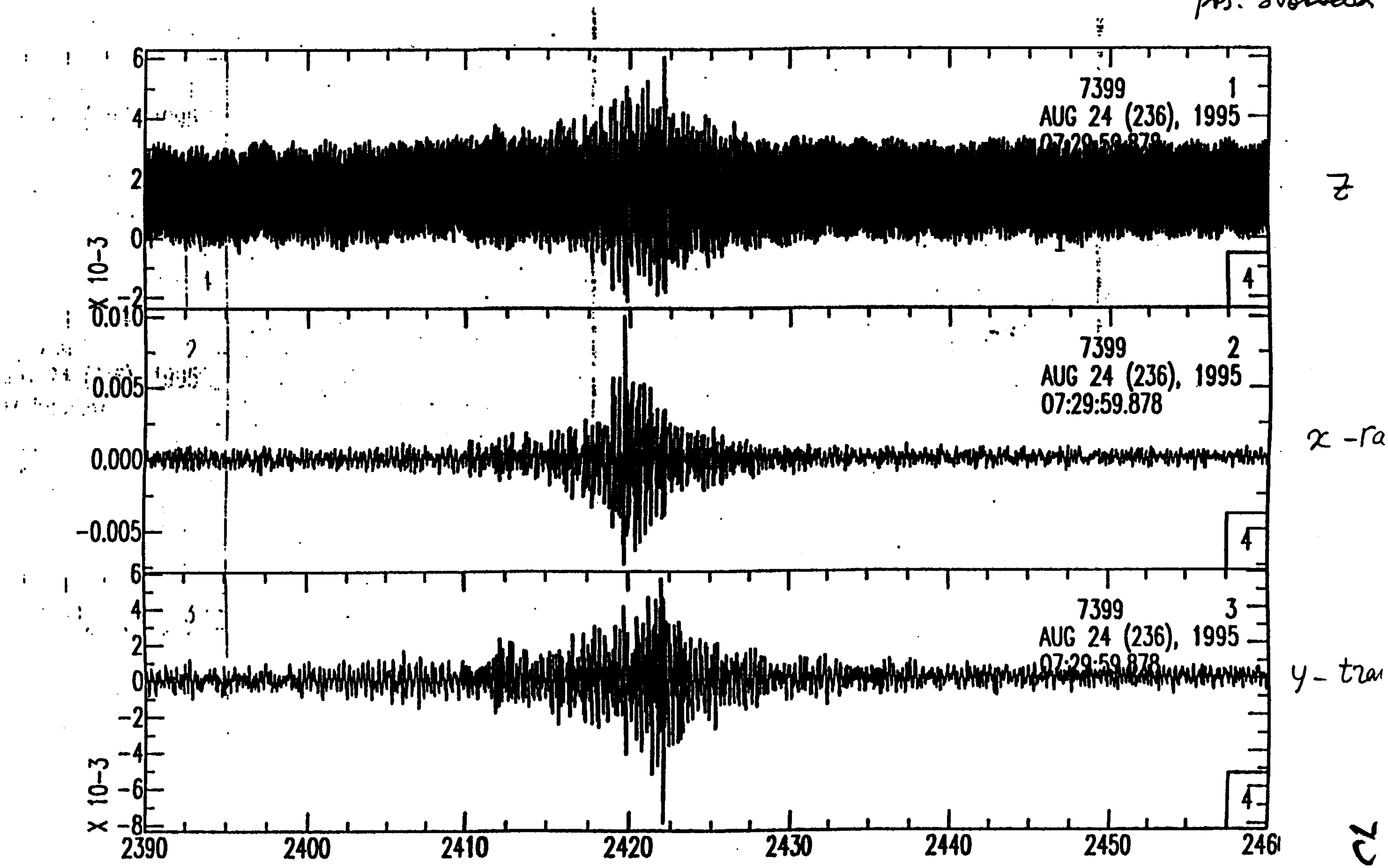
95-236



60 – 80 сек

95-236

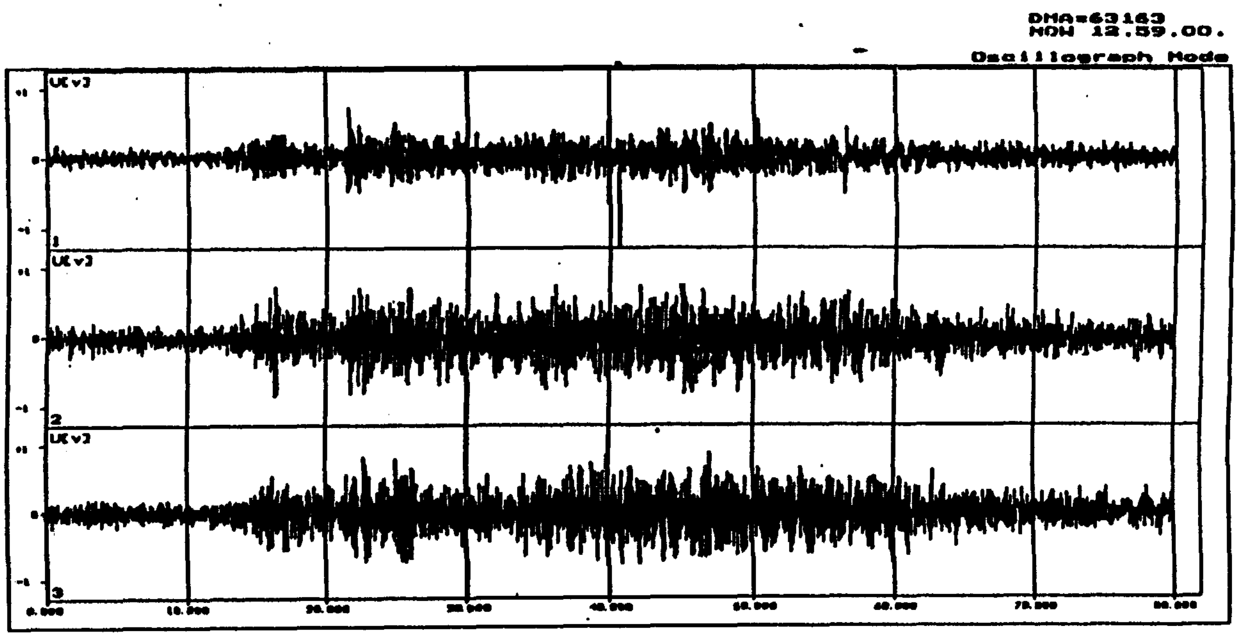
Lef. Vusky
24.08.95.
pos. Svoboda



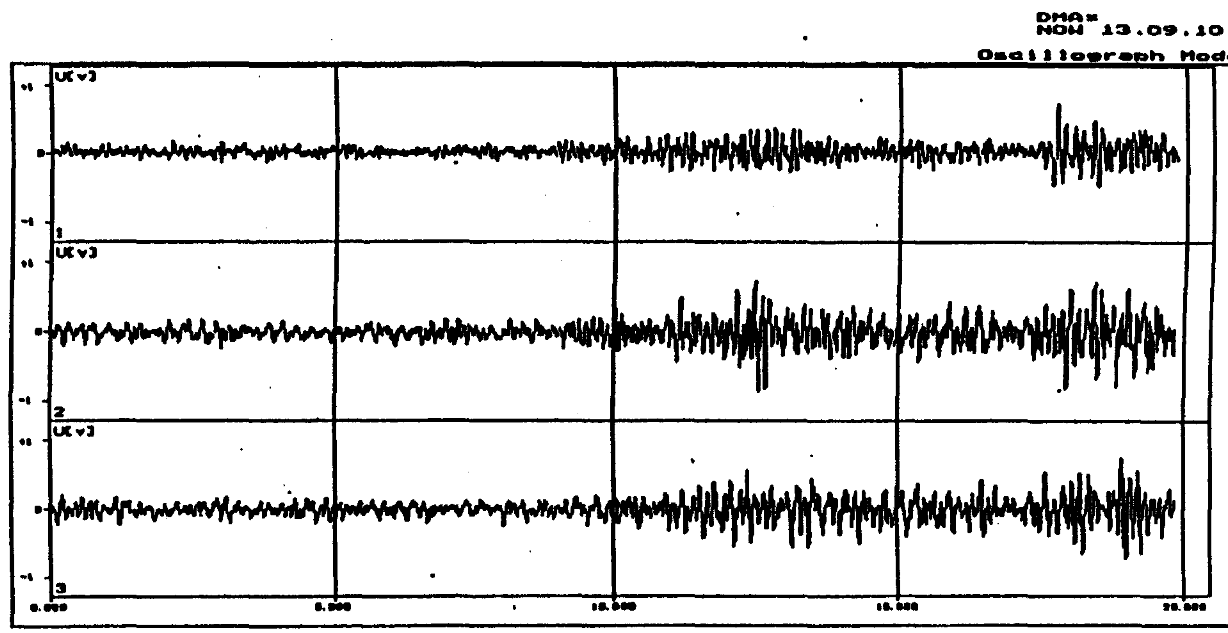
Вертикальная

Радиальная

Трансверсальная



Взрыв на Лебединском руднике.
24.08.95
Сейсмопункт Елец
Эпицентральное расстояние 150 км.
Масштаб записи I – 0.I мм/сек

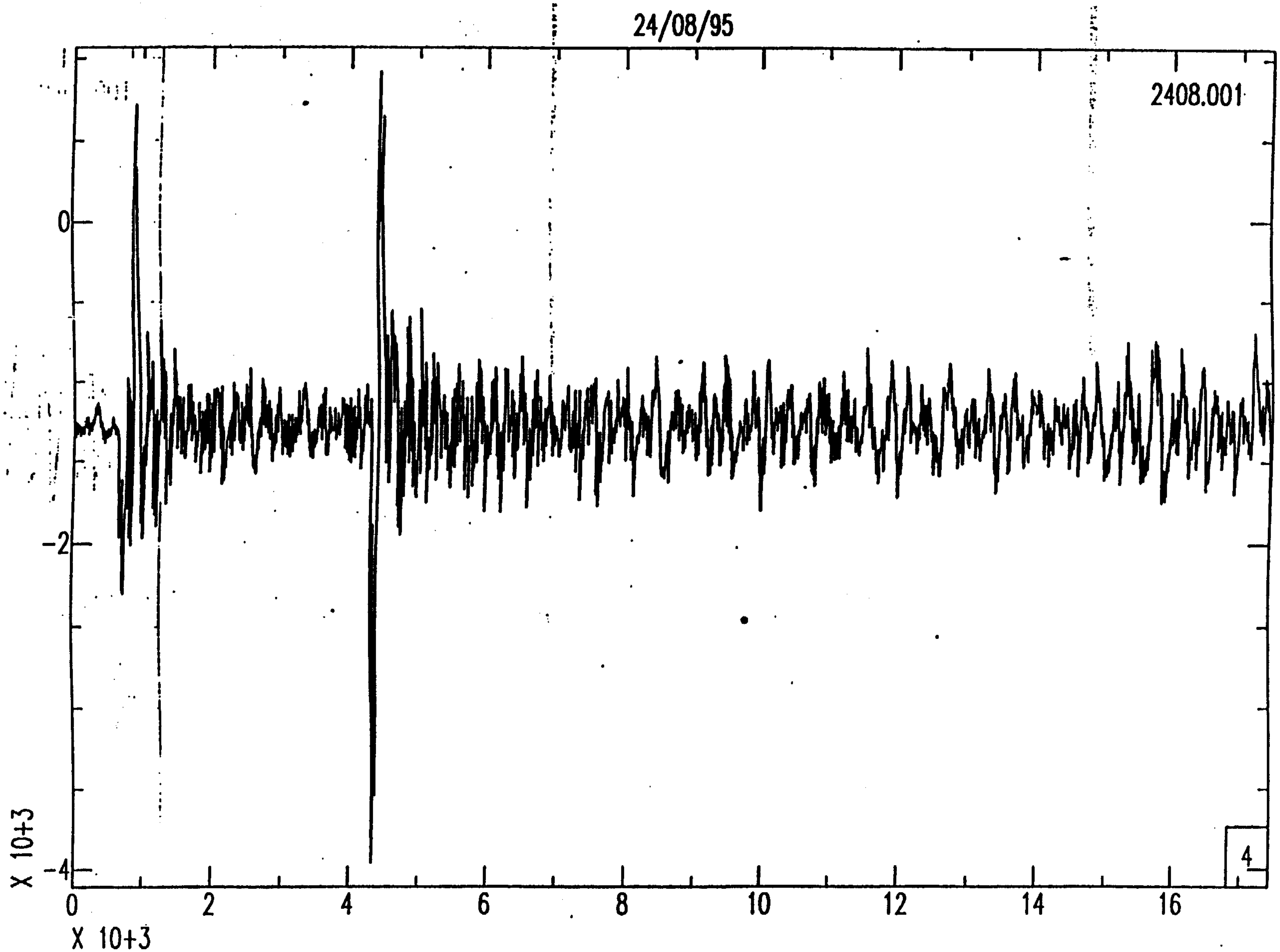


Сейсмопункт Елец.
Первые 20 секунд записи.

0 – 20 сек.

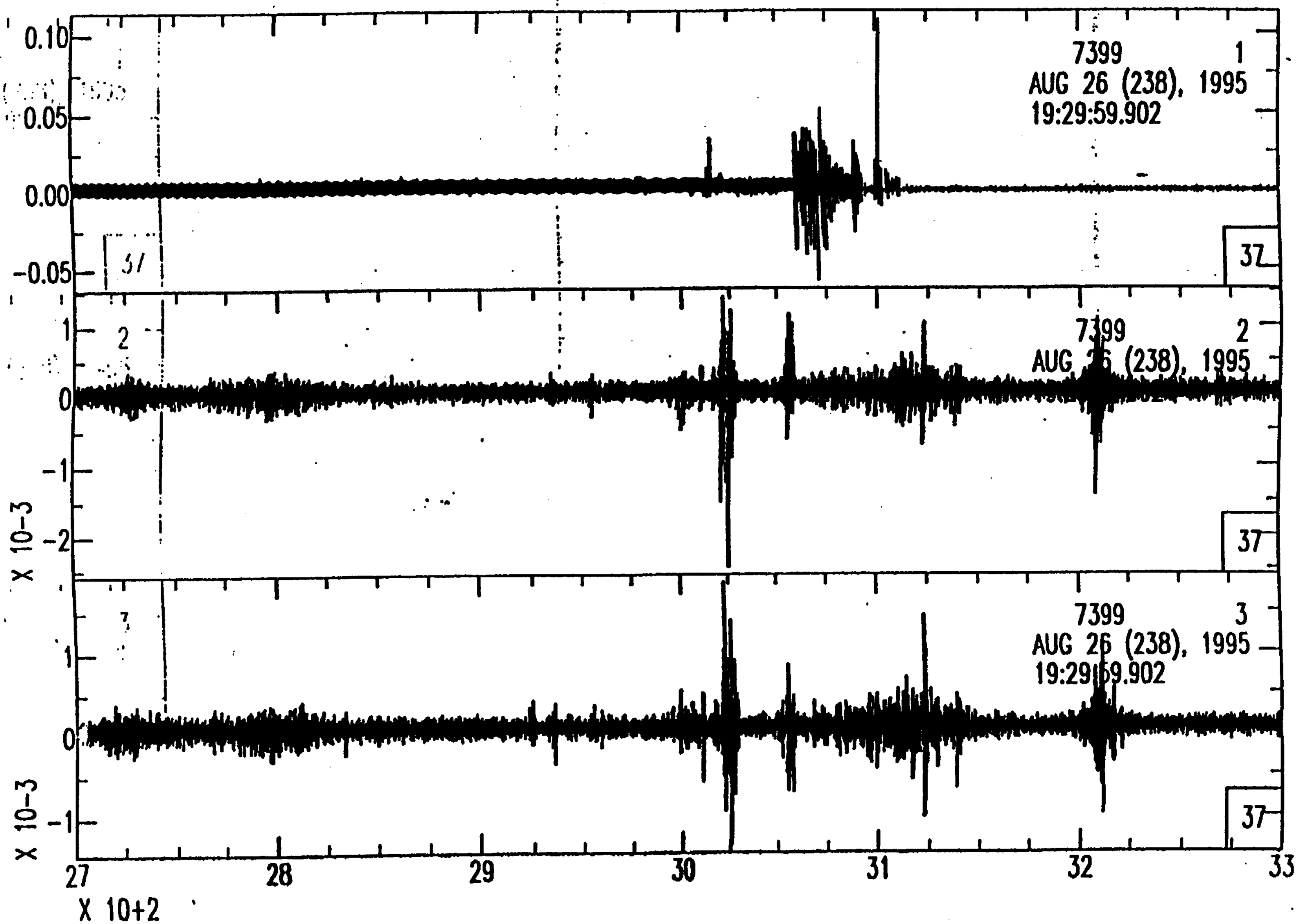
?? Лебединский ГОК. Время на 4 мин раньше

Mikhnevo



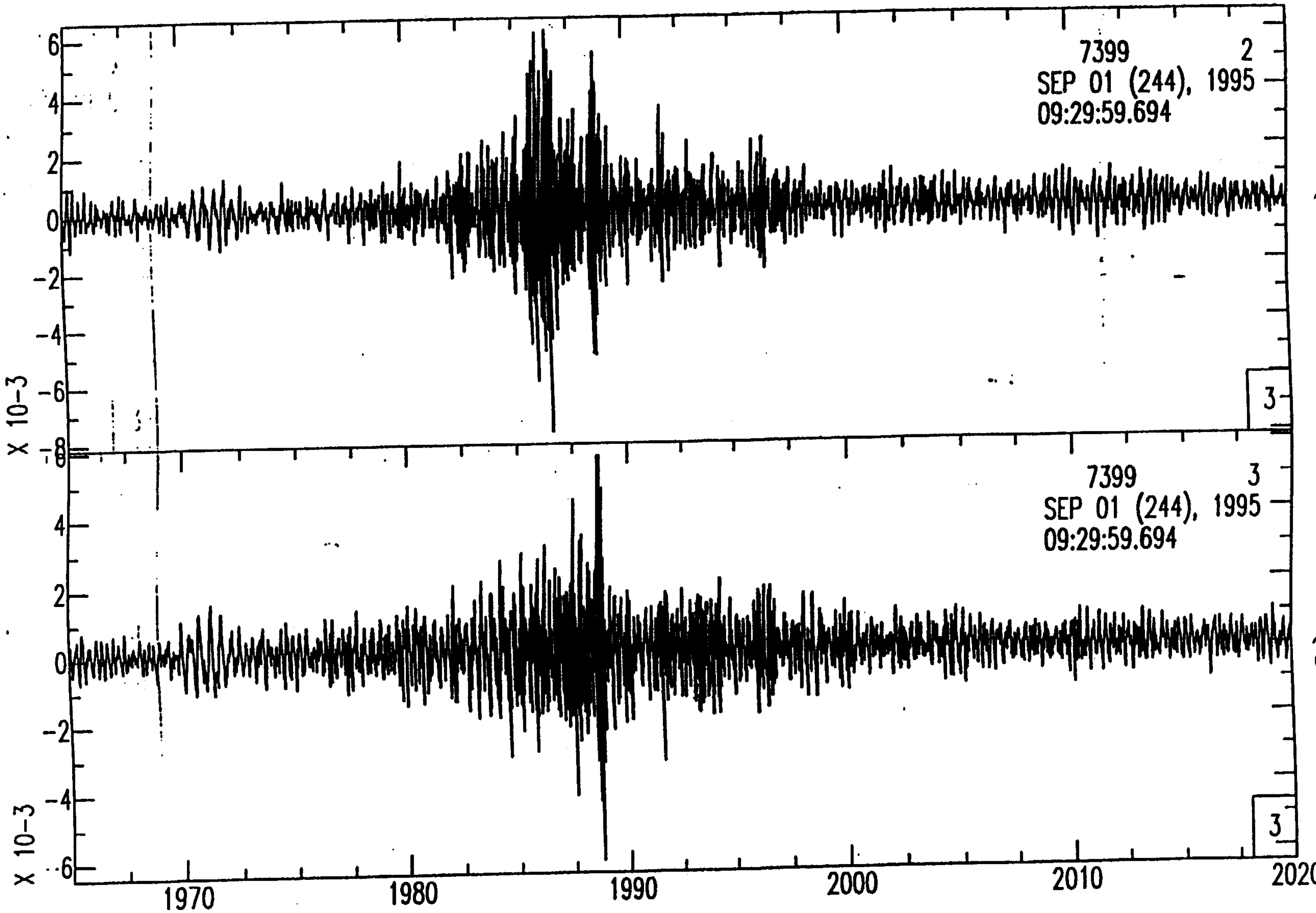
95-236

KMA (...dergroun
26.08.95
pos. Svoboda



95-238

Mikhailov-ky
01.0. 95
pos. Svoboda



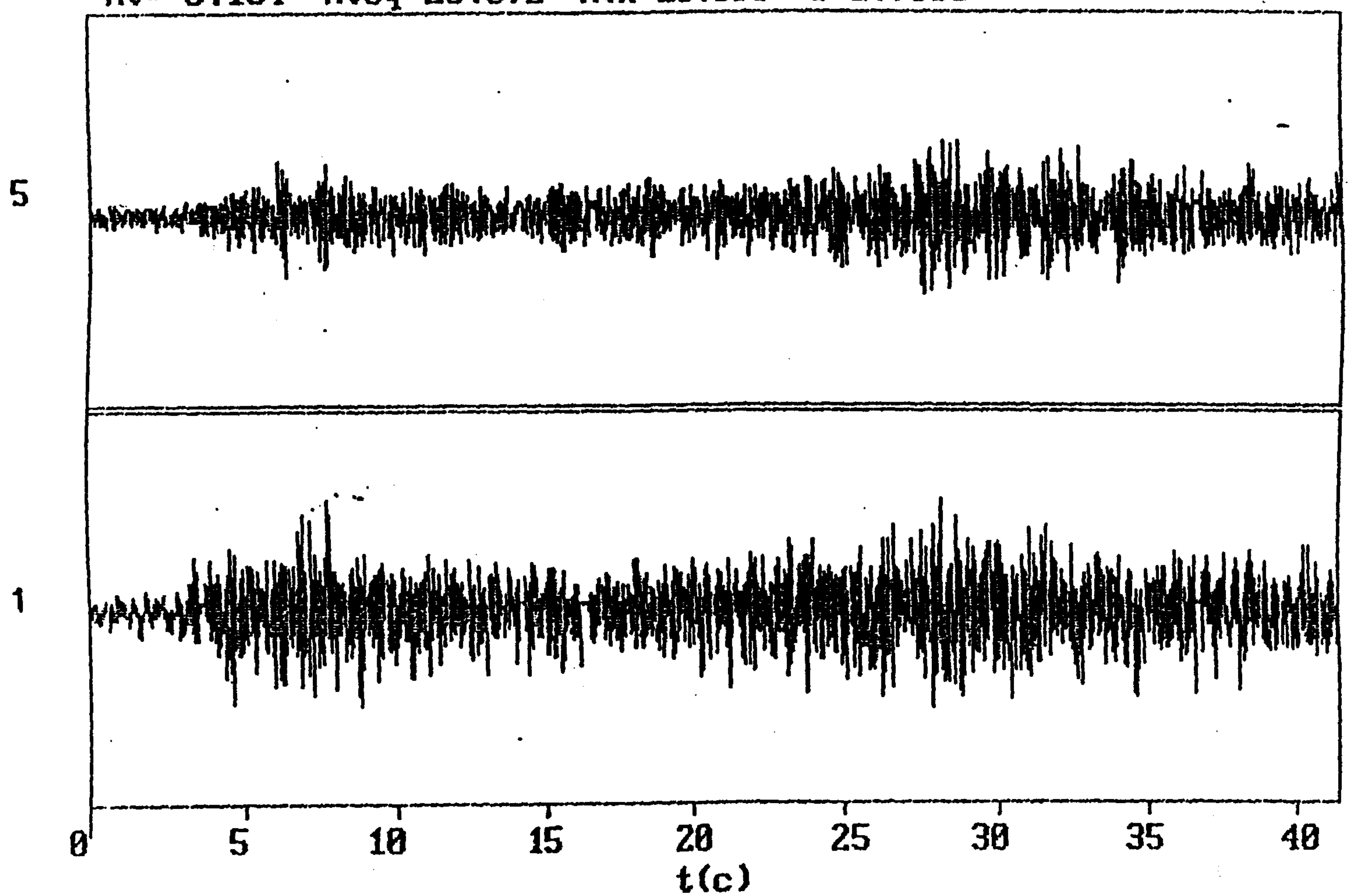
x-radial

y-transversal

95-244

Mikhailovsky 6
01.09.95 (~
pos. Tim

file a501 date 95-9-1 time 8:0:0. Y-ax f.=10.
Av=-3.154 AvSq=26.872 AvA=20.399 D=1.7353



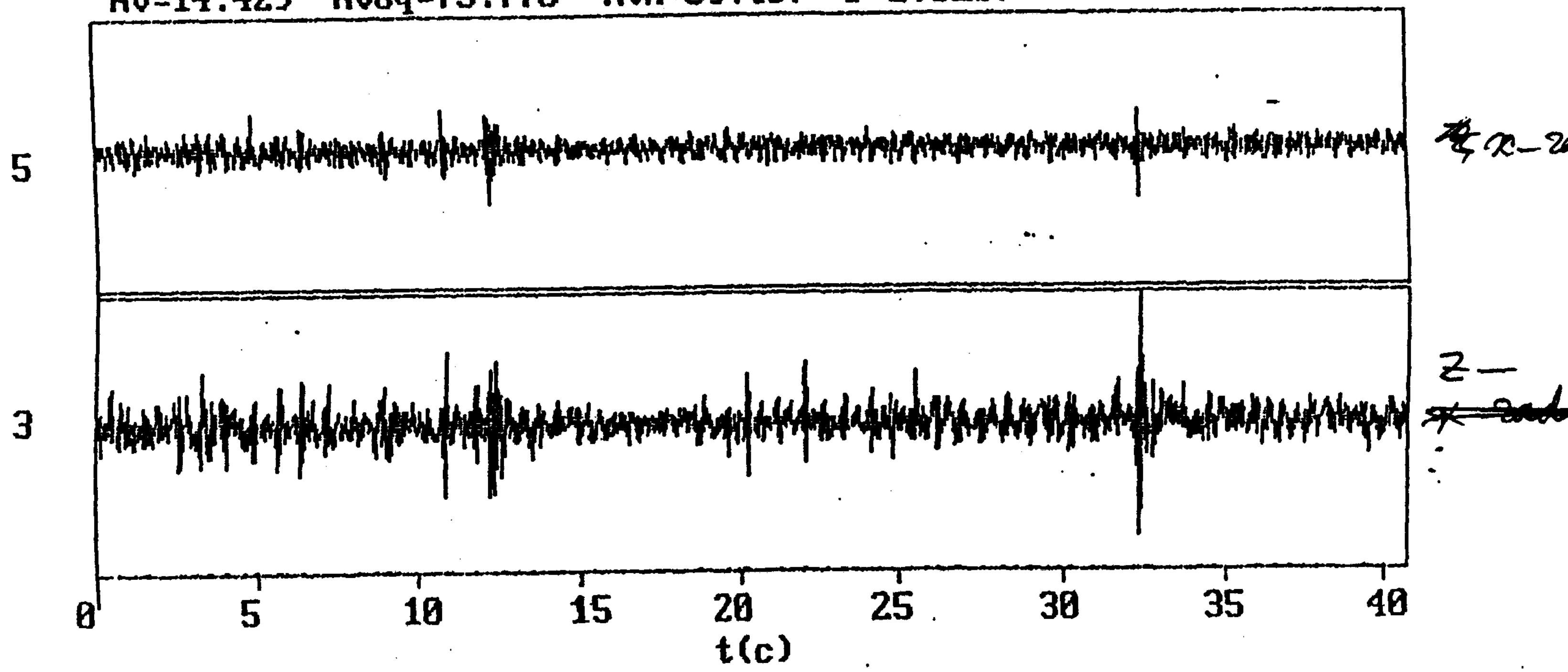
x-radia

z-verti

N.point=4096 S.point=1 Block=1 event=1

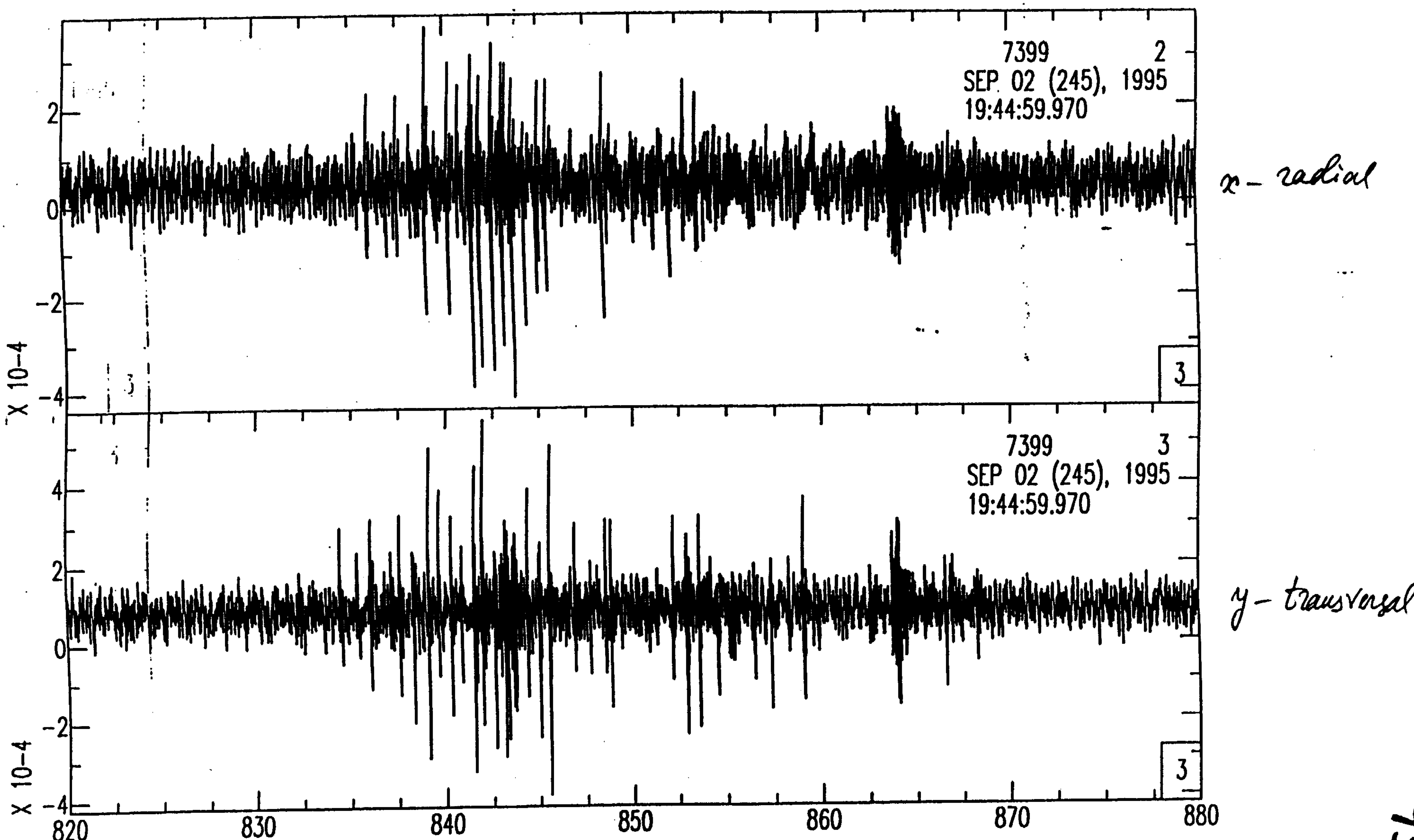
Stoilensky GOK
01.09.95 (~65
pos. Tim

file a501 date 95-9-1 time 10:0:0. Y-ax f.=20.
Av=14.429 AvSq=75.770 AvA=59.407 D=1.6267



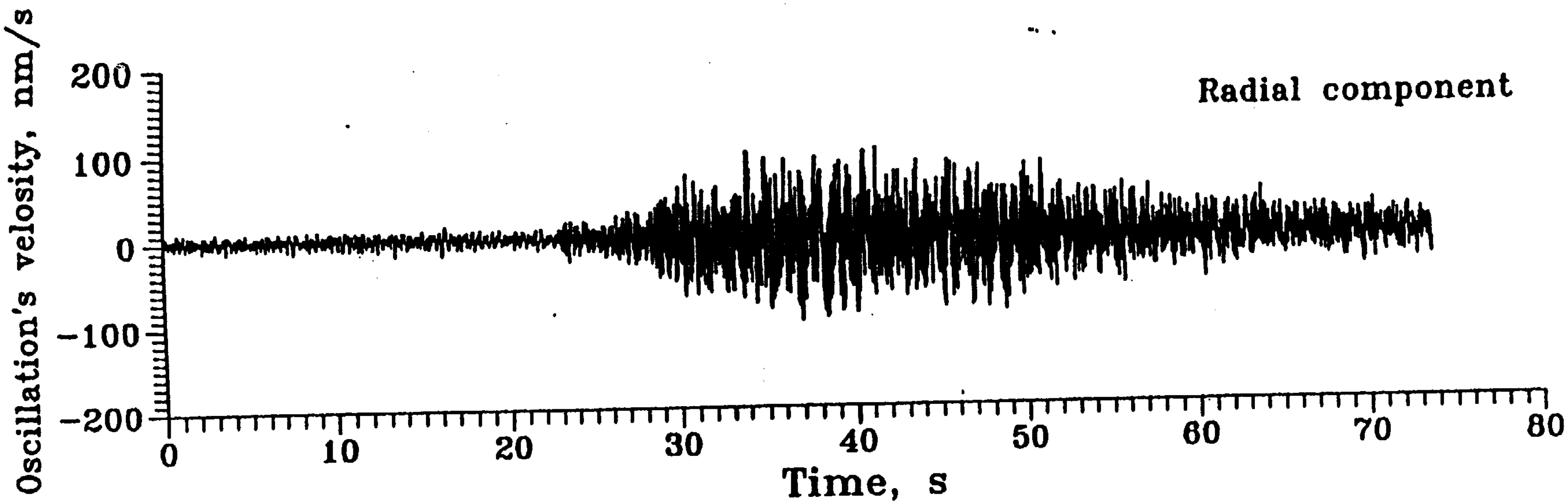
N.point=4096 S.point=1 Block=1 event=1

KMA
02.09.
pos. Svobode



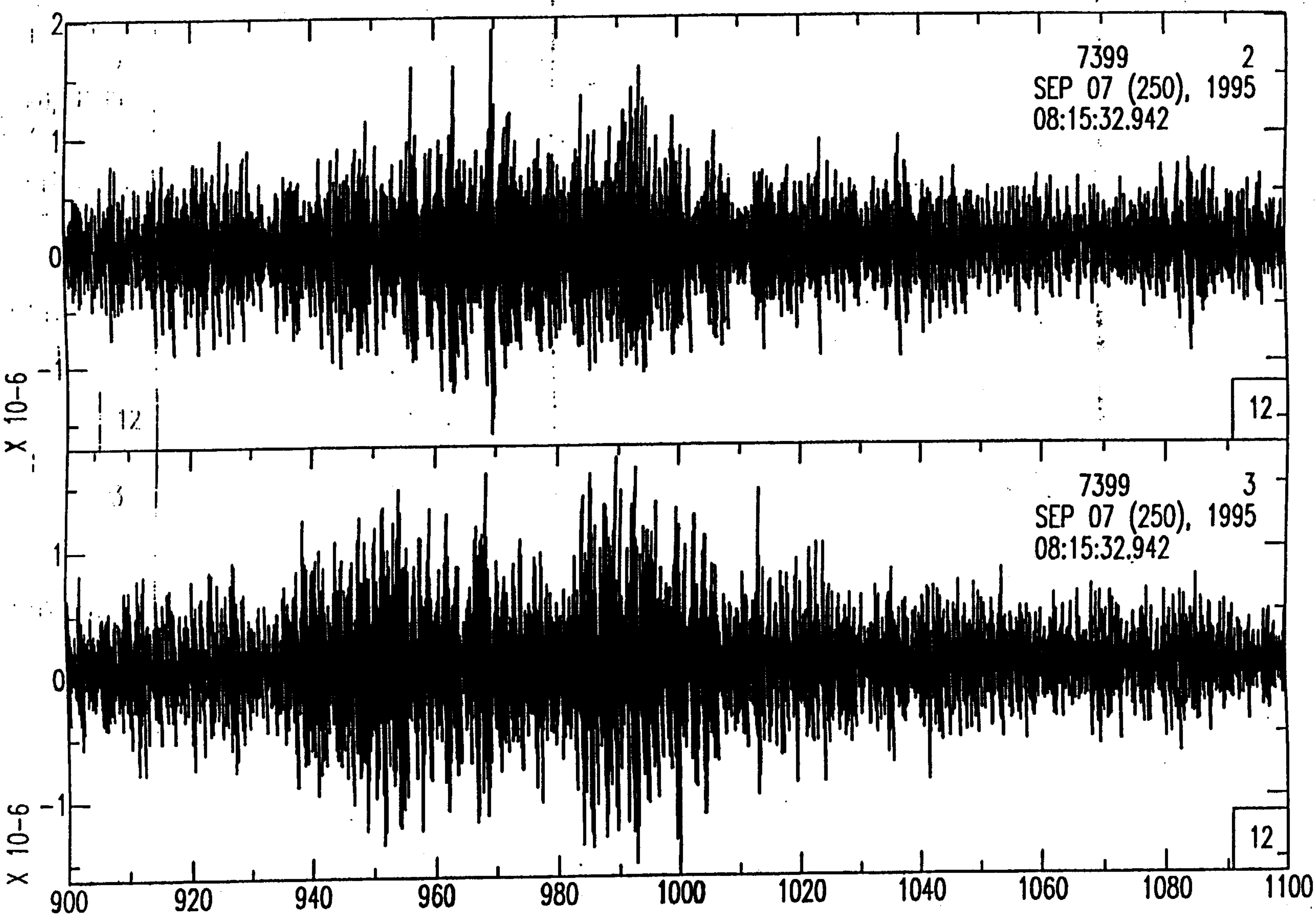
95-245

Explosion at Lebedinsky GOK (Sep 07, 1995)
Point of registration: pos. Tim



95-256

lebedinsky
07.09.95
pos. Svobode

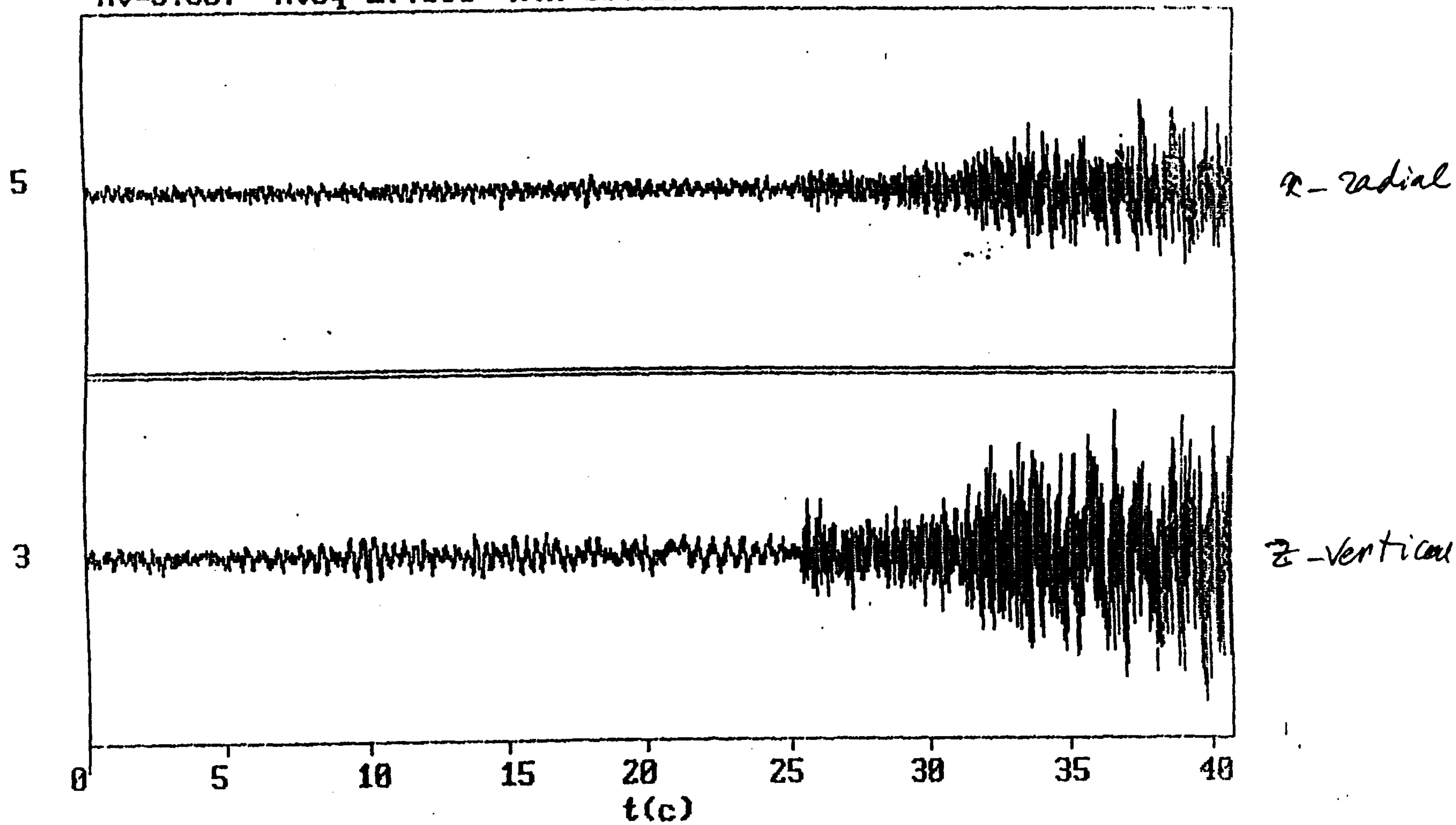


x- radial

y- transversal

Lebedinsky ^ok
07.09.95 (~65 км)
pos. Tim

file a501 date 95-9-7 time 8:31:0. Y-ax f.=10.
Av=5.857 AvSq=27.098 AvA=15.793 D=2.9439

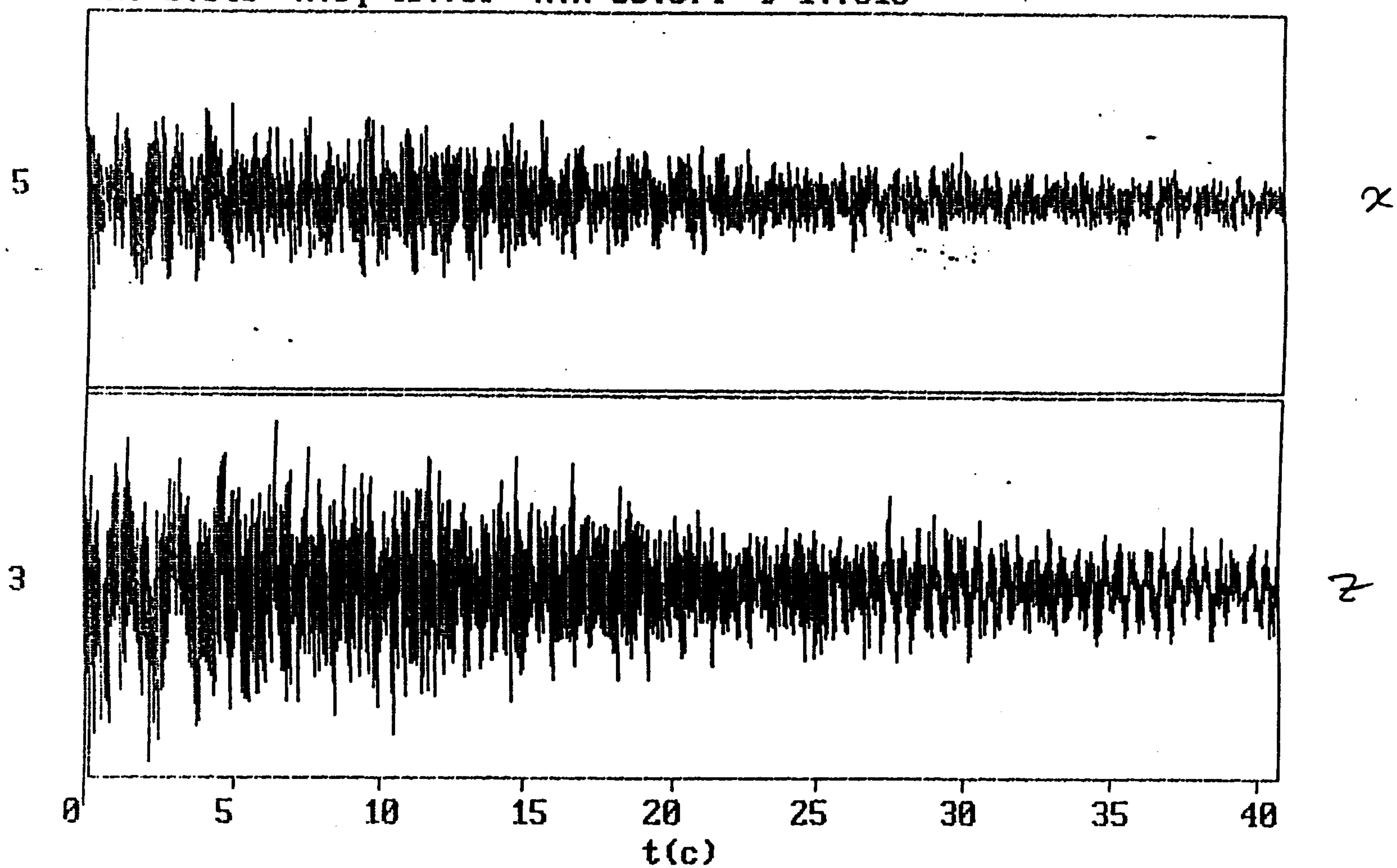


N.point=4096 S.point=1 Block=0 event=1

95-250

Lebedinsk, зап
07.09.95
pos. Tim

file a501 date 95-9-7 time 8:31:40.804 Y-ax f.=10.
Av=5.340 AvSq=40.709 AvA=30.674 D=1.7613



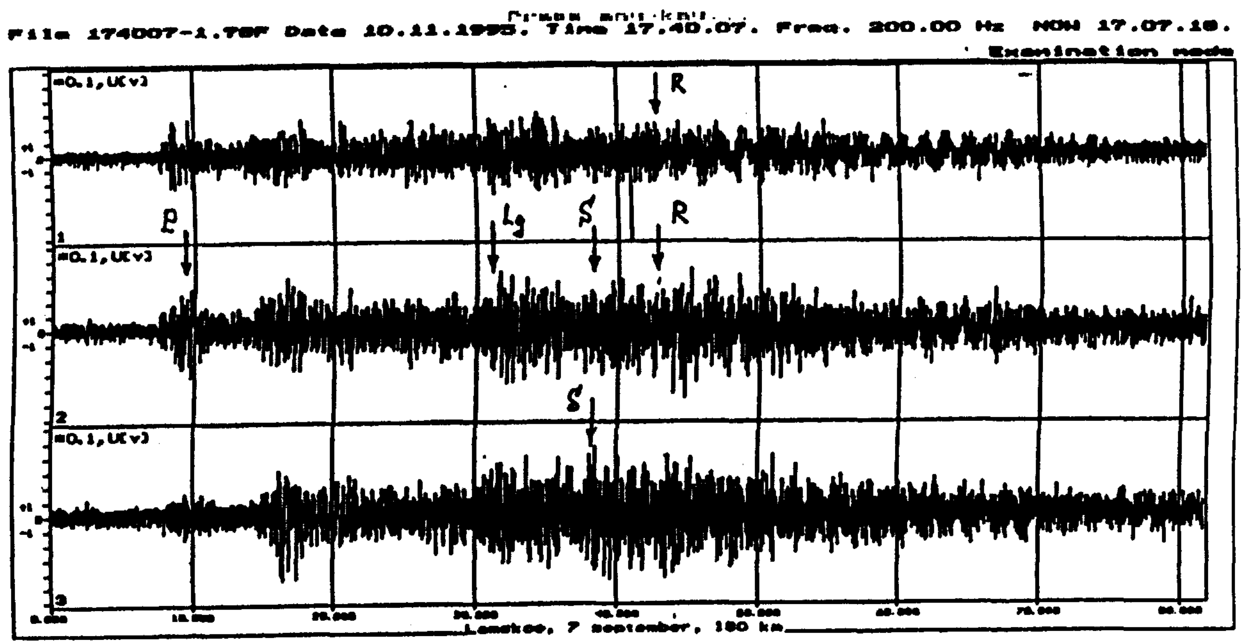
N.point=4096 S.point=4097 Block=0 event=1

95-25a

Вертикальная

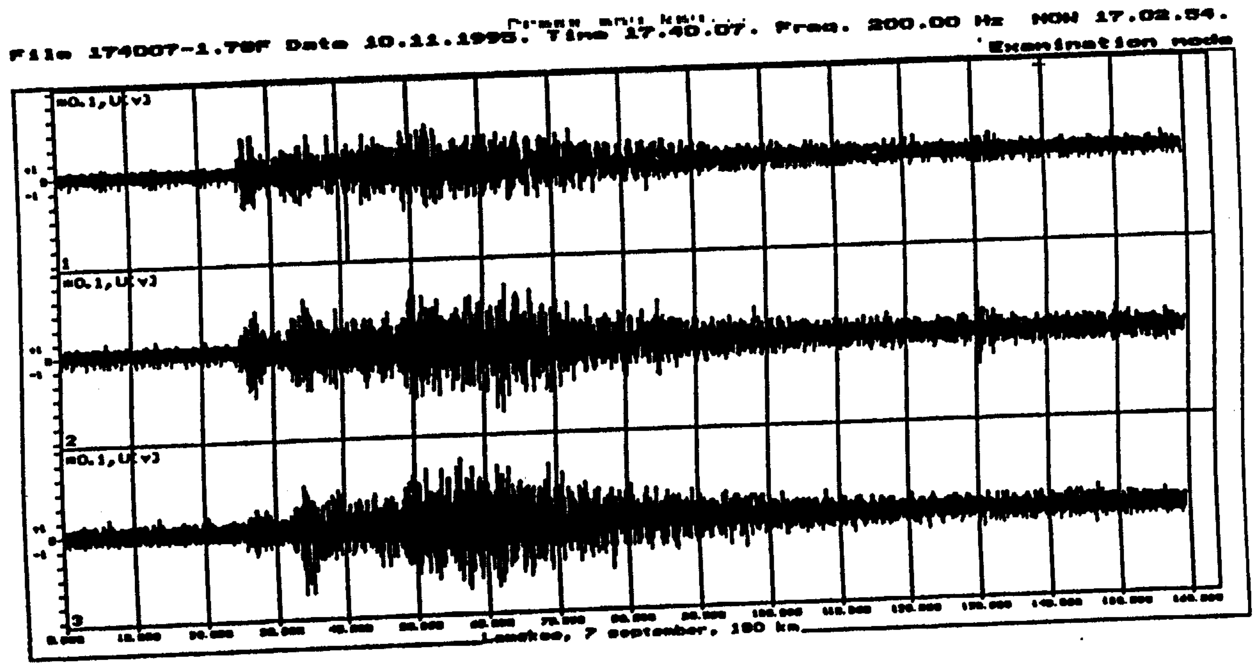
Радиальная

Тангенциальная

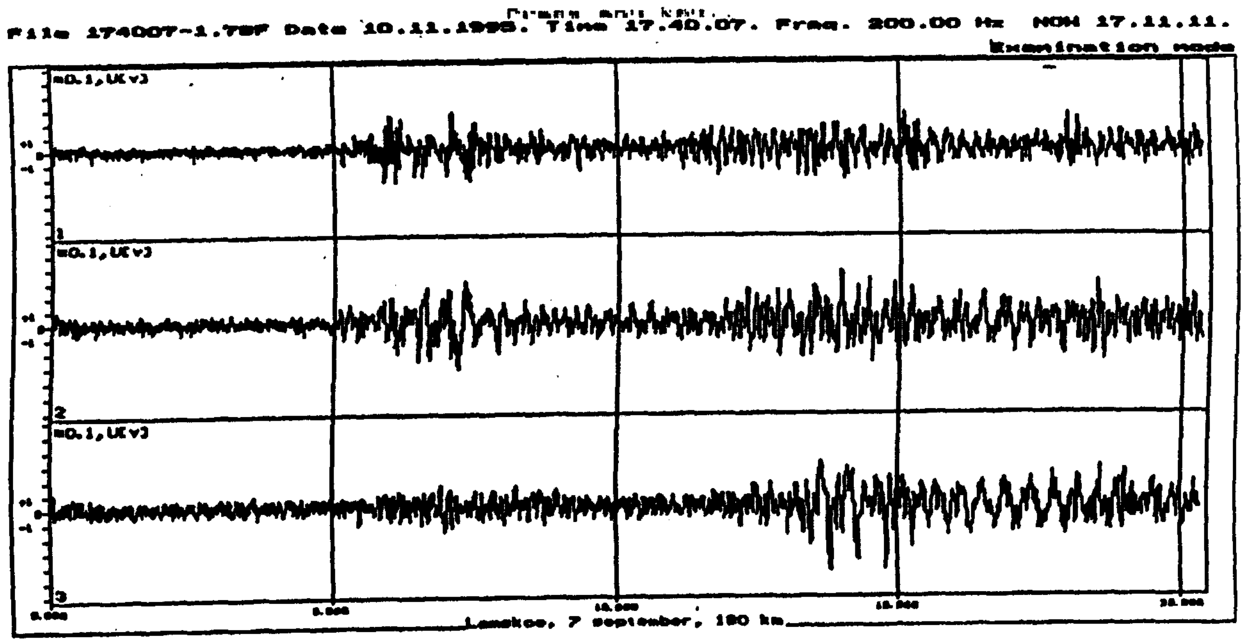


0 – 80 сек

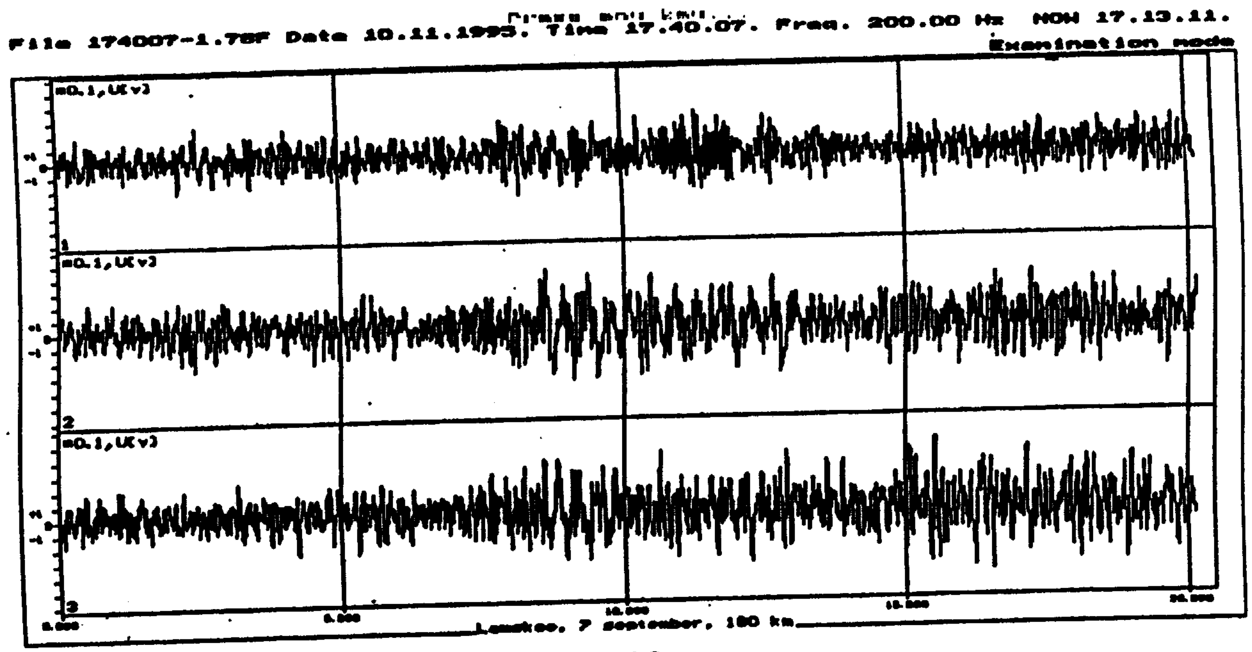
Взрыв на Лебединском ГОКе
7 сентября 1995г.
Сейсмопункт в с.Ламское, эпицентральное расстояние 180 км.
Амплитуды волн: P_x =3,15мкм/с , L_{gx} =3,8 мкм/с , S_y =4,2 мкм/с


Freq. 200.00 Hz NOW 17.02.54.
File 174007-1.78F Date 10.11.1995. Time 17.40.07.
Examination mode
1
2
3
7 september, 180 km

0 - I60 сек

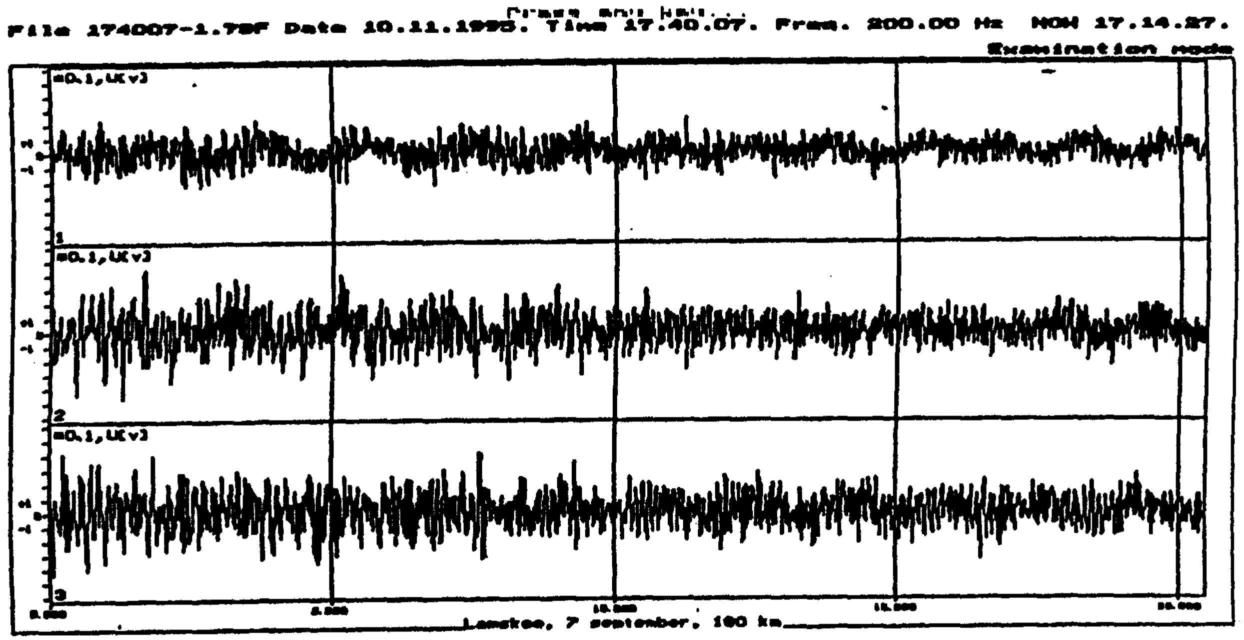

File 174007-1.78F Date 10.11.1998. Time 17.40.07. Freq. 200.00 Hz NOH 17.11.11.
Examination mode
m0.1,U(v)
m0.1,U(v)
m0.1,U(v)
Lanskoe, 7 september, 180 km

20 – 40 сек



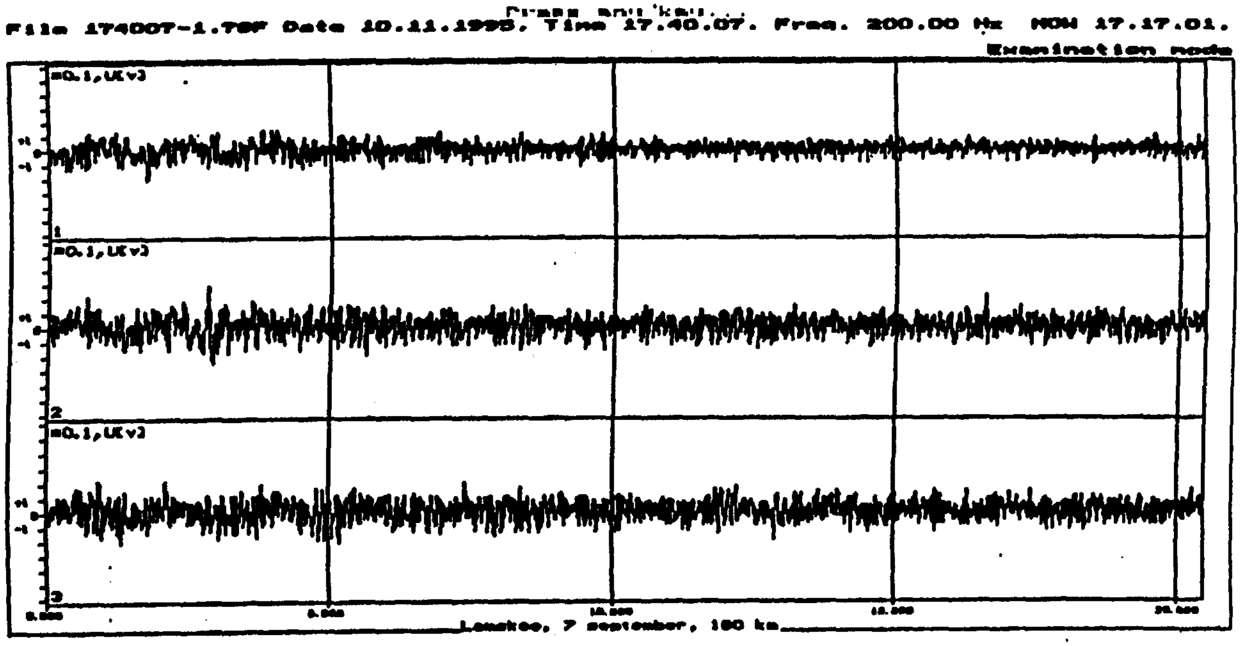
40 – 60 сек

95-250
40-60



60 – 80 сек

95-259
60-80

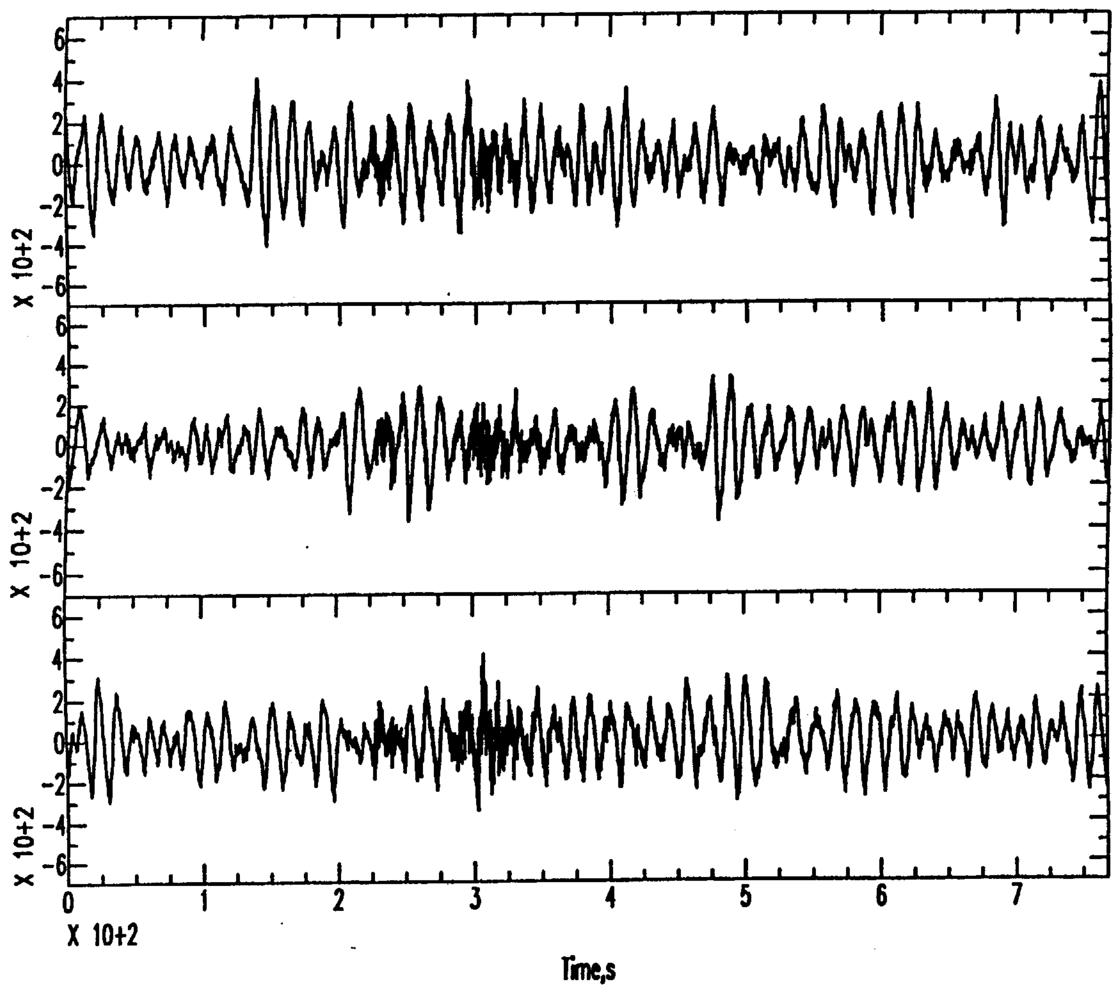


80 - I00 сек

95-250

Initial tras Mikhuwo

05 сент. 1995г.



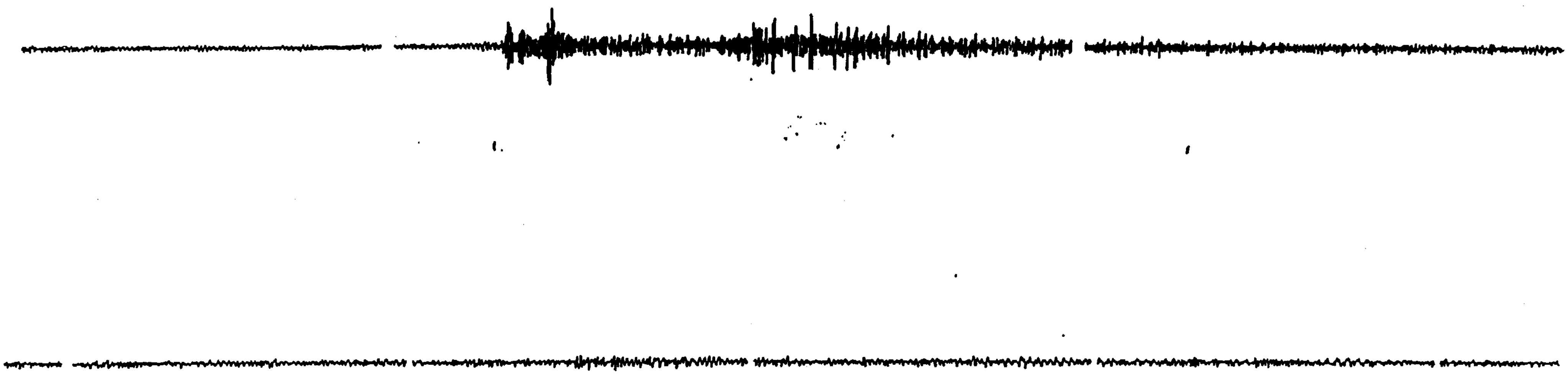
08. Sept. 1995

Mikhailovsk GOK

8:00:0.0

75-251

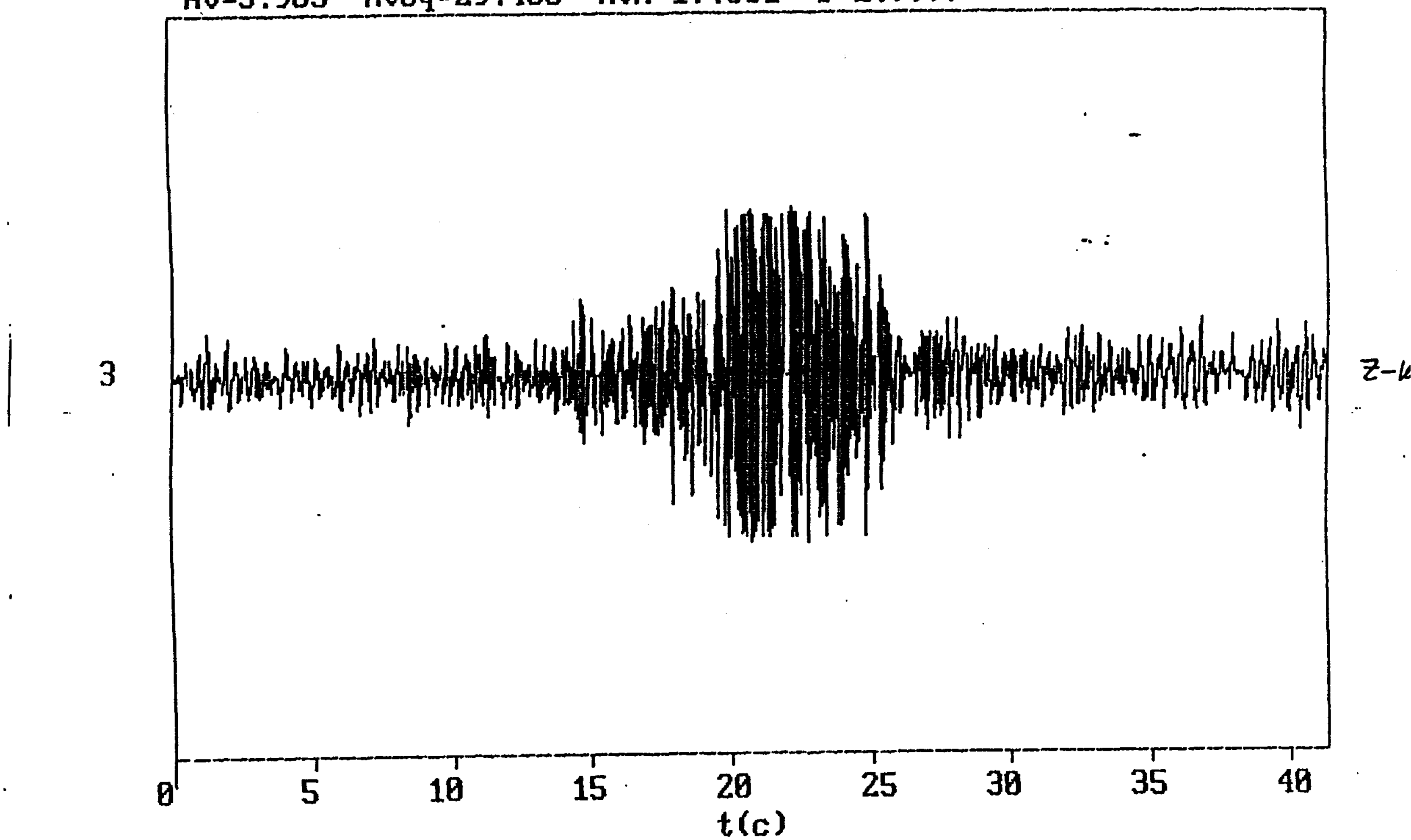
Explosion at Michailovsky GOK (Sept 08, 1995)
Point of registration : pos. Michnevo , R = 340 km



95-25

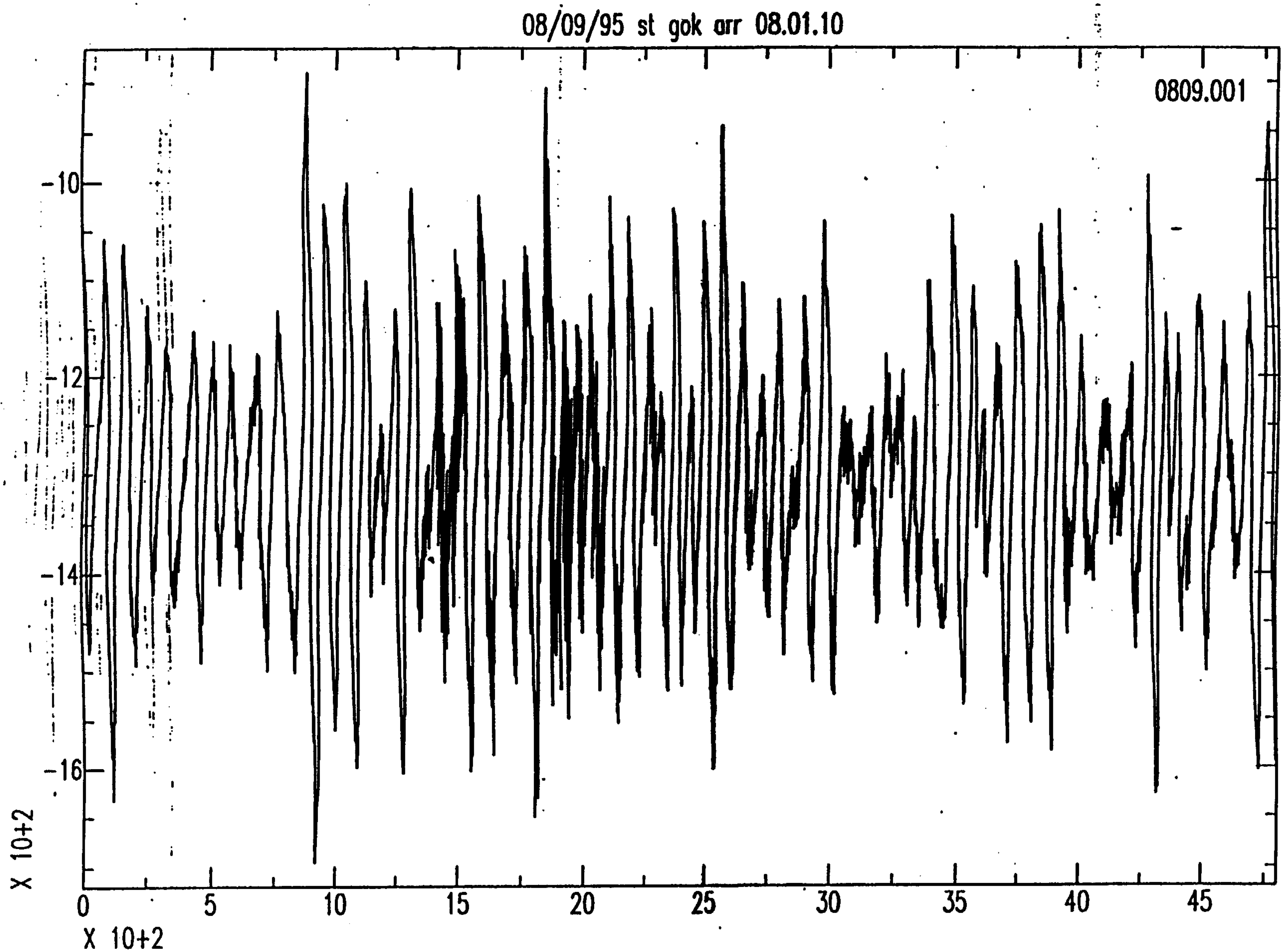
Взрив на Михал...
08.09.95
Регистрация в нос.
sept 08.1995
R=60km

file a301 date 95-9-8 time 8:4:0. Y-ax f.=7.
Av=3.983 AvSq=29.435 AvA=17.661 D=2.7777



N.point=4096 S.point=1 Block=0 event=1

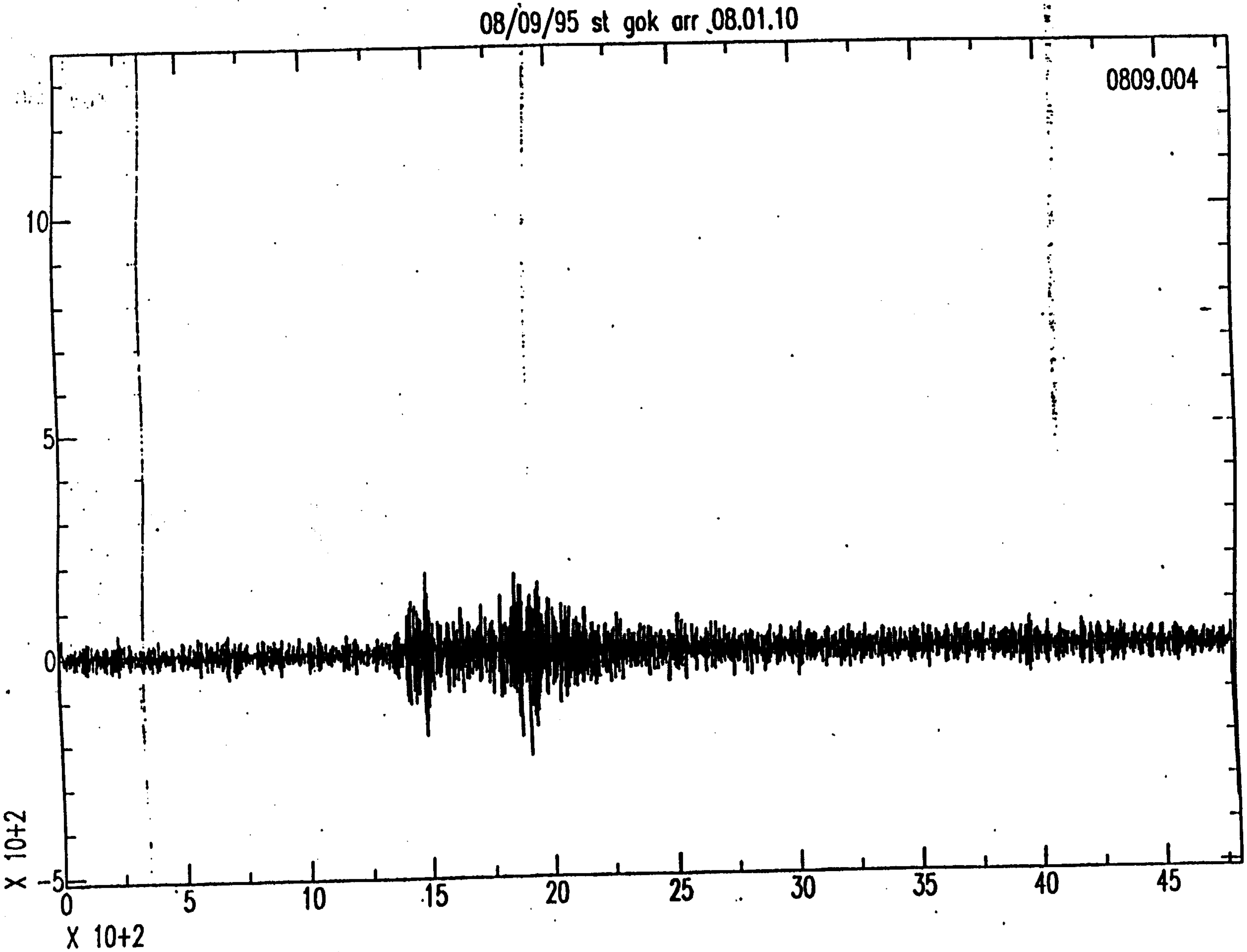
Михайловский ГОК, Michnevo 08.09.95 Вертикальная компонента



Z

95-251

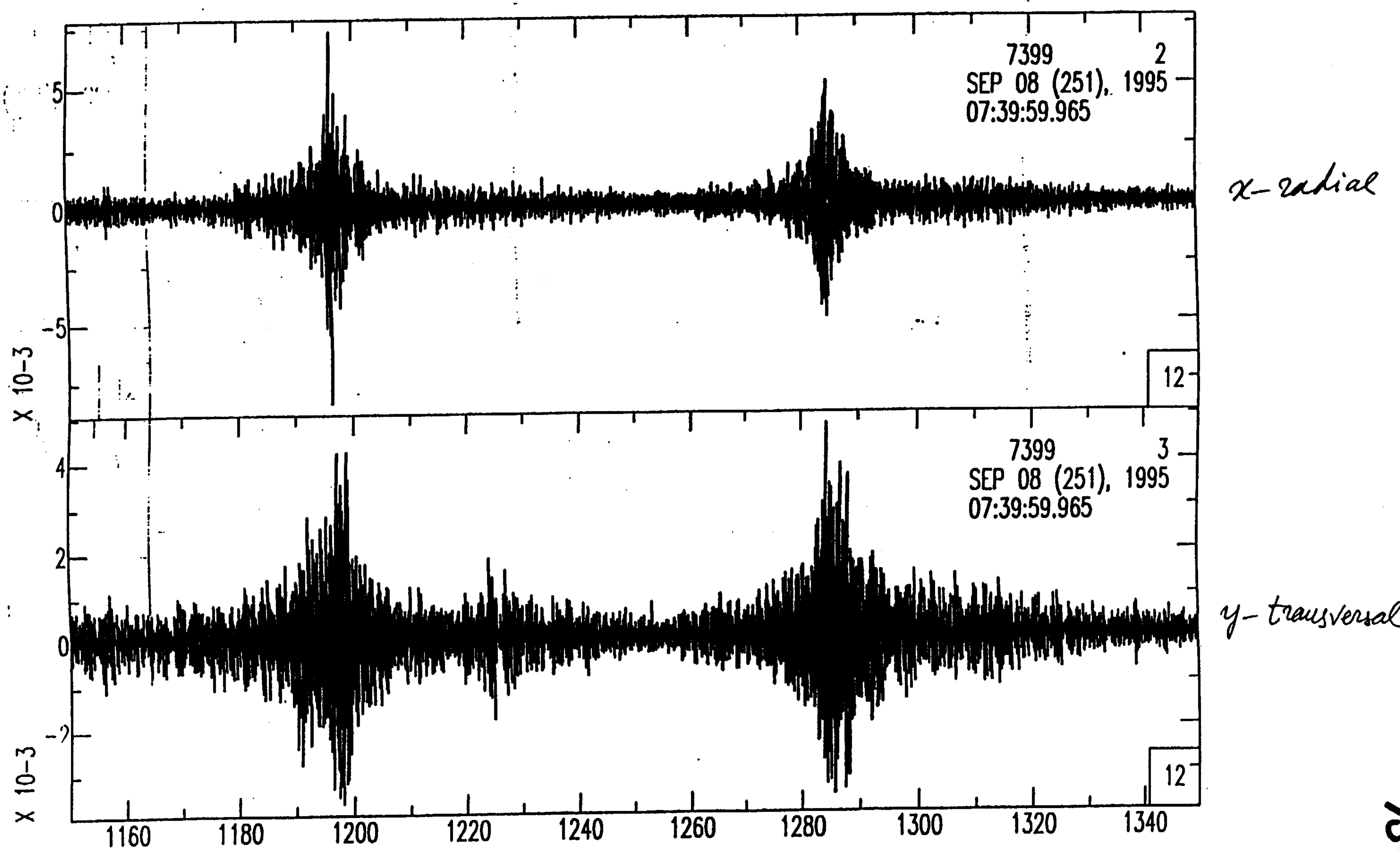
R=340км



95-251

Высокочастотный фильтр
с левой границей 1 Гц

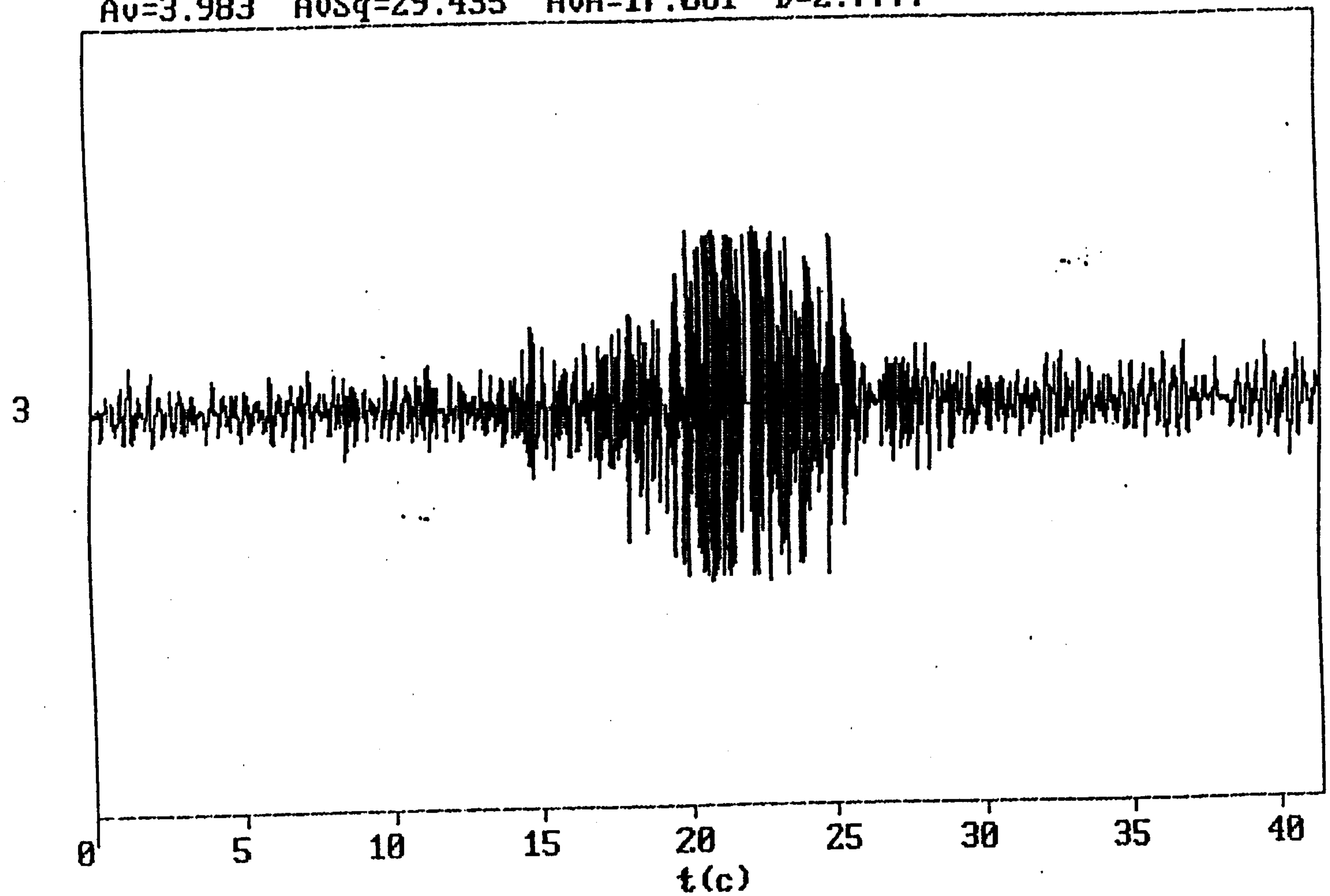
Mikhailovsk
08.09.95
pos. Svoboda



95-251

Взрыв на Михайловском ГОКе
08.09.95 (~ч. мин)
Регистрация в пос. Свобода

file a301 date 95-9-8 time 8:4:0. Y-ax f.=7.
Av=3.983 AvSq=29.435 AvA=17.661 D=2.7777



Z-компонента

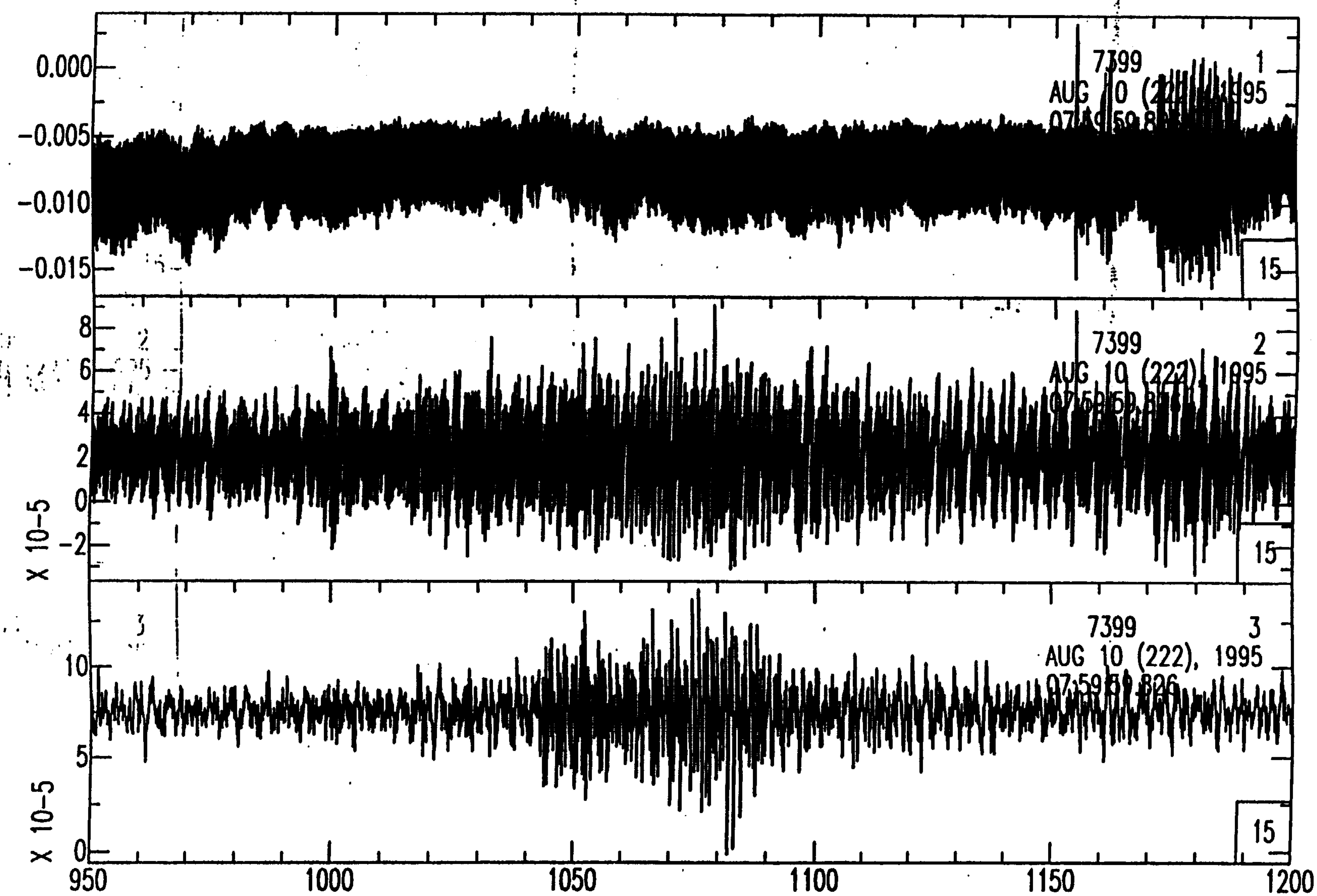
N.point=4096 S.point=1 Block=0 event=1

95-251


пос. Свобода, Курская обл.
08.09.1995 08^h04'00''
Z–компонента
0.5
Амплитуда, мкм/с
0
0
5
10
Время, с

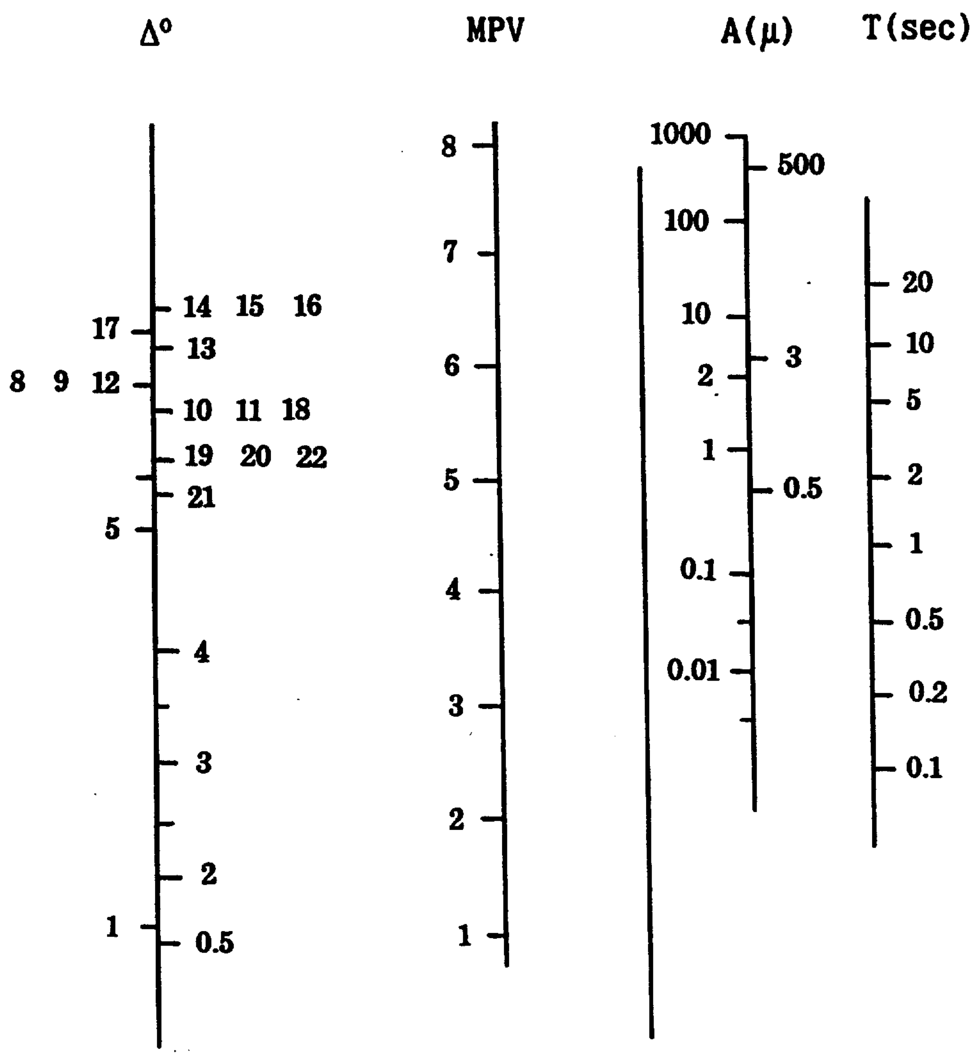
95-251

Le. 'insky
10.08.95
Mikhuevo



95-253

Appendix 6: Nomogram used for determing magnitudes of the Kursk mining blasts



Technical Information Department • Lawrence Livermore National Laboratory
University of California • Livermore, California 94551