CHARACTERIZATION OF SEISMIC SOURCE AND PATH IN CENTRAL EURASIA USING DIGITAL SEISMOGRAMS FROM BOROVOYE OBSERVATORY, NORTHERN KAZAKHSTAN

AFOSR-TR-96

0102

Won-Young Kim
Paul G. Richards

Lamont-Doherty Earth Observatory
of Columbia University
Route 9W
Palisades, NY 10964

4 February 1996

Final Report
September 1, 1992 - August 31, 1995

Approved for public release; distribution unlimited.

AFOSR
Air Force Systems Command, USAF
Bolling Air Force Base
Washington D.C., 20332-6448

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
2/5/96

3. REPORT TYPE AND DATES COVERED
Final Report (Sept. 1'92-Aug.31 '95)

4. TITLE AND SUBTITLE
Characterization of Seismic Source and Path in Central Eurasia Using Digital Seismograms from Borovoye Observatory, Northern Kazakhstan

5. FUNDING NUMBERS
Contract F49620-92-J-~~0479~~ 0497

6. AUTHOR(S)
Won-Young Kim
Paul G. Richards

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
The Trustees of Columbia University in the City of N.Y.
351 Engineering Terrace
500 W. 120th Street
New York, NY 10027

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
AFOSR
Dept. of the Air Force
Bolling Air Force Base
Washington, DC 20332-6448
Program Manager: Dr. Stanley Dickinson

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for Public Release: Distribution Unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)* This final report is in three sections:

1) Describes RMS Lg measurement for five Chinese nuclear explosions at Lop Nor recorded digitally at Borovoye, Kazakhstan (station BRVK). The regression shows scatter only a 0.045 magnitude units against ISC m_b(P).

2) Summarizes a new method to determine the response of digital seismographs from their transient calibration pulses by iterative inverse technique. The method is used to derive complete instrument responses for STsR-TSG system at BRVK.

3) Describes a major survey of regional seismic data for explosions at the Semipalatinsk test site, that has documented the occurrence of 18 small nuclear explosions at Degelen (since confirmed), not previously described in the open literature.

A new PC based system is installed at Borovoye Geophysical Observatory, Kazakhstan for archive tape copying and about 100 raw tape copies have been transferred to LDEO. Part of the digital waveform data have been reformatted and submitted to the IRIS-DMC for interested scientists.

14. SUBJECT TERMS
RMS Lg
Instrument responses of the Borovoye (BRVK) station
Small explosions near Semipalatinsk test site, Kazakhstan

15. NUMBER OF PAGES
73

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	Unclassified

TABLE OF CONTENTS

RMS *LG* MEASUREMENTS OF CHINESE UNDERGROUND EXPLOSIONS AT LOP NOR

Won-Young Kim and Paul G. Richards*
Lamont-Doherty Earth Observatory, Palisades, NY 10964
(* also, Dept. of Geological Sciences, Columbia University)

ABSTRACT

RMS *Lg* measurements using digital seismograms recorded at the Borovoye Geophysical Observatory, Kazakhstan (station BRVK) from Chinese underground nuclear explosions in the Lop Nor test site ($\Delta \approx 1880$ km) show fairly good correlation with ISC $m_b(P)$. Regression of five RMS *Lg* measurements using BRVK data yields a standard deviation of only 0.045 magnitude units.

INTRODUCTION

In this study, we used vertical component digital seismograms from five Lop Nor underground explosions (magnitude 4.7 - 6.2) recorded on short-period seismographs at BRVK. Epicentral distances ranges from 1879 to 1894 km with a mean distance of 1884 km (Table 1). Four explosions records on SKM-3 high-gain channel of STsR-SS seismograph and an explosion record on KSVM low-gain channel of STsR-TSG seismograph are used for RMS *Lg* measurements. Characteristics of the STsR-SS and -TSG seismographs are given in Table 2.

The SS-SKM-3 channels use Kirnos short-period seismometers and record three-component high-gain and vertical component low-gain channels. The high-gain channels have been operating with a nominal gain of about 2000 count/μ and have nearly flat response to ground displacement in the frequency band 0.8 - 3.3 Hz (3 dB level). This high-gain vertical channel provides good regional signals with frequencies up to about 3-4 Hz for most of the underground explosions from the Lop Nor test site (Fig. 1). The KSVM channel of the TSG seismograph has similar characteristics as SS-SKM-3 channels, but has only low- and high-gain vertical components.

METHOD

To measure the RMS *Lg*, we followed a procedure similar to Hansen et al. (1990), except that we used a gaussian window instead of the usual box-car window. Noise in the signal is corrected as suggested in Ringdal & Hokland (1987) by taking RMS values of the trace (50 sec window) preceding the first arrival *P*-wave. *Lg* signal-to-noise ratios were about 2.5 to 92.

We used a gaussian with width σ_{ref} = 45 s at a reference distance, Δ_{ref} = 1000 km. This gaussian window ($\pm\sigma$) covers the *Lg* phase in group velocity range 3.66 to 3.0 km/s when centered at the group velocity around 3.3 km/s. The gaussian is truncated at 2.58σ (99 % of unit area). The width of the gaussian can be conveniently scaled as a function of distance, $\sigma = \sigma_{ref} * \Delta/\Delta_{ref}$, allowing the RMS *Lg* measurements at many stations at different epicentral distance ranges to be combined to obtain a network $m_b(Lg)$ based on the RMS *Lg* measurements. The successive gaussian windows were shifted by 0.2 σ relative to the previous window to sample the *Lg* waves smoothly. The *Lg* signals are not corrected for the geometrical spreading and anelastic attenuation along the path because all explosions are at nearly the same location.

RESULTS

Fig. 2 shows the $\log_{10}$ of RMS *Lg* measurements in nanometer of ground displacement plotted against ISC $m_b(P)$. Regression of ISC $m_b(P)$ against $\log_{10}$ (RMS *Lg*) for five explosions in the magnitude range 4.7 - 6.2 yields a slope of 0.98 and a standard deviation of only 0.045 magnitude units. It appears that BRVK data is useful to measure source strength of Lop Nor explosions for explosions with magnitude down to about $m_b(P) \approx 4.5$. Examination of all available GSN (Global Seismograph Network) digital seismograms for 13 known underground explosions during 1976-1992 at Lop Nor indicates that BRVK provides unique regional data for RMS *Lg* studies.

Table 1. **Lop Nor Underground Explosions**(*)

Origin time		Latitude	Longitude	ISC Magnitude				$\log_{10}$(RMS *Lg*)	S/N
Year Mon Day	(h: m: sec)	(°N)	(°E)	(m_b)	#	(M_S)	#	(nanometer)	
1983 OCT 06	09:59:58.0	41.53	88.72	5.5	73	4.2	2	1.3907	13.7
1984 OCT 03	05:59:57.9	41.54	88.67	5.4	81	-		1.1956	10.8
1984 DEC 19	06:00:02.8	41.62	88.22	4.7	11	4.2	1	0.6236	2.5
1987 JUN 05	04:59:58.5	41.55	88.72	6.2	145	4.7	5	2.1385	92.3
1990 AUG 16	04:59:57.7	41.52	88.75	6.2	138	4.4	17	2.1008	67.4

(*) Origin time, location and magnitudes are from ISC bulletin; S/N=signal-to-noise ratio.

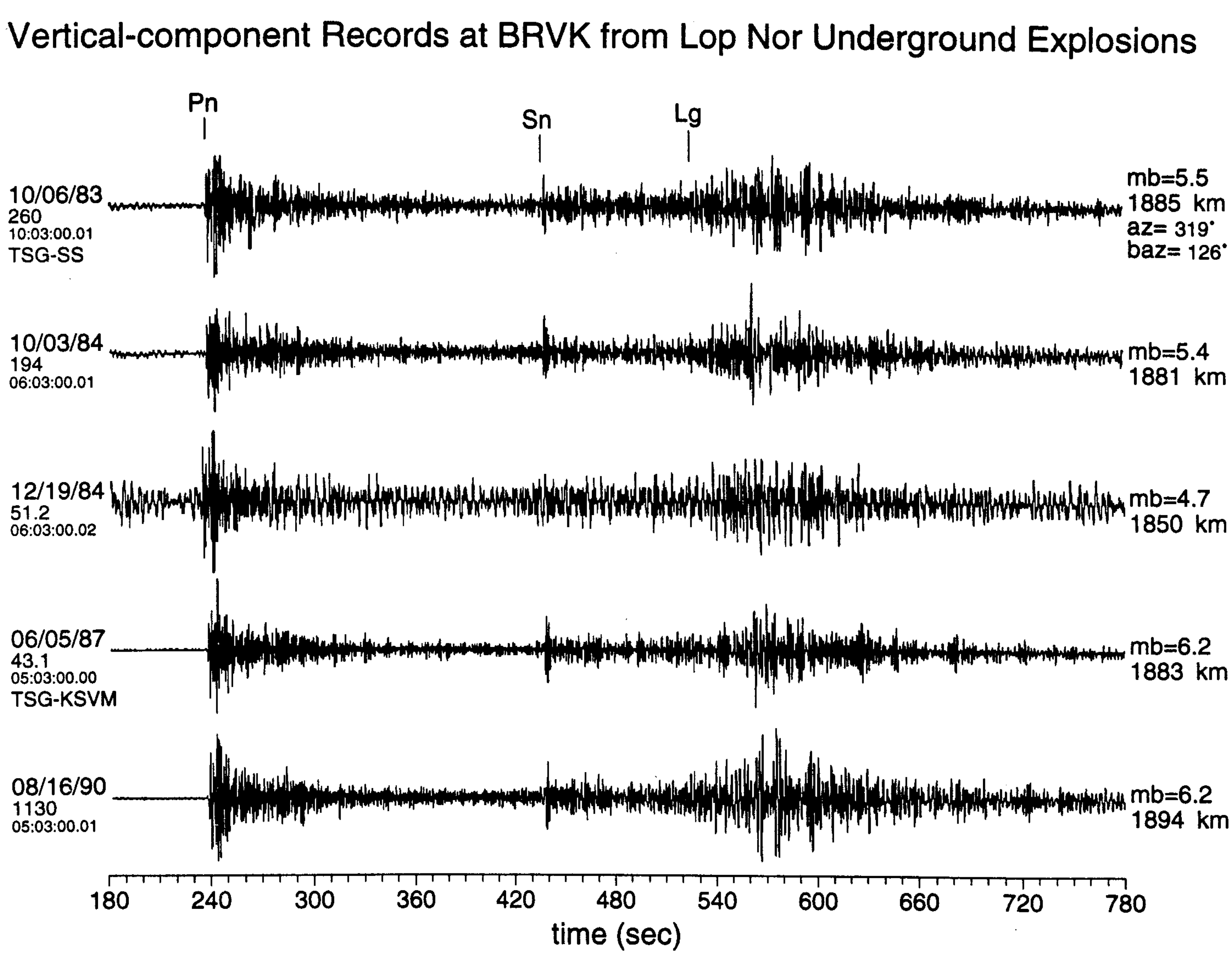


Fig. 1. Vertical component records (SS-SKM-3) recorded at BRVK from Lop Nor explosions.

The RMS measurements of *P* waves are also obtained following a similar procedure used for *Lg* signals to examine the stability of the method for the *P* signals. Regression of ISC $m_b(P)$ against $\log_{10}$ (RMS *P*) values at BRVK for six explosions in the magnitude range 4.7 - 6.2 yields a slope of 1.03 and a standard deviation of 0.065 m. u. Though this result is preliminary in nature, it indicates that RMS *P* wave signals may provide an alternative tool for measuring the strength of the seismic source when the records have only *P*-wave portion of triggered data.

Table 2. **Characteristics of STsR Seismographs at Borovoye Seismic Station(*).**

Seismograph	Seismometer	Data channel	T_s(a) (s)	D_s(b)	S_m(c) (unit/μ)	f_m(d) (Hz)	dt(e) (msec)	Channel(f) number
STsR-SS	SKM-3	High-gain	2.0	0.5	2000	0.8-3.3	24	7,8,9
		Low-gain (Z)†			200		32	1
					20		96	6
	SKD	High-gain	25.0	0.5	5.0	0.05-0.4	192	2,3,4
		Low-gain			0.5		192	1,5,10
STsR-TSG	KS		1.5	0.7	4500	1.0-3.3	26	7,8,9
	DS		20.0	0.5	50	0.05-0.2	312	19,20,21
	KSM	High-gain	1.5	0.35	100000	0.7-5.0	26	10,11,12
		Low-gain			1000		26	3,4,5
	DSM	High-gain	28.0	0.5	1000	0.04-0.1	312	22,23,24
		Low-gain			10		312	15,16,17
	KSVM	High-gain (Z)	1.5	0.35	4600	0.8-2.5	26	2
		Low-gain (Z)			50		26	1

(*) STsR system from Feb 1973 to present, (a) T_s=Seismometer natural period in second, (b) D_s=Seismometer damping constant, (c) S_m=Nominal gain in count/μ, (d) f_m=passband (90 % of peak), (e) dt=Sampling interval in millisecond, (e) Channel identifier, † Only vertical component .

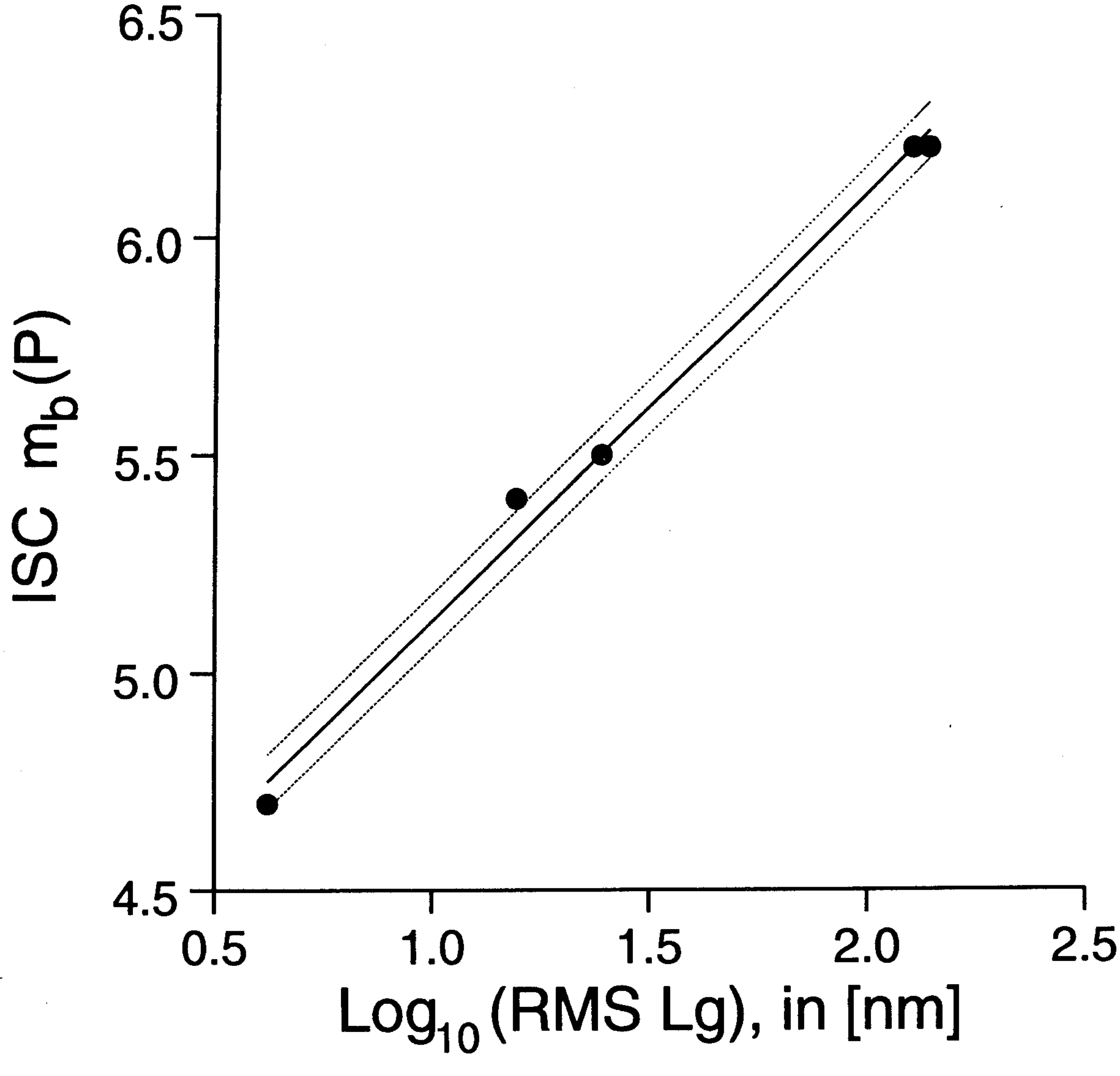


Fig. 2 Comparison of $\log_{10}$ of RMS *Lg* (in nm) at BRVK with ISC $m_b(P)$. Solid line is a fitted slope of 0.98 and an orthogonal rms misfit of 0.045 m. u. Dotted lines correspond to ±2 S.D.

CONCLUSIONS

The regional seismic data now becoming available for Central Asia, digitally recorded at Borovoye, Kazakhstan, appear to be useful to measure source strength of Lop Nor explosions for explosions with magnitude down to about $m_b(P) \approx 4.5$.

Instrument calibration (gains) of various seismographs at Borovoye station appear to be stable over many years. Stability of *Lg* amplitudes for explosions at the Lop Nor test site over several years suggests reasonable instrument calibration. The broadband nature of BRVK digital records provides an opportunity to examine seismic velocities and discontinuities in the upper mantle beneath Central Asia. In these conclusions, the common theme is new opportunities to work with high-quality regional signals for Central Asia recorded at BRVK. We recommend a concerted effort by academic institutions to ensure timely salvage of these valuable seismic data.

REFERENCES

Adushkin, V. V. and V. A. An, Seismic observations and monitoring of underground nuclear explosions at Borovoye Geophysical Observatory, *Izvestiya Akademii Nauk SSSR*: Fizika Zemli, 47-59, **No. 12**, 1990.

Hansen, R. A., F. Ringdal and P. G. Richards, The stability of RMS Lg measurements and their potential for accurate estimation of the yields of Soviet underground nuclear explosions, *Bull. Seism. Soc. Am.*, **80**, 2106-2126, 1990.

Richards, P. G. & G. Ekström , Report of a visit to the Borovoye Geophysical Observatory (seismic station BRV) in Kazakhstan, Technical Report No. 1 for DARPA/NMO, 18 September 1991.

Richards, P. G., W. Y. Kim and G. Ekström, The Borovoye Geophysical Observatory, Kazakhstan, *EOS*, **73**, 201-206, 1992.

Ringdal, F. and B. Kr. Hokland, Magnitudes of large Semipalatinsk explosions using P coda and Lg measurements at NORSAR, in Semiannual Technical Summary, NORSAR Sci. Rept. 1-87/88, NTNF/NORSAR, Kjeller, Norway, 1987.

INSTRUMENT RESPONSES OF DIGITAL SEISMOGRAPHS AT BOROVOYE, KAZAKHSTAN BY INVERSION OF TRANSIENT CALIBRATION PULSES

Won-Young Kim[1] and Göran Ekström[2]

[1]) Lamont-Doherty Earth Observatory of Columbia University,

[2]) Department of Earth and Planetary Sciences, Harvard University

EXTENDED ABSTRACT

A method is developed to determine the response of digital seismographs from their transient calibration pulses when there is no recourse to direct measurements. Based on linear system theory for small input signal, the digital seismograph is represented by a set of first- and higher-order linear filters characterized by their cutoff frequency and damping constant. The transient calibration pulse is parameterized by a set of instrument constants, and the problem is linearized for small perturbation with respect to their nominal values. The calibration pulse shape is matched in the time domain using an iterative linearized inverse technique.

The method is used to derive complete instrument responses for digital seismographs operating at the Borovoye (BRVK) in Kazakhstan, for which previously only the amplitude responses have been determined. To test the method, we apply it to digital calibration pulses from a modern digital seismograph system at Kislovodsk (KIV) in northern Caucasus, Russia, and obtained good agreement between known and derived instrument constants. The results of the calibration pulse shape inversion for these seismographs indicates that the method is efficient and that the results are reliable even when microseismic noise is present in the recorded transient calibration pulse. The derived parameters make possible improved quantitative waveform analysis of digital seismograms recorded at BRVK.

In this extended abstract, we present only summary tables (Table 1 & Table 2) and a figure for the STsR-TSG seismic system which operated since 1973 at BRVK. The full text with figures and tables will appear in February 1996 issue of the *Bulletin of the Seismological Society of America.*

Table 1. Characteristics of STsR-TSG Seismic System at Borovoye Seismic Station(*).

Seismograph	Data channel	T_S (a) (s)	ξ_S (b)	Gain (c) (count/μ)	f_n (d) (Hz)	dt (e) (msec)	Channel (f) number	Vaild (g) date
KS		1.5	0.7	2250	1.5	26	7,8,9	07/23/76 -
		1.5	0.7	4500	1.5	26	7,8,9	03/24/82 -
DS		20.0	0.5	50	0.1	312	19,20,21	07/12/74 -
KSM	HG (h)	1.5	0.35	100000	1.0	26	10,11,12	11/01/81 -
	LG (i)			1000		26	3,4,5	
DSM	HG	28.0	0.5	1000	0.07	312	22,23,24	09/08/82 -
	LG			10		312	15,16,17	
KSVM	HG (Z)†	1.5	0.35	4600	1.0	26	2	12/12/83 -
	LG (Z)†			50		26	1	

(*) STsR-TSG system from Feb 1973 to present, (a) T_S = Seismometer natural period in second, (b) ξ_S = Seismometer damping constant, (c) Gain = Nominal gain in counts/μ, (d) f_n = normalization frequency where the nominal gain is measured, (e) dt = Sampling interval in millisecond, (f) Channel identifier on the original station tape, (g) dates when the responses given are valid, (h) High-gain channel, (i) Low-gain channel, † Only vertical-component.

Table 2. Instrument constants of the STsR-TSG seismographs from inversion*.

	Seismometer		High pass		Low pass	Rms fit	Actual gain	f_n	Channel number
	T_s (sec)	ξ_s	f_H (Hz)		f_L (Hz)		(counts/μ)	(Hz)	
					KS[(a)] (07/23/76 -)				
			f_{H1}		f_{L1}				
Nominal	1.500	0.70	0.77		5.00	17.272	2250	1.5	7
Z	1.646 (+9.8%)	0.591 (-15.6%)	1.18		4.00	8.562	2240	1.5	7
NS	1.495 (-0.3%)	0.588 (-16.1%)	1.16		4.00	8.263	2279	1.5	8
EW	1.622 (+8.1%)	0.583 (-16.7%)	1.18		4.00	9.891	2183	1.5	9
					KSM[(b)] (11/01/81 -)				
			f_{H2}	ξ_{H2}	f_{L2}				
Nominal	1.500	0.350	0.650	0.707	8.00	34.521	100000	1.0	10
Z	1.481 (-1.4%)	0.332 (-5.4%)	0.630	1.042	8.13	1.249	100576	1.0	10
NS	1.515 (+1.0%)	0.345 (-1.4%)	0.636	1.049	8.47	1.781	97891	1.0	11
EW	1.520 (+1.3%)	0.349 (-0.3%)	0.644	1.034	8.77	2.365	99279	1.0	12
					KSVM[(c)] (12/12/83 -)				
			f_{H2}	ξ_{H2}	f_{L3}				
Nominal	1.50	0.350	0.667	0.707	5.00	22.640	4600	1.0	2

Table 2. Continued.

Z	1.49 (-0.6%)	0.356 (-1.7%)	0.671	1.056	5.29			7.828	4626	1.0	2
			DS (12/01/83 -)								
			f_{H2}	ξ_{H2}	f_{L1}	f_{L2}	ξ_{L2}				
Nominal	20.00	0.50	0.029	0.71	0.50	0.57	1.00	43.320	50.0	0.1	19
Z	20.10 (+0.5%)	0.60 (+20%)	0.027	0.79	0.49	0.49	0.77	5.763	48.29	0.1	19
NS	19.13 (-4.4%)	0.50 (+0.6%)	0.027	0.77	0.50	0.49	0.78	6.552	46.78	0.1	20
EW	19.49 (-2.6%)	0.53 (+5.7%)	0.028	0.75	0.52	0.57	0.91	6.130	46.32	0.1	21
			DSM[d] (09/08/82 -)								
			f_{H1}	f_{H1}	f_{L3}						
Nominal	28.00	0.50	0.017	0.033	0.125			10.630	1000	0.07	22
Z	26.58 (-5.3%)	0.48 (-3.4%)	0.018	0.029	0.130			1.600	992	0.07	22
NS	29.43 (+5.1%)	0.52 (+4.0%)	0.016	0.029	0.130			2.932	1001	0.07	23
EW	27.13 (-3.1%)	0.49 (-2.6%)	0.018	0.030	0.130			4.015	1002	0.07	24

* For each seismograph, date is indicated for which the instrument response listed is applicable;

(a) Calibration pulses recorded on 10/14/78 and on 02/04/80 are used. Nominal gain during 07/23/76 - 01/30/82 was 2,250 counts/μ, and the nominal gain since 03/24/82 - present is 4,500 counts/μ;

(b) KSM low-gain channels have identical responses, but with lower gains of Z (3) = 982, NS (4) = 1002, EW (5) = 995;

(c) KSVM low-gain channel has identical response, but with a lower gain of, Z (2) = 46.15;

(d) DSM low-gain channels have identical responses, but with lower gains of, Z (15) = 10.0, NS (16) = 9.9, EW (16) = 10.0.

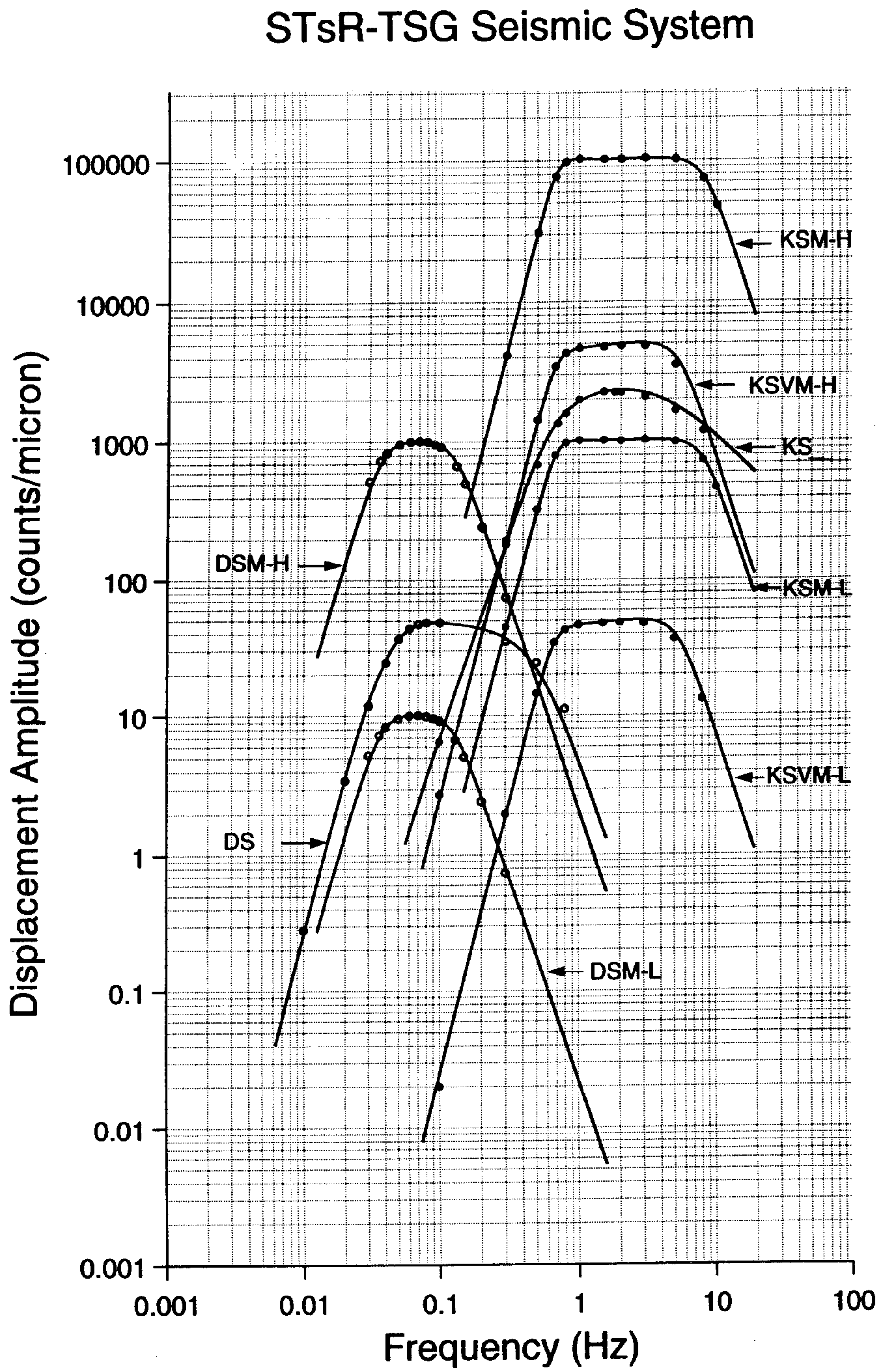


Fig. 1. A summary figure showing spectral amplitude responses of the all vertical-component seismographs of the TSG system. In each seismograph, frequency-amplitude responses given in the log book at BRVK (*closed circles*) and the amplitude responses obtained after the calibration pulse waveform inversion (*solid lines*) are plotted together for comparison.

A STUDY OF SMALL EXPLOSIONS AND EARTHQUAKES DURING 1961-1989 NEAR THE SEMIPALATINSK TEST SITE, KAZAKHSTAN

Vitaly I. Khalturin[1], Tatyana G. Rautian[1], and Paul G. Richards[2]

[1]Institute of Physics of the Earth, Russian Academy of Sciences, Moscow
[2]Lamont-Doherty Earth Observatory, Palisades, NY 10964,
and Dept. of Geological Sciences, Columbia University

ABSTRACT

Several Russian sources have stated that 343 underground nuclear explosions were conducted during 1961-1989 at the Semipalatinsk Test Site. However, only 282 of them appear to have been described, in the openly available technical literature, with well-determined coordinates; and only 272 have both good locations and magnitudes.

We have used regional data from 52 stations to study 65 seismic sources initially thought to be in or near the Semipalatinsk region, additional to the 272 underground nuclear explosions with known locations and magnitudes. Of these 65 events, we believe 8 are not explosions on the test site, namely: two earthquakes close to the test site (one of them, on March 20, 1976, was previously well-known); three earthquakes or chemical explosions 100-300 km from the test site; and three events at greater distances from Semipalatinsk. Of the remaining 57 events: 10 were known to be underground nuclear explosions with known locations and we have supplied magnitudes where none were previously available; one was a chemical explosion at Degelen (June 5, 1961, a few months prior to the first Soviet underground nuclear explosion); we believe 21 were underground nuclear explosions (20 at Degelen, one at Murzhik); 13 were chemical explosions at Balapan; 8 were chemical explosions elsewhere on the test site; three were either nuclear or chemical explosions; and one was either a chemical explosion or a cavity collapse.

Our seismological data is principally of two types: (1) the bulletins of stations in Central Asia, Kazakhstan and the Altai; and (2) the multi-channel narrowband analog records (ChISS) of the station at Talgar, operated throughout the time period 1961-89, together with other ChISS stations at Garm, Zerenda, and Novosibirsk, operated for part of this time. The largest magnitude of our 44 possible underground nuclear explosions is around 5 (February 4, 1965, obscured at many teleseismic stations by a large Aleutian earthquake). Others lie in the magnitude range 3.5-4.5, and clearly most have subkiloton yields.

Our data set of small events is important for purposes of evaluating the detection capability of teleseismic arrays, and the detection and identification capability of regional stations.

INTRODUCTION

This paper reports our practical experience in documenting the occurrence of small underground nuclear explosions and large chemical explosions at the main nuclear weapons test site of the U.S.S.R., near Semipalatinsk, Kazakhstan.

We have worked with five sources of information. First, are the various lists of explosions published by western scientists based upon teleseismic observations. Second, are lists of Soviet explosions and summary statements on total numbers of such explosions, published by Russian sources. We find that teleseismically observed events appear to be only about 90% of the total. Some of the teleseismically observed events are poorly located, or have not been assigned a magnitude, or appear on explosion lists that incorrectly include earthquakes. It appears that less than 80% of the underground nuclear explosions conducted at the Semipalatinsk Test Site have good locations and a magnitude, determined and published on the basis of teleseismic data. Third, we have used our experience in the analysis of data recorded at the Talgar station on a day-to-day basis, and at stations on the Kokchetav massif (Zerenda, Borovoye). Fourth, we used regional seismic data from 49 other stations in Kazakhstan, Kyrgystan, Russia, Tadjikistan and Uzbekistan, most of them operated at distances of less than 1000 km from the Semipalatinsk Test Site in East Kazakhstan. Fifth, we have used personal communications from western seismologists (Frode Ringdal, Peter Marshall, Jack Murphy, Bob North) giving us information based for the most part on teleseismic data from particular events.

Our goals were to reduce the discrepancies between explosion lists generated from teleseismic data and numbers of events reported by Russian sources, and thus to develop a more complete list of Soviet nuclear explosions; and to document some strengths and weaknesses of teleseismic and regional data for purposes of explosion detection and identification. More fundamentally, we wanted to build a database of small seismic events, so that efforts can be focussed on solving the hardest technical problems of monitoring a Comprehensive Test Ban Treaty, namely how to identify underground nuclear explosions that have very small seismic signals – and how to avoid false alarms over small events. This work is complicated in the case of seismic events near Semipalatinsk, by the fact that 75 chemical explosions have been carried out on the test site, according to Saybekov (1993), including 44 chemical explosions larger than ten tons that have been conducted during the period 1970-1988.

Our database so far, as reported in this paper, consists of numerous station reports and analog seismograms that we have analysed ourselves. We often relied upon methods of discrimination that cannot in general be used in CTBT monitoring (for example, the interpretation of the time of day at which the event occurred). However, we believe we have identified a suitable set of small events (both explosions and earthquakes), on and near the Semipalatinsk Test Site, that may be an important focus for future work. That is, we anticipate further efforts to acquire data for these events, preferably digital data, recorded at teleseismic and regional distances, in order to test objectively the capability of various detection and discrimination algorithms. In such future work we could digitize some of the analog data reported here, or we could hope to use digitally recorded data from Borovoye since 1965 (at a distance about 700 km), some digital data acquired by the Natural Resources Defense Council in 1987-1988 (at distances about 200 km from the test site), and, since 1988, IRIS/IDA digital data (at distances more than 1000 km).

SOURCES OF INFORMATION ABOUT SMALL EVENTS

In this section, we first summarize the information contained in a series of papers published in the West, concerning numbers of underground nuclear explosions (UNEs) that have occurred at the Semipalatinsk Test Site in Kazakhstan, and for which accurate locations and magnitudes are both available. We then briefly summarize additional information made available in recent years by various Russian and Kazakh sources, which indicates that a significant number of UNEs at Semipalatinsk have not been previously recognized in western publications. The section concludes with a list of 65 events which are the main focus of attention in this paper, being candidates for the additional UNEs, and/or UNEs with previously unknown locations or magnitudes, or perhaps earthquakes or chemical explosions in the region.

Table 1 gives the information available on 282 known UNEs at the Semipalatinsk Test Site. Our primary sources of information on locations comes (1) from Bocharov et al (1989), who published origin time, depth, latitude and longitude on 96 UNEs prior to 1973; and (2) from Lilwall and Farthing (1990) who used the Bocharov et al locations as master events for a joint epicentral determination of other UNEs at Semipalatinsk, using *P*-wave arrival times as reported by the ISC. The Lilwall and Farthing seismically determined locations were given to the nearest thousandth of a degree (five significant figures). The "area" entry in Table 1 is the area of the error ellipse given by Lilwall and Farthing (blank entries signify events given a location to the nearest tenth of a second of arc by Bocharov et al: such locations are listed in Table 1 with seven significant figures). An event of 1984 September 15, presumed to be a UNE located at 49.992 °N, 78.881 °E by Lilwall and Farthing, was apparently a chemical explosion at Balapan. The event of 1968 November 12 was a triple explosion (Bocharov et al) so we have counted it three times.

Table 1 also indicates the subsite (B = Balapan, D = Degelen, M = Murzhik); the ISC *P*-wave magnitude, where available; the number of stations upon which the ISC magnitude is based; the number of stations reporting dilatations and the number reporting polarity; and the number of stations reporting arrival times to the ISC. Other magnitudes in Table 1 include the *P*-wave magnitude for many Balapan UNEs reported by Ringdal et al (1992), which is a maximum likelihood value derived by the British Atomic Weapons Establishment (AWE); a *P*-wave magnitude also obtained by AWE for many Degelen and Murzhik UNEs (personal communication to Richards – these magnitudes have four significant figures) but which is not maximum likelihood; and an *Lg*-wave magnitude for many Balapan events reported by Ringdal et al (1992). Finally, the *Lg*-wave magnitude for two Balapan events (1980 April 25, and the large event of 1980 September 14) is given by Richards and Shi (1994), who digitized high quality *Lg* recordings from the station WMQ and calibrated RMS *Lg* measurements at WMQ in terms of the NORSAR *Lg* magnitude scale.

Note in Table 1 that there are ten events (reported by Bocharov et al, 1989) for which no magnitude information is listed. Thus, the Table gives locations for 282 UNEs (100 at Balapan, 157 at Degelen, 25 at Murzhik), and magnitude information for only 272.

In recent years, several Russian and Kazakh sources have published information on the total number of UNEs conducted at Semipalatinsk from the first event on 1961 October 11, to the last on 1989 October 19 prior to the break up of the U.S.S.R. and the closing down of this test site. For example, Mikhailov et al (1992) state that 343 UNEs were conducted at the Semipalatinsk Test Site. And van der Vink et al (1992, their Figure 6) give the number of UNEs in each year at this test site, the total coming to 343.

Figure 1 shows a histogram comparing the number of events per year from Table 1, with the number indicated by van der Vink et al. Such a comparison should be associated with several caveats, since it is not always clear what constitutes a "nuclear test" for counting purposes. For example, if three nuclear devices are shot at the same time in the same shaft, would that count as one or three tests? (It would be counted as one test according to the definition of a nuclear test under the verification protocol to the Threshold Test Ban Treaty, and there would be only one test apparent from seismic signals.) If a nuclear test explosion was initiated but did not result in significant nuclear yield, then there would typically be no seismic signal – yet for some purposes this would be counted as a nuclear test. (A successful one-point safety test would have these latter characteristics, as would a "fizzle" – a device that failed to attain even a small fraction of its design yield. Several of the UNEs conducted in the early years of testing at the Nevada Test Site have announced yields of either zero or less than a ton of TNT equivalent.) Note in Figure 1 for 1984 that there is one more UNE in the total of claimed explosions (based on Table 1), than in the total given by Russian sources: perhaps one of the claimed events is a chemical explosion. Finally, the number 343 for Semipalatinsk may refer to nuclear weapons tests only, when at least some of the explosions at this test site have been described in Soviet literature as part of the Peaceful Nuclear Explosion program. Nevertheless, the number reported from teleseismic observations (the 282 reported in Table 1) appears to be significantly lower that the 343 now reported as the total carried out at Semipalatinsk, and this difference was a stimulus for our project reported here.

The location of the test site itself appears not to have been shown accurately in any publication available in the western literature. But when the Threshold Test Ban Treaty entered into force in December 1990, the Soviet Union and the United States formally exchanged information on the boundaries of their respective test sites. The extent of the Semipalatinsk Test Site was then specified (a) by a list, given to the U.S., of the locations of 152 posts on the test site boundary, and (b) by a map, now held in the U.S. State Department Treaty Library. There are some slight discrepancies between (a) and (b), but the map (b) is presumably definitive and was used to prepare the illustration of test site boundaries shown in Figure 2.

In order to begin a systematic program of data acquisition for other seismic events that might or might not be UNEs at Semipalatinsk, or that were relevant to a program of research into regional discriminants for the area, we first made a list of all the seismic events for which we would seek additional information. The list appears here as Table 2, giving dates, sources of information, and approximate times, locations, and magnitudes (if available) for 65 events. It includes the 10 events in Table 1 that lack magnitude information. It includes 24 events pointed out by Sykes and Ruggi (1989) and claimed by these authors to be UNEs, that are located only approximately, since often the Large Aperture Seismic Array (LASA) in Montana was their only source of teleseismic data for small events.

(Their list also includes most of the events in Table 1.) The sources of information for Table 2 are as follows:

- Boch. = Bocharov et al (1989), 10 UNEs with no reported magnitude;
- H.R.R. = Hansen, Ringdal and Richards (1990), who incorrectly listed the event of 1988 September 26 as a UNE;
- Ring. = personal communication from Frode Ringdal, who sent us event magnitudes and estimated origin times for several events as detected by NORSAR or NORESS;
- Ring.(90) = Ringdal (1990), who describes teleseismic data for the small announced UNE of 1988 December 28;
- Sult. = Djamil Sultanov (personal communication), who informed us that the event of 1988 September 26 was not a UNE;
- S&R = Sykes and Ruggi (1989);
- V.An = Vadim An (personal communication), whose information was usually based upon data recorded at the Borovoye Geophysical Observatory;
- V.Kh. = The working notes of Vitaly Khalturin, based on observations made in Central Asia prior to working on this paper.

STATIONS AND INSTRUMENTATION

Our procedure was to study the 65 events of Table 2 using the seismological data from local networks receiving regional seismic waves from the Semipalatinsk Test Site. We wanted to determine event locations and magnitudes, and to get some evidence about their nature (whether UNE, earthquake, or chemical explosion).

We used readings of records from stations installed by the Complex Seismological Expedition of the Institute of Physics of the Earth, of the Russian Academy of Sciences. Part of this data was obtained from permanent stations GRM, NSB, TLG, and ZRN. Most of the Expedition's stations were temporary, each working for about 2 years. Also we have used the arrival times from bulletins of permanent stations in Central Asia, Kazakhstan and Altai, and in some cases from the digital station at Borovoye (station BRV: see Richards et al, 1992). Table 3 lists the 52 stations we used, and Figure 3 shows a station map.

The basic characteristics of the five different types of instruments that we used were as follows:

Type	T_1— T_2 seconds	Magnification
SKD	0.2 — 18	(1 — 1.5), K
SKM	0.1 — 1.4	(30 — 60), K
RVZT	0.2 — 1.2	(0.1 — 0.3), M
KSE	0.7 — 1.1	(0.5 — 1.0), M
ChISS	multichannel 0.022 — 40	-

T_1 and T_2 here are the periods at which the response is down to half the power of the peak response. Most stations were equipped with the standard short-period instrument known as SKM, which records displacement in a quite wide band (0.7-10 Hz). Their records or the bulletins were used to calculate epicentral distances and origin time as discussed below. Some of the stations listed in Table 3 also have the broad band instrument SKD, and some had the RVZT instrument. A few stations had the very high gain narrow-band KSE instrument. All four of these seismometers consist of a coupled inertial sensor/galvanometer sensor/velocity pickup, and can be described by the standard equations for such systems (see for example Aki and Richards, 1980, equation 10.63; or, equation 10.64 since coupling is negligible). Their displacement responses are shown in Figure 4a. It may be a surprise to some western seismologists that it is possible to achieve such a flat response to displacement (e.g. for SKM and SKD) in an instrument with a coil that provides a voltage proportional to velocity. The way the desired result is achieved, for the SKD instrument, is to have a strongly overdamped galvanometer (e.g. T_{gal} = 1 s, ε_{gal} in the range 4 to 6) and an underdamped inertial sensor (e.g. T_s = 20 s, ε_s in the range 0.4 to 0.45), with only a small amount of coupling (less than 0.1).

The fifth instrument we used is known by its Russian acronym, ChISS, and such data were obtained from 4 stations: TLG, NSB, ZRN and GRM. ChISS was designed by Zapolskii (1960, 1971) and is described by Zapolskii and Khalturin (1960), Rautian and Khalturin (1978), and Rautian et al (1978). The vertical component was analyzed. In this instrument, the signal from the seismometer, proportional to the velocity of ground motion, is passed through a system of narrow bandpass filters and recorded on photographic paper or by ink-recorder. Thus the amplitudes on each record are proportional to the velocity of ground motion in a particular frequency band. ChISS system at GRM and TLG stations have as many as 16 channels. We used data mostly from 8 channels in the range from 0.3 to 40 Hz. For a large event, (with magnitude 5 and more) the Rayleigh wave is strong enough to see, and in that case we widened the frequency range studied to 0.05 Hz to include long periods. The bandwidth of ChISS channels Δf is proportional to their central frequencies, f_c:

$$\Delta f = k f_c$$

The parameter k is equal 0.7 in the long-period part of the frequency range, 0.48 in the central part from 0.3 to 10 Hz, and 0.22 for high-frequency channels, where f_c values are 18, 27 and 40 Hz. Figure 4b (upper) shows the ChISS spectral amplitude response for an 8-channel system. The roll-off on either side of each peak is very steep. Figure 4b (lower) shows the impulse response for four channels. Note that time runs from right to left, a common convention in Russian seismograms.

Each channel was calibrated daily by driving the pendulum at constant velocity amplitude and very slowly decreasing frequency. The response of this calibration signal recorded directly on the seismogram has an envelope identical to the amplitude-frequency response curve. The maximum amplitudes of response usually correspond to 1 μm/s (i.e. one micron/second) of velocity of ground oscillation. This system lets us get the frequency-dependent content as well as the time-dependent content of each seismic wave. In kinematic studies we can choose the channel where the wave arrival looks most sharp and clear, to measure the time arrival more accurately. Figure 5a is an example of a ChISS record showing six channels (each with its calibration signal - in this case with maximum amplitude corresponding to 0.5 μm/s) with data for the UNE of 1976 December 30 at Degelen. Again, note that time runs from right to left in each channel. This example of ChISS data recorded at a distance of 730 km shows several different regional phases, as we discuss in the section below. Figure 5b shows six channels of a Talgar ChISS record of the Degelen explosion of April 21, 1976. Five minutes after this explosion, there was a Balapan explosion of similar magnitude, for which the Talgar ChISS record is shown in Figure 5c. Detailed examination of Figs 5b and 5c shows that different regional phases recorded at Talgar are excited to a slightly different degree by Degelen and Balapan explosions.

REGIONAL PHASES IN CENTRAL ASIA AND KAZAKHSTAN

Several different regional phases are seen at distances from 0 to 1400 km from the Semipalatinsk Test Site.

At distances up to about 240 km the main regional phases are $\bar{P}$ and $\bar{S}$. Their velocities are 6.2 and 3.54 km/s respectively. Beyond 230-250 km the *Pn* wave appears as a first arrival. This wave has stronger high-frequency spectral content than all other regional waves.

As shown by Nersesov and Rautian (1964), the *Pn* wave is not simple. It consists of 2 or 3 waves. Each successive wave appears as a later arrival, with amplitude larger than the previous one. As distance increases, the Pn_2 time arrival moves closer to the first arrival and amplitudes of Pn_2 decrease. We do have not a good range of distances with the data of this paper to see this picture clearly. We can say only that the interval of distances where we observe Pn_2 is small - between 500 and 750 km. Pn_2 is observed at some stations, but not at each of them.

At TLG the Pn_2-wave arrives about 8-10 s later then Pn_1 and has a larger amplitudes (2-5 times). Examples can be seen in Figures 5abc (the phases marked P_1 and P_2). At ZRN the amplitudes of Pn_2 are small. At NSB (all three stations are near the same distance from the test site), Pn_2 is absent. The Pn_1 amplitudes attenuate up to 1600-1800 km, and then increase with distance, presumably due to a deep mantle arrival (which, however, is a continuation of the straight-line Pn_1 travel-time curve, with only a slight increase in phase velocity). The amplitude behavior is strongly different depending on the direction of wave propagation from the Semipalatinsk Test Site. At the East direction amplitudes decrease with distance steeper and then, after 1600-1800 km, increase sharper, than in the West direction.

The *Pg* wave can be observed up to distances of about 700-800 km. The *Pg* arrival is impulsive at distances 250-400 km. Its amplitudes are more than *Pn* (5-10 times). But beyond 500 km *Pg* looks like a group of low-frequency waves with an emergent arrival. Its amplitudes are of the same order as *P*-coda amplitudes, increasing gradually with lapse time.

The *Sn* wave diverges from *Lg* near 280 km. It can be seen clearly only on 40-50% of the records. If the propagation path is through the shield, *Sn* is stronger and can be seen better then in an orogenic area. In the shield it has nearly the same high-frequency spectral content as *Pn*.

Beyond 1200-1400 km the *S* wave appears about 20-25 s later then the *Sn* wave (unlike the relation between *Pn* and *P*, for which there is no time offset). This is the *S* wave, with phase velocity 5.7 km/s pointed out in J-B tables. It arrives clearly after 1400-1500 km. Its spectral content is much more low-frequency, than that of *Sn*. At Garm (1350 km from the test site) one can observe both *S* and *Sn* on the records from Semipalatinsk. The regional variations in travel time of *Sn* and especially for *S* at 1300-1500 km are very large: up to about 8 s.

Before the *Lg* wave arrival we sometimes find the low-frequency wave called *Li*.

At all the distances under consideration the dominant wave is *Lg*. It appears to consist of several groups, from which we can identify arrivals that we call Lg_1 and Lg_2. The Lg_1 arrival is impulsive, whereas Lg_2 is emergent, with increasing amplitudes within a long group of interfering *Lg* oscillations.

The final recognizable wave is a Rayleigh wave, *Rg*, but if the magnitude of the explosion is less then 4, the signal-to-noise ratio is too small for this wave to be seen. This point requires some discussion. Thus, the terminology here implies a dispersive wave, but in practice there is little surface wave dispersion over paths extending less than 500 km from Semipalatinsk: periods from about 5-6 s, up to 25-30 s, are superimposed. The maximum amplitude of *Rg* for an explosion recording appears to have a period of about 5 to 6 s: for an earthquake, the period is longer. Note that for a conventional measurement of surface-wave magnitude, M_s, made from a fundamental mode 20-s Rayleigh wave at a distance where the wave is well dispersed, the difference between body-wave magnitude m_b and surface wave magnitude for a nuclear explosion is on average about 1.2. But for a measurement made around 500 km, where M_s is measured at 5 to 6 s period, the difference $m_b - M_s$ is about 0.6. However, it needs a fairly large explosion (say, $m_b >$ 4.8) for such *Rg* observations to be made.

Although we had access to some data from over 50 stations, in practice our data came mostly from about ten stations. At the other extreme, about 60% of the stations were used for only 1-3 events. The number of events for which each station was used was as follows:

Sta.	#	Sta.	#	Sta.	#	Sta.	#	Sta.	#	Sta.	#	Sta.	#
TLG	60	KRG	9	CHR	4	BOM	2	SVE	2	BAY	1	NGN	1
KZA	44	FRZ	7	NRN	4	CHGU	2	TDK	2	DZK	1	PDG	1
UKN	31	EEE	6	ORT	4	CHK	2	TGM	2	FBR	1	RYB	1
BRV	25	MDO	6	ATA	3	KBZ	2	ZRN1	2	ILI	1	TUR	1
NSB	23	PRZ	6	KRD	3	KKB	2	ABL	1	KKR	1	VED	1
KRM	16	SEM	6	UKG	3	MIX	2	ALB	1	KSU	1		
ZRN2	11	MAK	5	ULG	3	MRT	2	AND	1	KUS	1		
CHL	10	BYK	4	VOS	3	SKL	2	ART	1	MKR	1		

The availability of quiet sites in the region enables the deployment of high gain instrumentation. The RVZT and KSE records of a presumed UNE at Degelen on January 29, 1971, are shown in Figure 6ab, indicating excellent signal-to-noise, in this example with gains of 120,000 and 1,100,000.

THE TRAVEL-TIMES IN A REGION AROUND THE TEST SITE

Most of the events we have studied are small and high-gain records were not often available. Thus, in some records the Pn_1 wave cannot be found and the only arrival times that can be read are for shear waves, such as *Sn*, *Li* and/or *Lg*. So we need to use such shear wave data when calculating the epicentral distances and origin time. Earthquakes in the nearby orogenic Tien Shan region were studied by Nersesov and Rautian (1964) and Shazilov (1989), but in our case the seismic waves propagated in the Kazakh platform and we needed to obtain the travel times versus distances for this zone. For this purpose we used the data from UNEs for which the epicenters are known very accurately.

The Pn_1 velocity is practically constant up to 1200-1300 km and is 8.1 km/s, and then slightly increasing up to 8.5 km/s over the range 1300-1700 km.

The velocity of Pn_2 is 8.3 km/s.

The velocity for $\bar{P}$ as well as for *Pg* is the same, 6.2 km/s. This value is a little higher than usually observed in the Tien Shan and Pamir regions, and stays constant throughout the distance range within which these waves are observed.

Figure 7 shows the travel times for 9 different regional phases in East Kazakhstan. The following relationships between distance and arrival time are available to determine epicentral distances *D* in kilometers:

$D = 6.2 * t(\bar{P})$	0 – 240 km
$D = 3.54 * t(\bar{S})$	0 – 240
$D = 8.1 * t(Pn_1)-69$	240 – 1200
$D = 8.3 * t(Pn_2)-166$	500 – 750
$D = 6.2 * t(Pg)$	240 – 900
$D = 4.62 * t(Sn)-69$	240 – 1400
$D = 3.9 * t(Li)$	600 – 1000
$D = 3.54 * t(Lg_1)$	240 – 1400
$D = 3.4 * t(Lg_2)$	600 – 1400.

The reliability of measured arrival times for small events is poor due to the small signal-to-noise ratios, and results in a typical standard error of about 15 km when the above relations are used to estimate D. The error in estimated epicentral distances is smallest for Pn_1 and Lg_1, when D calculated from the above equations is compared with the real distances from published accurate epicenters.

DETERMINATION OF EPICENTERS

By taking the difference in arrival time between pairs of phases at a single station, and using the above relationships between distance and arrival time, we can estimate the epicentral distance from each station that has adequate data. The actual epicenter can then be found graphically as the point of intersection of circles with the stations at their centers and radius being the epicentral distance from the station. Figure 8 shows several examples. Using the data from many stations, we get an intersection point from each pair of stations. The epicenter is calculated by averaging all points of intersection, with a weight for each point, equal to the sine of the intersection angle.

If the epicenter is close to the center of the Test Site, we can simplify the calculation of epicenters, using straight lines rather than arcs of circles. To do this we choose the central point of Degelen, (49.85°E, 78.08°N), as a master epicenter and estimate the value of $\Delta D = D - D_0$ where D_0 is the distance from the station to the central point. In many cases ΔD is only a few percent of D_0. For example, for the event of 1988 December 28 we had several phases recorded at 7 different stations. The average value of ΔD, and the value of D_0, were as follows (all in km):

		ΔD	D_0
E	KSU	-4.0	219
E	SEM	4.8	171
E	UKN	-6.4	488
S	MRT	9.1	525
S	PDG	-9.6	727
S	TLG	4.2	733
W	BAY	0.7	211.

Letters E, N, S or W here indicate the direction from source to station (whether East, North, South or West). Because ΔD is so much smaller than D_0, the curvature of arcs is low and we can replace the arcs by straight lines, perpendicular to the direction from epicenter to stations.

If data were available from only 2 stations, we can get a single intersection of straight lines. The longer axis of the error area was calculated as 10 km divided by sin(az1-az2), and the minimum was taken as 10 km. The azimuth of max error was taken as the average azimuth of the pair of stations.

Several UNEs with accurate epicenters were used to check the accuracy of epicenter determination. Results are shown in Table 4. Calculations were done in 2 versions: using only Pn_1 (indicated as Pn in the Table), and using the average error in location from all waves where more than just Pn was used. In most cases the error is about 1-12 km, but for a few UNEs it is large, up to 100 km. The low accuracy can be due to error of arrival times (for some cases only bulletin data were available), and/or because stations were available only in one general direction (e.g. South) from the source. The standard deviation for an estimate of the distance, using Pn_1 for a single station, is 12 km.

One can see from Table 4 that the accuracy of epicenter location is of the same order for Pn alone, as for averaged data from all available waves. So, if Pn data of many stations are available, we need not use other waves. But for small events, when Pn is not readable on seismograms, we used all wave data available.

The list of 52 stations (see Table 3) includes 10 to the East, 1 to the North, 24 to the South, and 17 to the West. If the stations recording an event are all from only one side, (for example May 7 and Aug 19, 1966, where we had data only from the South side), then only one coordinate can be found accurately. The number of stations for which data are available varied for each event from 1 (11%), 2-4 (46 %); 5-9 (27 %) ; to 10-11 (only 8 %). For 10 events the data were obtained from stations localized only to one side, usually South or East.

DETERMINATION OF EPICENTERS

Of the 65 events studied in this paper (Table 2), 10 already have known locations (Bocharov et al, 1989). In this section we describe our first location estimates for the remaining 55 events, presenting the results in Tables 5, 6, 7, and 8 (and see also Figure 8, for 12 events). Throughout the year in which we worked on this project together at Lamont, we continued to receive additional information on arrival times for specific events at specific stations. Table 12, in a later section presenting our final results, reflects this additional information, and reports hypocentral estimates that are slightly different for some events from the results reported in this section.

Table 5 gives our first location estimates, for events that appear to be on or very close to the Semipalatinsk Test Site, and for which we have data available from more than one general azimuthal direction. These are our best located events.

Table 6 describes four events for which data were available at only one azimuth, either to the South (three events) or the East (one event). In these cases we can estimate only one coordinate, but it is consistent with a location on the test site. The estimated origin time in three of these cases is consistent with being on the exact minute (00 seconds) – further evidence that these events are explosions.

Table 7 describes six events for which data were available at only one station. The calculated epicentral distances D for two of the events are practically the same as the distance D_0 to the central point of Degelen. For four of the events, $\Delta D = D - D_0$ was as much as 10–30 km. Although we cannot find these epicenters, the data do not contradict our assumption that these events lie on the test site.

Table 8 describes three events (1967 June 3, 1967 July 16, 1981 March 31) at distances 100–300 km from the test site; and three more events that are even farther away. Thus, the event of 1980 October 26 is 1545 km from Talgar, more than twice the distance from Talgar to Degelen (733 km). The event of 1983 February 13 is 765 km from station UKN, whereas the distances from UKN to Degelen and Balapan are 488 and 425 km respectively The event of 1984 August 26, for which we have readings from two stations, lies at one of the two intersection of two circles. Both choices of epicenter lie far from the test site.

Commenting in general on this work of event location, we can say that the network of regional stations in Central Asia uncovered many events additional to those located from teleseismic data. The most important stations are those at distances less that 500 km from the Semipalatinsk Test Site. Even at 700 km, detection becomes significantly worse. The worst distances are around 1000 km. At 2000 km and beyond, amplitudes are stronger than at 1000 km, these signals coming from the deep mantle phases P and S , and teleseismic methods apply. These results about amplitude dependence on distance have been known for more than 30 years, and were well understood during test ban negotiations in the period 1960-1963. The data of Sykes and Ruggi (1989) for small events, based principally upon LASA signals, indicated that teleseismic data can be useful for detection of events with magnitude around 4 and below, but that locations based upon data from a single teleseismic array are often poor (compare Sykes' and Ruggi's locations noted in Table 2, with our locations in Tables 5-8).

DETERMINATION OF MAGNITUDES

We found there are significant differences, some of which are systematic, between the determinations of magnitude by ISC, NORSAR, and AWE (the British Atomic Weapons Establishment) for small events. The ISC and AWE magnitudes are both based upon teleseismic P-wave observations; and the NORSAR magnitude is based upon RMS Lg measurements (which usually require Semipalatinsk events to be above magnitude 5.5 in order to have an adequate signal-to-noise ratio at NORSAR, more than 4000 km away). It seems to us that the AWE determinations are preferable, especially for events with magnitudes less then 5. The differences between AWE and ISC are due to the systematic error that can follow when working with signals that are close to the noise level, since, in the ISC procedure, signals that are below the noise level are not allowed for in forming the average, so the averaged magnitude is biased high. The AWE maximum likelihood magnitude allows for the statistics of non-observation in the presence of noise. Figure 9a shows a comparison of ISC and AWE magnitudes, and the ISC magnitudes are indeed to be too high for the smaller events. Figure 9b shows that the AWE and NORSAR magnitudes are in good agreement, as noted and discussed by Ringdal et al (1992).

However, although we prefer AWE values, we recognize that ISC magnitudes are widely used as a standard. Therefore we have used ISC $m_b(P)$ and separately AWE and NORSAR magnitudes when comparing our regional measurements with teleseismic observations.

We used two ways to calculate magnitude from regional data. One way is based on the K scale (energy class) which is used in the former Soviet Union in all local networks. K is approximately equal to log E where E is the radiated energy in joules (Rautian, 1960). To derive the relationship between K and teleseismic magnitude and to calculate the magnitudes M(K) reported in Table 9, we took K values from Soviet bulletins or calculated K ourselves from amplitude readings. Using the data on K and the ISC values of $m_b(P)$ for large UNEs at the Semipalatinsk Test Site the relationship can be found as

$$m_b(P) \ = \ 0.42 \text{ K}.$$

The values of ISC $m_b(P)$ are not good for small events (as noted from Figure 9a), and if we compare K with the magnitudes from AWE or NORSAR we find a different relationship:

$$m(\text{AWE or NORSAR}) \ = \ 0.44 \text{ K} - 0.53.$$

The points to which this last equation is fit, are shown in Figure 9c across six orders of magnitude in energy. (In addition to the $m_b(P)$ values from AWE and the $m_b(Lg)$ values from NORSAR, we sometimes used $m_b(P)$ values from NORSAR for small events.) Either of the above two formulae may be used to estimate a magnitude based on K, denoted M(K). We preferred to use the second formula.

Our next method of determining $m_b(P)$ was to get the separate relationship between log A (from ChISS records at TLG, NSB and ZRN) and ISC $m_b(P)$ for each station using the large events. We then extrapolated the formula using the observed values of log A to estimate magnitudes for the smaller events.

The equations were obtained separately for each wave (Pn_1, Pn_2, Pg, Sn, Lg_1, Lg_2, Lg_3, Rg and amplitudes of coda at the lapse time 500 seconds). Also we used the averaged amplitudes of all P waves; the sum of amplitudes of Lg_1, Lg_2, and Lg_3; and the absolute max of Lg, independent of its time of arrival. The coda is the best parameter for magnitude calculation, giving the more accurate results. But for the small events we cannot see coda on records late enough in lapse time.

The estimations were made for each frequency band separately. In general the frequency range of ChISS used in this problem was from 14 s to 2.5 Hz. The correlation equations obtained are as follows:

$$m_b(P) \;=\; k^*\log A + b.$$

with the values of k and b being different for each station, each wave, and each frequency band. Figure 9d shows the comparison between m_b(AWE) and m_b determined from ChISS measurements.

Small events sometimes were recorded by only 2-3 channels, corresponding to the maximum of the spectrum, and coda cannot be seen and used. So to estimate a magnitude for a small event we can use only a limited number of the above correlations between $m_b(P)$ and ChISS amplitudes, corresponding to those for which we have ChISS data. We form an average over all the magnitudes derived from ChISS readings in this way. The system of coefficients in the last equation, above, to calculate $m_b(P)$ from ChISS amplitudes, was obtained using ISC magnitudes. To get a second version of m_b(ChISS), corresponding to AWE and NORSAR estimations, we use the relationship (e.g. from Figure 9a)

$$\begin{aligned} m_b(\text{AWE and NORSAR}) &= 1.25\, m_b(\text{ISC}) - 1.50 \text{ (for Balapan)} \\ &= 1.25.m_b(\text{ISC}) - 1.37 \text{ (for Degelen).} \end{aligned}$$

Our magnitude results are given in Table 9, and we see that values for previously unknown events typically lie in the range 3.5 – 4.5, so these explosions are mostly subkiloton. The magnitude of the first Semipalatinsk UNE, assigned here as 4.81, is somewhat uncertain. This event (on October 11, 1961) had an amplitude 6.7 times smaller than that of the second UNE (on February 2, 1962) on the Talgar record - and the latter event had a relatively well-determined K value of 14.0 from four stations and hence a magnitude of 5.63. Thus the magnitude of the first UNE at the Semipalatinsk Test Site is assigned as 5.63 - log 6.7 = 4.81.

In view of the often excellent teleseismic detection capability of arrays (Ringdal, 1990), it was a surprise to us that the events were in many cases not detected by NORSAR. One difficulty with assessing the performance of teleseismic arrays, with our event set, is that until about 1980 it was not common for array data to be archived on a continuous basis. Only the detections that were noticed, were saved. (In the case of LASA, not even detections were saved, except within a limited period of operation of this array.) We checked with Yellowknife and learned that the only events confirmed at that array after 1978 (when it is possible to check against an archive) were those of 1981 March 31 and 1982 June 11 (personal communication from Bob North). This failure to demonstrate teleseismic detections is important to explore further, since plans are under development to build a global network of so-called alpha stations, mostly arrays, intended to provide continuous and virtually complete coverage of Eurasia at the magnitude 3.5 level and better using teleseismic signals, for purposes of monitoring compliance with a Comprehensive Test Ban Treaty (CTBT). If array detection is not reliable at the magnitude 3.5 level using teleseismic signals, then increased attention must be paid to regional signals for purposes of detection as well as identification – a conclusion that has implications for the numbers of seismic stations needed in an effective network for CTBT monitoring.

DISCUSSION AND CONCLUSIONS

The problem of identification of seismic events at the Semipalatinsk Test Site is considerably complicated by the occurrence of chemical explosions. To begin the discussion of identification, Table 10 reports for this test site the numbers of UNEs each year claimed by van der Vink et al (1993), the number of UNEs each year that have been identified from teleseismic data (see Table 1), and the number of chemical explosions greater than 10 tons in each year from 1970-1988 reported by Saybekov (1993). The Natural Resources Defense Council and the USSR Academy of Sciences set off a 10 ton chemical explosion near the test site in 1987, that was recorded successfully at Talgar (a distance of more than 700 km), so we should expect no problem with observability of chemical explosions at regional distances in Central Asia

One important indicator that an event was an explosion, is whether it was shot on the exact minute. Prior to September 1980, it appears that virtually all previously known UNEs at Semipalatinsk were carried out either on or very close to an exact minute. The only exceptions in Table 1 are a single UNE at Murzhik (1978 July 18), and five UNEs that in each case were the second event of a pair carried out a few seconds apart, with the first shot being on the minute (1972 December 10, 1974 January 30, 1977 October 29, 1978 August 29, and 1978 November 29). For many years, a practical rule for identifying a UNE at Semipalatinsk was to note any event whose first arrival was about 29 s after the minute at Borovoye, and 38 s after the same minute at Talgar! We find that many of the previously unknown events studied in this paper did occur, if prior to September 1980, on or very close to an exact minute. However, this method does not work after that date, nor does it help us directly to distinguish between chemical and nuclear explosions.

We have not carried out a systematic study of spectral ratios (using ChISS data), to attempt to discriminate between earthquakes and explosions, although a preliminary study of such ratios has indicated that *P* to *S* amplitude ratios are somewhat sensitive to event type, when signal-to-noise ratios are high. We did generate a preliminary summary of our results for 48 events – locations, magnitudes, and a brief and somewhat subjective comment on event type – which is given here as Table 11. Almost all of these events are listed as explosions. The only exceptions are the events of 1966 December 26 (listed as an earthquake because of the time of day and location just off the test site), 1980 November 6 (listed as an earthquake in this preliminary summary because of the time of day), 1988 September 26 (which a Russian colleague had told us was an earthquake and not a UNE - but which we have listed as either an earthquake or a chemical explosions), and 1989 October 20 (which a Russian colleague had told us was a UNE collapse).

Note in Table 11 that prior to 1978 the explosion candidates are listed as UNEs (except for one known ChE in 1961), but for 1978 and later they are listed as UNE or ChE (except for two UNEs at Degelen). The reason for this change in listing is that we noticed several differences between events occurring before and after about 1979, as follows:

- the error in latitude determination became worse with time (for 1964-1979, out of 23 events only 4 have latitude error > 10 km; for 1980-1988, out of 18 events, only 4 have latitude error < 10 km).

- We developed our travel time table and identification of wave types using the well-recorded data from known UNEs from the test site. Events from other locations can have slightly different wave properties. For all events up till 1977 for which we have the records, the wave form is approximately similar. But after 1978 at least half of the events have a slightly different wave form: the arrival of the *Lg* group is not so sharp; and there is a very impulsive arrival of Pn_2 on the ChISS 5 Hz channel. We called such events the Balapan series.
- Before 1973 all our small events occurred at Degelen. In 1973-1978 only half occurred at Degelen. In 1979-1984, among 19 events only one could have occurred at Degelen. And the last six events were again mostly at Degelen.
- For the period 1981-1984 the number of UNEs claimed per year by Russian sources (see Figure 1 or Table 10) was about equal to the number of events already identified as UNEs (Figure 1 or Table 1), so our small events for this period appear to be in excess of the number of UNEs.

We therefore suspected at the time of preparing Table 11 that some of the Balapan series were special chemical explosions - quite large ones, in view of their seismic magnitudes.

When we circulated this preliminary summary table to a small number of individuals for comment, we received the following additional information from Jack Murphy:

> "Of the 21 events since 1970 which you locate as being at or near Balapan [Table 11 identifies] 4 as probable UNE (probability > 0.9), 9 as likely UNE (0.5 < probability < 0.9), 1 as definite EQ (probability = 1.00), 6 as likely CE (probability > 0.7) and 1 as about equally likely to be either CE of EQ. In fact, more reliable data indicate that none of these events are UNE or EQ."

Obviously, this comment reinforced our opinion that a significant fraction of the events we have studied are chemical explosions at Balapan. The above statement can be used to infer that 21 events in Table 11, on or near Balapan, are chemical explosions. We continue to believe that the explosions we have found at Degelen are UNEs.

Before giving our final results, Figure 10 shows the location of 282 UNEs at Semipalatinsk, one earthquake, and one chemical explosion, all previously known (further information for these UNEs, given in Table 1).

Our final results are given in Table 12 and Figures 11 and 12. Figure 11 shows our locations for 43 events not previously known on the

Semipalatinsk Test Site. Most of those at Degelen, we believe to be UNEs. Most of those at Balapan, we now believe to be chemical explosions. (Two of the ChE events are co-located in Figure 11, as are two pairs of UNEs on Degelen.) Figure 12 shows events in our study that are located off the test site, but are still within about 300 km.

It should be emphasized that we have no seismological basis for discriminating between UNEs and chemical explosions. We have chosen to make the final distinction, in Table 12, by inference from Murphy's comment on our preliminary Table 11 (which named many events at or near Balapan as either UNE or ChE). Note that we used seismic methods to detect them – and indeed to label them, in almost all cases – as some type of explosion. But under a CTBT, it would appear to be necessary to use non-seismic methods (for example, on-site inspection) to confirm that explosions as large as these did indeed have a chemical nature.

One particularly interesting event is that of December 26, 1966, which we believe to be a small earthquake just off the test site to the southeast (see Figure 12). Figure 13a shows the three-component SKM record of this event at a station only 260 km away. The *P* and *S* waves both have very high frequency content, and *Lg* has a sharp onset and an amplitude several times bigger than that of *Pg* (which in turn is more than 20 times bigger than *Pn*). Figure 13b shows a similar record of a presumed small UNE at Degelen, at a distance of 306 km. The regional phases are different in several respects from those of Figure 13a - for example, in the *Pn* to *Lg* ratio.

Our list of UNEs in Table 12 includes 13 occurring in the period prior to 1973 that was the subject of the paper by Bocharov et al (1989). We therefore believe that the 96 UNEs Bocharov et al describe were not a complete set of UNEs for 1961-1972 at Semipalatinsk.

The problem remains, of a significant difference between the 303 UNEs we would now claim at Semipalatinsk (282 from Table 1, plus 21 additional UNEs from Table 12), and the 343 claimed as the total by several Russian sources (see earlier discussion: no doubt some very small UNEs at Semipalatinsk, as at the Nevada Test Site, did not generate observable seismic signals, even at regional distances).

In conclusion, we believe we have successfully located and identified about 50 small events on or near the Semipalatinsk Test Site, not previously listed or well-located from openly available teleseismic data. These events presumably include a few earthquakes, and a few tens of explosions (chemical or nuclear). We have no capability with the data we have used, to distinguish between chemical and nuclear explosions. A useful guide to identification is the number of each type of event reported by various sources (see Table 10), but, though of some interest, it would not be prudent to rely too greatly on these numbers; nor can such a guide be used in future CTBT monitoring. Our event list can be made the basis for numerous projects to evaluate teleseismic detection capability, and also to evaluate regional discriminants. We have accumulated and used several hundred analog seismograms for these events. Many of these seismograms, particularly those obtained on ChISS instruments, can be used for spectral analysis; and we believe digital data can also be found, now that we have a list of events as the basis for data requests.

ACKNOWLEDGEMENTS

We thank many station operators in Central Asia for their response to our numerous requests for information; and Jack Murphy for technical advice. This work was supported initially by contract B239589 with Lawrence Livermore National Laboratory, and later by grant F49620-92-J-0497 from the Air Force Office of Scientific Research.

REFERENCES

Aki, K., and P.G. Richards, *Methods of Quantitative Seismology*, W.H. Freeman and Co., San Francisco, 1980.

Bocharov, V.S., S.A. Zelentsov, and V.I. Mikhailov, Characteristics of 96 underground nuclear explosions at the Semipalatinsk test site (in Russian), *Atomnaya Energiya*, **67**, 210-214, 1989.

Hansen, R., F. Ringdal, and P.G. Richards, The stability of RMS Lg measurements and their potential for accurate estimation of the yields of Soviet underground explosions, *Bulletin of the Seismological Society of America*, **80**, 2106-2126, special issue, December 1990.

Lilwall, R.C., and J. Farthing, Joint epicentre determination of Soviet underground nuclear explosions 1973-89 in Eastern Kazakhstan, AWE Report No. O 12/90, H.M. Stationery Office, 1990.

Nersesov, I.L, and T.G. Rautian, Kinematics and dynamics of seismic waves at epicentral distances less than 3500 km, *Proceedings (Trudy) of the Institute of Physics of the Earth, Academy of Sciences of the U.S.S.R.* (in Russian), **32**, 1964.

Mikhailov, V.N., A.M. Matuschenko, V.P. Dumik, V.G. Safronov, and G.A. Tsyrkov; "Chronicle and Phenomenology of Nuclear Tests on the Novaya Zemlya Range", in Proceedings of a Conference on *The Radiological and Radiation Protection Problems in Nordic Regions*, Tromsø 21-22 Nov 1991, ed. Johan Baarli, published by the Nordic Society for Radiation Protection, Oslo 1992.

Rautian, T.G., Attenuation of seismic waves and energy of earthquakes, *Proceedings of the Institute of Seismology, Tadjikian Academy of Sciences* (in Russian), #7, 1960

Rautian, T.G., and V.I. Khalturin, The use of the coda for determination of the earthquake source spectrum, *Bulletin of the Seismological Society of America*, **68**, 923–948, August 1978.

Rautian, T.G., V.I. Khalturin, V.G. Martynov, and P. Molnar, Preliminary analysis of spectral content of *P* and *S* waves from local earthquakes in the Garm, Tadjikistan Region, *Bulletin of the Seismological Society of America*, **68**, 949–971, August 1978.

Richards, Paul G., Won-Young Kim, and Göran Ekström, The Borovoye Geophysical Observatory, Kazakhstan, *EOS, Transactions of the American Geophysical Union*, **73**, 201 and 205-6, May 5 1992.

Richards, Paul G., and Jinghua Shi, in Final Report on RMS *Lg* studies of underground nuclear explosions in the U.S.S.R. and the U.S., Air Force Phillips Laboratory Technical Report, PL-TR-93-2227, 1994.

Ringdal, F., Teleseismic event detection using the NORESS array, with special reference to low-yield Semipalatinsk explosions, *Bulletin of the Seismological Society of America*, **80**, 2127–2142, special issue, December 1990.

Ringdal, F., P.D. Marshall, and R. Alewine, Seismic yield determination of Soviet underground nuclear explosions at the Shagan River test site, *Geophysical Journal International,* **109**, 65-77, 1992.

Saybekov, Toqtasyn, Impact of nuclear explosions in Semipalatinsk, *Ata Meken*, August 14, 1993 (in Kazakh); also in JPRS-TAC-93-019 (in English), September 29, 1993.

Shazilov, V.I., *Methods of evaluation of seismic risk*, Publishing House Nauka, Alma Ata (in Russian), 1989.

Sykes, L.R., and S. Ruggi, Soviet Nuclear Testing, chapter 10 in the book *Soviet Nuclear Weapons*, vol IV of the Nuclear Weapons Databook series, ed. T.B. Cochran, W.M. Arkin, R.S. Norris, and J.I. Sands, Harper & Row, Ballinger Division, New York, 1989.

van der Vink, Gregory E., Vitaly V. Adushkin, and Vitaly A. Laushkin, "Experience of the Verification of the Nonproliferation of Nuclear Weapons Tests at the Network of Open Seismic Stations", unpublished ms. of a paper given at a Princeton conference, Fall 1992, on Non-Proliferation; also a similar paper at AGU, Baltimore, Spring 1993.

Zapolskii, K.K., Measurement of the level and spectral content of short-period microseisms, *Proceedings (Trudy) of the Institute of Physics of the Earth, Academy of Sciences of the U.S.S.R.* (in Russian), #10, 1960.

Zapolskii, K.K., The ChISS frequency-selective seismic station, in *Experimental Seismology*, Publishing House Nauka, Moscow (in Russian), 1971.

Zapolskii, K.K., and V.I. Khalturin, Frequency of seismic vibration, in *Method of detailed study of seismicity, Proceedings (Trudy) of the Institute of Physics of the Earth, Academy of Sciences of the U.S.S.R.* (in Russian), #10, 1960.

LIST OF TABLES

LIST OF FIGURES

Degelen and Balapan events, as recorded at Talgar.

Figure 6. Examples of high gain records:

(a) the RVZT records (three component); and

(b) the KSE records, both at station Krasny Kordon, for the presumed UNE of January 29, 1971, at Degelen.

Figure 7. Regional travel time curves for East Kazakhstan.

Figure 8. Twelve examples of worksheets for event location.

Figure 9. Relations between magnitude scales and energy class:

(a) comparison between maximum likelihood $m_b(P)$ values due to the British Atomic Weapons Establishment, and the ISC $m_b(P)$, showing the latter is biassed high for small events;

(b) comparison between the AWE $m_b(P)$ and the NORSAR $m_b(Lg)$, showing lack of bias and hence a rough equivalence for these two magnitude scales;

(c) comparison of magnitudes and the energy class , K. Circles denote m_b(NORSAR) vs. K(Talgar), triangles denote m_b(AWE) vs. K(bulletins), and crosses denote m_b(AWE) vs. K(bulletins); and

(d) comparison of m(ChISS) against m_b(AWE).

Figure 10. The location of 282 previously known UNEs, one chemical explosion, and one earthquake, all on or near the Semipalatinsk Test Site. (Epicenters of these UNEs are given in Table 1.)

Figure 11. The location of 43 previously unknown events on or very near the Semipalatinsk Test Site. Most of the UNEs are at Degelen, most of the chemical explosions (ChEs) are at Balapan. Part of the test site boundary is also shown.

Figure 12. Similar to Figure 11, but with a different scale to show seismic events off the test site but within 300 km. Two earthquakes are also indicated, one previously known (1976 March 20), one unknown (1966 December 26).

Figure 13. SKM records of two events recorded at Ust-Kamenogorsk:

(a) an event we believe to be a small earthquake - note the efficient excitation of Lg;

(b) a presumed UNE at Degelen.

Date	h	mi	s	lat	long	area km**2	subsite	MAG (ISC)	AMP	REV/POL	TOT	mb(P) AWE	mb(Lg) NOR/GRF
61-Oct-11	7	39	59.9	49.77272	77.99500		D						
62-Feb-02	8	0	0.2	49.77747	78.00164		D						
64-Mar-15	8	0	0.4	49.81597	78.07517		D	5.6	14	5/ 32	68	5.563	
64-May-16	6	0	59.8	49.80772	78.10197		D	5.6	15	9/ 35	80	5.549	
64-Jul-19	6	0	0.6	49.80908	78.09292		D	5.2	14	4/ 33	68	5.433	
64-Nov-16	6	0	0.2	49.80872	78.13344		D	5.6	15	3/ 35	83	5.642	
65-Jan-15	6	0	0.8	49.93500	79.00936		B	5.8	11	6/ 50	79	5.87	
65-Mar-03	6	14	59.4	49.82472	78.05267		D	5.5	14	5/ 36	53	5.443	
65-May-11	6	40	0.2	49.77022	77.99428		D	4.9	4	2/ 13	19	4.742	
65-Jun-17	3	45	0.0	49.82836	78.06686		D	5.2	10	5/ 23	36	5.244	
65-Jul-29	3	5	0.2	49.77972	77.99808		D						
65-Sep-17	4	0	0.1	49.81158	78.14669		D	5.2	9	3/ 16	34	5.219	
65-Oct-08	6	0	0.4	49.82592	78.11144		D	5.4	14	5/ 32	54	5.471	
65-Oct-14	4	0	0.2	49.99064	77.63572		M						
65-Nov-21	4	58	0.0	49.81919	78.06358		D	5.6	33	6/ 48	114	5.605	
65-Dec-24	5	0	0.2	49.80450	78.10667		D	5.0	13	3/ 7	47	4.944	
66-Feb-13	4	58	0.1	49.80894	78.12100		D	6.1	51	15/ 113	179	6.256	
66-Mar-20	5	50	0.3	49.76164	78.02389		D	6.0	53	7/ 90	154	6.040	
66-Apr-21	3	58	0.1	49.80967	78.10003		D	5.3	33	11/ 54	99	5.370	
66-May-07	3	58	0.2	49.74286	78.10497		D	4.8	16	3/ 7	32	4.734	
66-Jun-29	6	58	0.5	49.83442	78.07336		D	5.6	34	8/ 50	96	5.508	
66-Jul-21	3	58	0.0	49.73667	78.09703		D	5.3	31	12/ 51	99	5.360	
66-Aug-05	3	57	59.6	49.76431	78.04242		D	5.4	30	8/ 47	98	5.390	
66-Aug-19	3	52	59.9	49.82708	78.10875		D	5.1	8	2/ 4	28	4.633	
66-Sep-07	3	51	59.7	49.82883	78.06375		D	4.8	8	2/ 4	27	4.661	
66-Oct-19	3	57	59.9	49.74711	78.02053		D	5.6	39	10/ 67	132	5.669	
66-Dec-03	5	2	0.2	49.74689	78.03336		D	4.8	9	3/ 4	17	4.600	
66-Dec-18	4	58	0.0	49.92458	77.74722		M	5.8	42	5/ 94	166	5.922	
67-Jan-30	4	1	59.5	49.76744	77.99139		D	4.8	12	1/ 6	43	4.627	
67-Feb-26	3	57	59.8	49.74569	78.08231		D	6.0	53	12/ 99	196	6.034	
67-Mar-25	5	58	1.1	49.75361	78.06300		D	5.3	34	6/ 47	101	5.320	
67-Apr-20	4	8	1.0	49.74161	78.10542		D	5.5	37	12/ 68	105	5.556	
67-May-28	4	7	59.6	49.75642	78.01689		D	5.4	38	8/ 57	127	5.464	
67-Jun-29	2	56	59.9	49.81669	78.04903		D	5.3	32	9/ 38	95	5.336	
67-Jul-15	3	26	59.9	49.83592	78.11817		D	5.4	35	5/ 48	109	5.387	
67-Aug-04	6	58	0.3	49.76028	78.05550		D	5.3	32	10/ 53	95	5.316	
67-Sep-16	4	4	0.3	49.93719	77.72811		M	5.3	28	14/ 61	106	5.245	
67-Sep-22	5	4	0.0	49.95964	77.69106		M	5.2	26	8/ 39	84	5.160	
67-Oct-17	5	4	0.2	49.78089	78.00383		D	5.6	45	9/ 80	134	5.629	
67-Oct-30	6	4	0.0	49.79436	78.00786		D	5.3	42	9/ 45	112	5.413	
67-Nov-22	4	3	59.9	49.94194	77.68683		M	4.8	5	2/ 3	14	4.410	
67-Dec-08	6	3	59.8	49.81714	78.16378		D	5.4	26	2/ 37	88	5.314	
68-Jan-07	3	46	59.9	49.75442	78.03094		D	5.1	23	14/ 31	77	4.977	
68-Apr-24	10	35	59.7	49.84519	78.10322		D	5.0	18	5/ 18	58	4.911	
68-Jun-11	3	5	59.7	49.79300	78.14508		D	5.2	30	5/ 32	92	5.240	
68-Jun-19	5	5	59.8	49.98025	78.98550		B	5.4	38	9/ 63	119	5.28	
68-Jul-12	12	8	0.0	49.75469	78.08994		D	5.3	25	8/ 37	85	5.169	
68-Aug-20	4	5	59.6	49.82264	78.07447		D	4.8	14	2/ 4	43	4.761	
68-Sep-05	4	5	59.6	49.74161	78.07558		D	5.4	41	3/ 55	114	5.439	
68-Sep-29	3	43	0.0	49.81197	78.12194		D	5.8	54	9/ 86	160	5.861	
68-Oct-21	3	52	0.0	49.72786	78.48628		M						
68-Nov-09	2	54	0.1	49.80053	78.13911		D	4.9	11	2/ 9	41	4.751	
68-Nov-12	7	30	0.0	49.71244	78.46133		M						
68-Nov-12	7	30	0.0	49.71244	78.46133		M						

Table 1 (1 of 5)

68-Nov-12	7	30	0.0	49.71244	78.46133		M						
68-Dec-18	5	1	59.7	49.74594	78.09203		D	5.0	22	4/ 23	78	5.044	
69-Mar-07	8	26	59.8	49.82147	78.06267		D	5.6	54	13/ 90	156	5.664	
69-May-16	4	2	59.7	49.75942	78.07578		D	5.2	41	6/ 39	105	5.264	
69-May-31	5	1	59.4	49.95031	77.69422		M	5.3	39	8/ 46	98	5.290	
69-Jul-04	2	46	59.6	49.74603	78.11133		D	5.2	42	3/ 41	111	5.241	
69-Jul-23	2	47	0.2	49.81564	78.12961		D	5.4	46	5/ 67	130	5.504	
69-Sep-11	4	2	0.0	49.77631	77.99669		D	5.0	19	5/ 19	63	4.910	
69-Oct-01	4	2	59.9	49.78250	78.09831		D	5.2	36	5/ 28	97	5.256	
69-Nov-30	3	32	59.7	49.92428	78.95575		B	6.0	65	12/ 115	202	6.02	6.043
69-Dec-28	3	47	0.2	49.93733	77.71422		M	5.7	54	14/ 90	171	5.791	
69-Dec-29	4	2	0.0	49.73367	78.10225		D	5.1	3	2/ 2	12	4.217	
70-Jan-29	7	3	0.0	49.79558	78.12389		D	5.5	50	8/ 68	138	5.599	
70-Mar-27	5	2	59.6	49.74781	77.99897		D	5.0	20	0/ 18	58	4.929	
70-May-27	4	3	0.0	49.73131	78.09861		D						
70-Jun-28	1	58	0.0	49.80150	78.10681		D	5.7	54	15/ 92	168	5.870	
70-Jul-21	3	2	59.7	49.95242	77.67289		M	5.4	43	8/ 50	120	5.376	
70-Jul-24	3	57	0.0	49.80972	78.12839		D	5.3	36	1/ 38	103	5.337	
70-Sep-06	4	2	59.9	49.75975	78.00539		D	5.4	49	6/ 69	134	5.533	
70-Nov-04	6	2	59.8	49.98922	77.76244		M	5.4	45	5/ 62	143	5.439	
70-Dec-17	7	1	0.0	49.74564	78.09917		D	5.4	42	3/ 61	132	5.433	
71-Mar-22	4	33	0.3	49.79847	78.10897		D	5.7	54	10/ 83	198	5.767	
71-Apr-25	3	32	59.9	49.76853	78.03392		D	5.9	62	18/ 112	219	6.076	
71-May-25	4	3	0.4	49.80164	78.13883		D	5.1	21	2/ 20	74	5.048	
71-Jun-06	4	2	59.7	49.97542	77.66028		M	5.5	43	10/ 50	146	5.526	
71-Jun-19	4	4	0.1	49.96903	77.64081		M	5.4	52	13/ 57	126	5.538	
71-Jun-30	3	56	59.8	49.94600	78.98047		B	5.2	30	6/ 31	113	4.94	
71-Oct-09	6	2	59.7	49.97789	77.64144		M	5.3	46	13/ 53	142	5.371	
71-Oct-21	6	2	59.7	49.97381	77.59733		M	5.5	49	11/ 54	133	5.580	
71-Nov-29	6	2	59.9	49.74342	78.07850		D	5.4	41	6/ 49	113	5.462	
71-Dec-15	7	52	59.8	49.82639	77.99731		D	4.9	7	2/ 4	31	4.677	
71-Dec-30	6	21	0.2	49.76003	78.03714		D	5.7	56	4/ 73	162	5.838	
72-Feb-10	5	3	0.0	50.02428	78.87808		B	5.4	41	17/ 59	143	5.27	5.372
72-Mar-10	4	56	59.8	49.74531	78.11969		D	5.4	54	5/ 62	157	5.453	
72-Mar-28	4	22	0.1	49.73306	78.07569		D	5.1	35	7/ 35	109	5.177	
72-Jun-07	1	28	0.0	49.82675	78.11547		D	5.4	42	13/ 46	145	5.422	
72-Jul-06	1	3	0.0	49.73750	78.11006		D	4.4	6	1/ 1	21	4.275	
72-Aug-16	3	16	59.8	49.76547	78.05883		D	5.0	30	6/ 29	95	5.105	
72-Aug-26	3	46	59.7	49.98197	77.71661		M	5.3	37	4/ 36	131	5.363	
72-Sep-02	8	56	59.9	49.95942	77.64089		M	5.1	6		21	4.788	
72-Nov-02	1	27	0.2	49.92697	78.81725		B	6.1	75	16/ 124	259	6.16	6.118
72-Dec-10	4	27	0.0	49.81939	78.05822		D	5.6	62	14/ 80	230	5.715	
72-Dec-10	4	27	10.0	50.02700	78.99556		B	6.0	26	6/ 49	133	5.96	6.092
72-Dec-28	4	27	0.0	49.73919	78.10625		D						
73-Feb-16	5	3	0.0	49.816	78.116	3.9	D	5.5	49	5/ 52	153	5.477	
73-Apr-19	4	32	59.9	49.984	77.614	5.3	M	5.4	40	10/ 46	133	5.356	
73-Jul-10	1	27	0.2	49.792	78.042	4.4	D	5.2	39	4/ 43	130	5.335	
73-Jul-23	1	23	0.1	49.966	78.810	2.1	B	6.1	81	19/ 161	261	6.17	6.199
73-Oct-26	4	27	0.1	49.753	78.122	4.7	D	5.2	39	4/ 34	116	5.228	
73-Dec-14	7	46	59.7	50.054	78.987	2.3	B	5.8	67	16/ 101	210	5.79	5.868
74-Jan-30	4	57	0.2	49.829	78.012	12.2	D	4.9	13	2/ 3	55	4.429	
74-Jan-30	4	57	4.6	49.845	78.051	6.4	D	5.4	36	2/ 41	134	5.477	
74-Apr-16	5	52	59.8	50.039	78.946	15.3	B	4.9	11	0/ 1	23	4.35	
74-May-16	3	3	0.10	49.745	78.053	4.5	D	5.2	47	6/ 50	133	5.242	
74-May-31	3	26	60.0	49.953	78.846	2.2	B	5.9	83	9/ 102	236	5.81	
74-Jun-25	3	57	0.2	49.844	78.111	66.9	D	4.7	8	0/ 4	28	4.419	
74-Jul-10	2	56	60.0	49.772	78.088	6.6	D	5.2	47	3/ 40	118	5.168	

Table 1 (2 of 5)

74-Sep-13	3	3	0.0	49.775	78.036	6.8	D	5.2	40	5/ 31	96	5.144	
74-Oct-16	6	33	0.10	49.985	78.896	3.0	B	5.5	63	22/ 68	167	5.41	5.411
74-Dec-07	6	0	0.0	49.916	77.605	31.6	M	4.7	4	0/ 2	23	4.369	
74-Dec-16	3	23	0.1	49.787	78.092	8.7	D	4.8	24	3/ 11	71	4.938	
74-Dec-16	6	41	0.3	49.858	78.053	8.7	D	5.0	26	1/ 14	70	4.887	
74-Dec-27	5	46	59.4	49.949	79.011	2.9	B	5.6	60	8/ 73	175	5.50	5.708
75-Feb-20	5	33	0.0	49.781	78.019	3.6	D	5.7	70	9/ 83	188	5.765	
75-Mar-11	5	43	0.10	49.740	78.102	4.0	D	5.4	56	10/ 55	145	5.424	
75-Apr-27	5	36	59.7	49.955	78.926	2.6	B	5.6	71	22/ 97	201	5.51	5.547
75-Jun-08	3	26	60.0	49.757	78.008	4.1	D	5.5	61	11/ 60	164	5.551	
75-Jun-30	3	26	59.9	50.001	78.996	17.0	B	5.0	15	1/ 4	38	4.52	
75-Aug-07	3	57	0.10	49.808	78.120	4.9	D	5.2	41	10/ 37	116	5.187	
75-Oct-29	4	46	59.8	49.955	78.877	2.8	B	5.8	64	7/ 67	207	5.61	5.629
75-Dec-13	4	56	60.0	49.806	78.121	6.6	D	5.1	43	3/ 22	84	5.001	
75-Dec-25	5	16	59.7	50.051	78.813	2.2	B	5.7	70	16/ 97	232	5.69	5.801
76-Jan-15	4	46	60.0	49.817	78.161	5.4	D	5.2	48	3/ 34	107	5.182	
76-Apr-21	4	58	0.2	49.773	78.109	8.3	D	5.1	42	1/ 17	77	4.940	
76-Apr-21	5	2	59.7	49.906	78.827	4.1	B	5.3	70	8/ 45	125	5.12	
76-May-19	2	57	0.2	49.789	78.019	17.4	D	5.0	28	2/ 14	47	4.722	
76-Jun-09	3	2	59.8	50.002	79.025	3.2	B	5.3	47	4/ 40	143	5.07	5.199
76-Jul-04	2	56	59.9	49.912	78.908	2.3	B	5.8	83	10/ 117	231	5.85	5.810
76-Jul-23	2	33	0.2	49.774	78.046	6.3	D	5.1	49	9/ 22	100	4.961	
76-Aug-28	2	56	60.0	49.979	78.928	2.3	B	5.8	82	10/ 100	223	5.74	5.733
76-Oct-30	4	57	0.2	49.825	78.022	25.1	D	4.9	15	1/ 4	33	4.618	
76-Nov-23	5	2	59.8	50.013	78.962	2.2	B	5.8	93	14/ 140	264	5.79	5.819
76-Dec-07	4	56	59.9	49.927	78.847	2.1	B	5.9	76	10/ 107	236	5.80	5.741
76-Dec-30	3	57	0.3	49.795	78.030	7.8	D	5.2	40	1/ 26	78	5.086	
77-Mar-29	3	56	60.0	49.781	78.042	4.6	D	5.4	60	11/ 51	162	5.405	
77-Apr-25	4	7	0.2	49.811	78.107	7.9	D	5.1	46	3/ 29	91	5.066	
77-May-29	2	57	0.0	49.932	78.774	2.0	B	5.8	97	7/ 147	289	5.75	5.655
77-Jun-29	3	7	0.4	50.033	78.861	3.6	B	5.3	69	6/ 80	171	5.20	5.077
77-Jul-30	1	57	0.1	49.754	78.057	6.4	D	5.1	58	5/ 46	116	5.127	
77-Aug-17	4	26	60.0	49.817	78.128	7.9	D	5.1	35	2/ 23	81	5.010	
77-Sep-05	3	2	59.9	50.048	78.923	2.1	B	5.8	97	20/ 145	293	5.73	5.879
77-Oct-29	3	6	60.0	49.827	78.091	3.3	D	5.6	68	9/ 100	245	5.515	
77-Oct-29	3	7	4.9	50.068	78.977	5.0	B	5.6	53	3/ 56	148	5.56	5.757
77-Nov-30	4	6	59.9	49.966	78.890	2.1	B	6.0	90	11/ 162	285	5.89	5.753
77-Dec-26	4	3	0.2	49.843	78.070	15.3	D	4.9	38	4/ 33	69	4.908	
78-Mar-19	3	46	59.8	49.945	77.704	5.0	M	5.2	53	6/ 67	128	5.190	
78-Mar-26	3	56	60.0	49.766	78.008	3.0	D	5.6	98	11/ 121	254	5.689	
78-Apr-22	3	7	0.0	49.756	78.140	4.1	D	5.3	83	11/ 90	184	5.347	
78-May-29	4	56	59.9	49.762	78.092	23.2	D	4.7	35	4/ 15	55	4.678	
78-Jun-11	2	57	0.10	49.903	78.791	2.0	B	5.9	92	23/ 157	281	5.83	5.755
78-Jul-05	2	46	60.0	49.896	78.868	1.8	B	5.8	96	18/ 162	279	5.77	5.794
78-Jul-28	2	46	59.9	49.752	78.100	3.2	D	5.7	90	15/ 134	230	5.747	
78-Aug-29	2	36	60.0	49.807	78.107	5.9	D	5.2	61	11/ 56	147	5.041	
78-Aug-29	2	37	8.8	50.011	78.976	2.2	B	5.9	80	8/ 130	247	5.90	6.010
78-Sep-15	2	36	59.9	49.922	78.876	1.9	B	6.0	100	14/ 162	276	5.89	5.908
78-Sep-20	5	3	0.0	49.848	78.212	22.2	D	4.3	15	0/ 0	20	4.205	
78-Oct-15	5	37	0.1	49.746	78.121	5.3	D	5.2	71	7/ 64	137	5.150	
78-Oct-31	4	17	0.2	49.803	78.099	4.0	D	5.2	82	9/ 79	150	5.251	
78-Nov-04	5	5	59.8	50.040	78.941	2.0	B	5.6	106	12/ 139	261	5.56	5.690
78-Nov-29	4	33	0.2	49.808	77.999	4.2	D	5.3	75	17/ 81	176	5.205	
78-Nov-29	4	33	5.0	49.959	78.801	2.7	B	6.0	82	13/ 116	214	5.96	5.971
78-Dec-14	4	43	0.0	49.805	78.103	27.1	D	4.8	18	1/ 3	33	4.736	
78-Dec-20	4	33	0.0	49.850	78.047	13.9	D	4.7	28	2/ 15	49	4.713	
79-Feb-01	4	13	0.2	50.101	78.863	2.5	B	5.4	93	19/ 98	177	5.29	

Table 1 (3 of 5)

79-Feb-16	4	4	0.5	49.974	77.668	5.1	M	5.4	72	9/ 73	153	5.386	
79-May-06	3	17	0.10	49.770	78.008	4.8	D	5.2	78	1/ 67	138	5.217	
79-May-31	5	55	0.10	49.830	78.087	5.4	D	5.3	71	7/ 68	133	5.265	
79-Jun-23	2	57	0.0	49.913	78.857	1.7	B	6.2	121	25/ 232	335	6.16	6.064
79-Jul-07	3	46	59.8	50.032	78.989	1.9	B	5.8	109	18/ 178	288	5.84	5.966
79-Jul-18	3	17	4.9	49.919	77.812	6.1	M	5.2	58	2/ 58	132	5.158	
79-Aug-04	3	56	60.0	49.900	78.900	1.6	B	6.1	137	18/ 228	337	6.13	6.100
79-Aug-18	2	51	59.6	49.949	78.937	1.5	B	6.1	135	18/ 219	338	6.13	6.126
79-Sep-27	4	13	0.0	49.757	78.097	24.9	D	4.5	19	1/ 2	30	4.421	
79-Oct-18	4	17	0.1	49.829	78.104	7.3	D	5.2	61	2/ 56	105	5.233	
79-Oct-28	3	16	59.5	49.982	78.996	1.7	B	6.0	127	23/ 204	306	5.98	6.051
79-Nov-30	4	53	0.6	49.781	78.104	15.4	D	4.5	20	4/ 8	41	4.424	
79-Dec-02	4	36	60.0	49.900	78.793	1.9	B	6.0	118	17/ 186	277	5.99	5.929
79-Dec-21	4	42	0.10	49.795	78.127	18.9	D	4.7	20	1/ 4	36	4.714	
79-Dec-23	4	56	59.9	49.920	78.753	1.7	B	6.2	116	14/ 190	281	6.13	6.039
80-Apr-04	5	32	59.8	50.000	77.823	15.7	M	4.9	26	2/ 20	58	4.903	
80-Apr-10	4	7	0.2	49.796	78.068	7.7	D	5.0	47	13/ 52	105	4.983	
80-Apr-25	3	57	0.0	49.981	78.756	2.2	B	5.5	103	12/ 129	220	5.45	5.492
80-May-22	3	57	0.1	49.780	78.037	3.5	D	5.5	75	11/ 104	172	5.528	
80-Jun-12	3	27	0.1	49.986	78.998	2.1	B	5.6	91	15/ 135	225	5.52	5.627
80-Jun-29	2	33	0.2	49.951	78.815	2.2	B	5.7	88	14/ 143	214	5.69	5.706
80-Jul-31	3	33	0.10	49.803	78.105	4.2	D	5.3	77	4/ 91	155	5.329	
80-Sep-14	2	42	41.6	49.930	78.801	1.6	B	6.2	104	13/ 202	326	6.21	6.094
80-Sep-25	6	21	13.1	49.826	78.071	17.7	D	4.7	32	3/ 27	55	4.828	
80-Oct-12	3	34	16.6	49.967	79.026	1.6	B	5.9	118	16/ 160	301	5.88	5.927
80-Dec-14	3	47	8.9	49.909	78.932	1.7	B	5.9	115	14/ 177	292	5.93	5.936
80-Dec-26	4	7	9.3	49.863	78.119	40.0	D	4.5	5	1/ 4	19	4.157	
80-Dec-27	4	9	10.6	50.063	78.982	2.0	B	5.9	90	13/ 146	245	5.87	5.933
81-Mar-29	4	3	52.5	50.011	78.978	1.8	B	5.6	105	10/ 133	258	5.49	5.548
81-Apr-22	1	17	13.8	49.891	78.811	1.6	B	6.0	127	12/ 200	340	5.94	5.929
81-May-27	3	58	14.8	49.992	78.979	2.6	B	5.5	93	10/ 96	184	5.30	5.456
81-Jun-30	1	57	15.3	49.761	78.071	5.9	D	5.2	65	4/ 50	109	5.164	
81-Jul-17	2	37	18.1	49.800	78.126	4.7	D	5.2	67	6/ 69	125	5.071	
81-Aug-14	2	27	15.2	49.781	78.077	6.7	D	5.0	49	4/ 33	92	4.875	
81-Sep-13	2	17	20.8	49.920	78.911	1.6	B	6.1	131	15/ 217	350	6.06	6.108
81-Oct-18	3	57	5.1	49.927	78.854	1.7	B	6.1	111	15/ 192	322	6.00	5.981
81-Nov-20	4	57	5.1	49.746	78.120	7.1	D	5.1	47	2/ 49	96	5.001	
81-Nov-29	3	35	11.1	49.898	78.857	2.1	B	5.7	109	15/ 153	256	5.62	5.580
81-Dec-22	4	31	5.3	49.821	78.107	11.4	D	5.1	34	4/ 18	63	4.961	
81-Dec-27	3	43	16.6	49.930	78.792	1.6	B	6.2	128	14/ 216	340	6.16	6.075
82-Feb-19	3	56	13.4	49.806	78.029	6.0	D	5.4	89	7/ 85	147	5.397	
82-Apr-25	3	23	7.9	49.912	78.906	1.6	B	6.1	121	24/ 228	347	6.03	6.072
82-Jun-25	2	3	7.2	49.801	78.089	10.6	D	4.8	28	6/ 17	66	4.570	
82-Jul-04	1	17	16.7	49.958	78.800	2.0	B	6.1	114	11/ 193	326	6.08	
82-Aug-23	2	43	6.7	49.758	78.044	19.8	D	4.7	31	2/ 13	53	4.444	
82-Aug-31	1	31	3.2	49.926	78.760	2.5	B	5.3	91	10/ 71	179	5.20	
82-Sep-21	2	57	3.2	49.785	78.121	4.5	D	5.2	78	7/ 77	143	5.150	
82-Dec-05	3	37	15.0	49.924	78.812	1.6	B	6.1	137	26/ 239	346	6.08	5.996
82-Dec-25	4	23	8.4	49.799	78.037	31.4	D	4.8	12	2/ 2	34	4.473	
82-Dec-26	3	35	16.7	50.078	78.986	1.8	B	5.7	117	21/ 151	262	5.58	5.655
83-Mar-30	4	17	10.2	49.792	78.029	15.7	D	4.9	20	1/ 5	39	4.605	
83-Apr-12	3	41	8.3	49.815	78.076	12.1	D	4.9	29	3/ 12	49	4.654	
83-May-30	3	33	47.0	49.736	78.120	3.8	D	5.5	105	15/ 113	201	5.431	
83-Jun-12	2	36	46.0	49.920	78.914	1.5	B	6.1	104	26/ 245	347	6.02	6.072
83-Jun-24	2	56	13.9	49.757	78.039	10.1	D	4.7	30	4/ 17	47	4.461	
83-Sep-11	6	33	13.1	49.820	78.118	13.6	D	4.9	14	1/ 7	34	4.484	
83-Oct-06	1	47	9.1	49.924	78.761	1.5	B	6.0	123	28/ 229	331	5.95	5.868

Table 1 (4 of 5)

83-Oct-26	1	55	7.3	49.912	78.828	1.6	B	6.1	133	32/ 256	359	6.04	6.016
83-Nov-20	3	27	6.9	50.055	78.997	1.9	B	5.5	103	12/ 121	221	5.33	5.409
83-Nov-29	2	19	8.8	49.739	78.105	3.7	D	5.4	93	7/ 81	174	5.313	
83-Dec-26	4	29	9.3	49.804	78.098	4.2	D	5.6	87	12/ 99	189	5.480	
84-Feb-19	3	57	5.9	49.894	78.745	1.6	B	5.9	107	20/ 204	311	5.77	5.725
84-Mar-07	2	39	8.8	50.049	78.950	1.6	B	5.7	106	19/ 161	292	5.56	5.680
84-Mar-29	5	19	10.7	49.922	78.949	1.5	B	5.9	131	22/ 215	348	5.86	5.902
84-Apr-15	3	17	11.5	49.749	78.101	3.5	D	5.7	112	12/ 171	307	5.718	
84-Apr-25	1	9	6.0	49.935	78.867	1.4	B	6.0	135	24/ 247	376	5.90	5.867
84-May-26	3	13	14.9	49.973	79.000	1.3	B	6.1	126	29/ 269	413	6.01	6.079
84-Jul-14	1	9	13.0	49.901	78.879	1.4	B	6.2	140	31/ 289	406	6.10	6.054
84-Sep-09	2	59	8.9	49.809	78.072	7.4	D	5.1	51	6/ 43	108	4.889	
84-Oct-18	4	57	8.3	49.775	78.133	18.0	D	4.5	17	5/ 5	26	4.246	
84-Oct-27	1	50	12.9	49.925	78.776	1.2	B	6.2	158	25/ 310	477	6.19	6.098
84-Nov-23	3	55	7.5	49.830	78.073	16.5	D	4.7	21	2/ 3	34	4.379	
84-Dec-02	3	19	8.9	49.990	79.009	1.5	B	5.9	151	25/ 202	388	5.77	5.880
84-Dec-16	3	55	5.1	49.930	78.816	1.3	B	6.1	150	24/ 242	424	6.12	6.043
84-Dec-28	3	50	13.1	49.875	78.700	1.3	B	6.0	147	32/ 238	408	6.00	5.980
85-Feb-10	3	27	10.0	49.893	78.783	1.5	B	5.9	138	32/ 224	356	5.83	5.806
85-Apr-25	0	57	9.0	49.921	78.899	1.4	B	5.9	133	22/ 225	412	5.84	5.859
85-Jun-15	0	57	3.1	49.903	78.839	1.2	B	6.1	147	17/ 261	477	6.05	5.987
85-Jun-30	2	39	5.1	49.857	78.659	1.3	B	6.0	137	25/ 241	403	5.92	5.928
85-Jul-20	0	53	16.9	49.943	78.783	1.3	B	6.0	139	19/ 258	405	5.89	5.865
85-Jul-25	3	11	9.2	49.836	77.998	7.7	D	5.0	60	5/ 51	103	4.815	
87-Feb-26	4	58	24.3	49.844	78.088	3.50	D	5.4	83	13/ 98	215		
87-Mar-12	1	57	19.6	49.929	78.824	1.8	B	5.6	106	12/ 128	267	5.31	5.218
87-Apr-03	1	17	10.3	49.910	78.786	1.1	B	6.2	134	36/ 313	519	6.12	6.063
87-Apr-17	1	3	7.1	49.874	78.663	1.2	B	6.0	127	28/ 279	470	5.92	5.910
87-May-06	4	2	8.1	49.777	77.984	4.60	D	5.6	97	9/ 129	259		
87-Jun-06	2	37	9.3	49.837	78.065	3.90	D	5.4	89	16/ 107	232		
87-Jun-20	0	53	7.1	49.927	78.740	1.2	B	6.1	145	33/ 332	540	6.03	5.971
87-Jul-17	1	17	9.2	49.769	78.035	3.20	D	5.8	96	23/ 200	391		
87-Aug-02	0	58	9.2	49.877	78.873	1.2	B	5.9	127	34/ 311	493	5.83	5.871
87-Sep-18	2	32	10.0	49.976	78.024	115.6	D	4.3	7	0/ 0	10		
87-Oct-16	6	6	7.0	49.802	78.140	35.0	D	4.6	9	2/ 2	19		
87-Nov-15	3	31	9.1	49.881	78.753	1.3	B	6.1	155	38/ 272	483	5.98	5.975
87-Dec-13	3	21	7.2	49.957	78.792	1.3	B	6.1	146	29/ 290	487	6.06	6.082
87-Dec-20	2	55	9.1	49.774	77.975	10.0	D	4.8	36	6/ 18	65		
87-Dec-27	3	5	7.2	49.867	78.718	1.2	B	6.1	145	26/ 298	485	6.00	6.042
88-Feb-06	4	19	9.1	49.787	77.975	14.0	D	4.7	23	2/ 4	40		
88-Feb-13	3	5	8.2	49.932	78.878	1.3	B	6.1	143	37/ 300	527	5.97	6.042
88-Apr-03	1	33	8.1	49.909	78.918	1.4	B	6.0	117	28/ 314	518	5.99	6.063
88-Apr-22	9	30	9.4	49.824	78.102	7.3	D	4.9	35	4/ 21	81		
88-May-04	0	57	9.1	49.931	78.741	1.4	B	6.1	150	31/ 307	571	6.09	6.046
88-Jun-14	2	27	9.0	50.034	78.964	2.9	B	5.1	67	12/ 52	182	4.80	
88-Sep-14	3	59	59.7	49.869	78.825	1.4	B	6.1	160	30/ 335	654	6.03	5.969
88-Oct-18	3	40	9.2	49.802	78.002	9.2	D	4.9	27	6/ 12	67		
88-Nov-12	3	30	6.3	50.048	78.960	2.2	B	5.4	85	19/ 130	296	5.24	
88-Nov-23	3	57	9.0	49.765	78.029	5.2	D	5.4	85	13/ 92	228		
88-Dec-17	4	18	9.2	49.879	78.924	1.5	B	5.9	131	42/ 313	543	5.83	5.801
89-Jan-22	3	57	9.0	49.934	78.815	1.4	B	6.0	150	28/ 314	491	6.10	5.960
89-Feb-12	4	15	9.2	49.911	78.704	1.5	B	5.8	153	32/ 256	452	5.86	5.791
89-Feb-17	4	1	9.2	49.849	78.064	5.5	D	5.0	55	7/ 49	124		
89-Jul-08	3	47	0.0	49.869	78.775	1.7	B	5.6	102	25/ 196	375	5.55	5.418
89-Sep-02	4	16	59.9	50.019	78.988	3.0	B	5.0	60	11/ 46	135	4.94	
89-Oct-04	11	30	0.2	49.751	78.005	14.3	D	4.6	24	3/ 14	39		
89-Oct-19	9	49	59.8	49.927	78.927	1.6	B	6.0	108	25/ 190	428	5.86	5.789

Table 1 (5 of 5)

Date	approx. time hr:min	sources of information	Tzero, s NORSAR	Tzero, s S&R	lat/long S&R	mag NORSAR	mag HFS	mag S&R
61-Jun-05	03:50	V.Kh.						
61-Oct-11	07:40	Boch.						
62-Feb-02	08:00	Boch.						
64-Jun-06	00:00	V.Kh.						
64-Aug-18	06:00	V.Kh.						
65-Feb-04	06:00	V.Kh.						
65-Mar-27	06:30	V.Kh.						
65-Jul-29	03:05	V.Kh.; Boch.						
65-Oct-14	04:00	V.Kh.; Boch.						
66-Oct-29	03:58	V.An						
66-Nov-19	03:58	V.Kh.						
66-Dec-26	17:40	V.Kh.						
67-Jun-03	09:21	S&R		-1	(50, 77)			4.5
67-Jul-16	04:07	V.Kh						
67-Sep-02	04:04	V.Kh.						
68-Oct-21	03:52	Boch.						
68-Oct-29	03:54	V.Kh.						
68-Nov-12	07:30	Boch.						
68-Nov-12	07:30	Boch.						
68-Nov-12	07:30	Boch.						
69-Apr-04	04:57	V.Kh.						
69-Apr-13	04:04	V.Kh.						
69-Nov-27	05:02	V.Kh.						
70-May-27	04:03	V.Kh.; S&R; Boch.		-3	(48.3, 78.2)			3.8
71-Jan-29	05:03	V.Kh.						
71-Apr-09	02:33	V.Kh.						
72-Dec-28	04:27	V.Kh.; S&R; Boch.		0	(51.7, 77.2)			4.9
73-Mar-23	06:30	V.An	0			3.7		
73-Dec-31	04:03	V.Kh.				4.0		
74-Sep-27	07:34	Ring.						
75-Oct-05	04:27	V.Kh.; S&R	-15	43.9	(55.8, 75.1)	4.0		4.6
76-Mar-20	04:04	numerous						
76-Aug-04	02:57	V.Kh.; S&R	-15	-2	(49.9, 77.7)	3.8		4.1
77-Nov-27	03:57	Ring.						
78-Jul-31	08:00	Ring.						
79-May-24	04:07	V.Kh.; S&R	-03	0	(50, 78)	3.9		4.9
79-Sep-14	07:33	V.Kh.; S&R	-04	0	(50, 78)	4.4		5.2
79-Sep-15	04:07	V.Kh.; S&R	01	0	(50,78)	3.8		4.6
80-Jul-13	08:10	V.Kh.; S&R		0	(50,78)		5.0	5.0
80-Sep-20	10:40	V.Kh.; S&R	-03	0	(50, 78)	3.8		4.9
80-Sep-30	05:57	V.Kh.; S&R	12	0	(50, 78)	3.8		4.6
80-Sep-30	05:57	V.Kh.; S&R	17	0	(50, 78)	4.4		5.2
80-Oct-26	11:50	Ring.						
80-Nov-06	17:43	Ring.						
81-Mar-31	07:51	V.Kh.		56	(50, 79)			3.6
81-May-28	04:08	V.An						
81-Jun-05	03:22	V.Kh.; S&R	16	0	(50, 78)	4.0		4.7
81-Jul-05	03:59	V.Kh.; S&R			(50, 78)		4.6	4.6
81-Sep-30	12:55	V.Kh.; S&R	01	0	(50, 78)	4.3		4.6
81-Nov-19	05:57	Ring.						
82-Jun-11	10:59	V.Kh.; S&R	01	0	(50, 78)	4.1		4.7
82-Jul-12	10:29	V.Kh.; S&R		0	(50, 78)			4.6
82-Sep-04	05:47	V.Kh.; S&R		0	(50, 78)			4.1
82-Sep-15	04:33	V.Kh.; S&R		0	(50, 78)			5.1
83-Feb-13	03:02	V.An						
83-Jul-28	03:41	V.Kh.; S&R		0	(49, 78)			5.0
84-Jun-23	02:57	V.Kh.; S&R		0	(50, 79)			4.4
84-Aug-26	03:33	V.An						
85-Jun-27	11:57	V.An						
85-Jul-11	02:57	V.Kh.; S&R		0	(50, 78)			4.0
87-Jun-29	04:55	V.An						
87-Sep-16	07:30	V.Kh.; S&R		1	(49, 78)			5.0
88-Sep-26	07:45	V.Kh.; Sult.;H.R.R.						
88-Dec-28	05:28	V.Kh.; Ring.(90)						
89-Oct-20	13:23	V.An						

Table 2

Station code	Name	Lat	Long	Distance	Azimuth	Permanent	
		° N	° E	km	° from N	or	
						Temporary	
	STATIONS TO THE EAST						
CHGU	Chagan-Uzun	50.10	88.35	739	83	P	
ELT	Eltsovka	53.25	86.27	687	53	P	
KBZ	Kebezen	51.92	87.19	685	66	T	
KSU	Karasu	49.95	81.08	219	84	T	
MIX	Mikhailovka	48.49	81.22	273	121	T	
SEM	Semipalatinsk	50.40	80.25	171	66	P	
SKL	Skalistaya	49.57	82.60	329	93	T	
UKG	Ust-Kamenogorsk	49.83	82.28	304	88	T	
UKN	Ust-Kan	50.60	84.77	488	77	P	
ULG	Ust-Elegest	51.34	94.05	1144	75	P	
	STATION TO THE NORTH						
NSB	Novosibirsk	54.85	83.23	667	30	P	ChISS
	STATIONS TO THE SOUTH						
AND	Andizan	40.80	72.40	1094	206	P	
ATA	Alma-Ata	43.27	76.95	731	187	P	
BOM	Boomskoye	42.55	76.00	821	192	T	
BYK	Bayan-Kol	42.63	79.98	810	169	T	
CHL	Chilik	43.57	78.42	693	178	T	
CHR	Charyn	43.48	79.22	708	172	T	
EEE	E	43.03	80.46	775	165	T	
FRZ	Frunze	42.80	74.60	823	200	P	
GRM	Garm	39.01	70.32	1345	210	P	ChISS
ILI	Ili	43.95	77.08	655	187	T	
KRG	Krasnogorka	43.13	76.43	747	190	T	
KRM	Kurmenty	43.00	78.28	756	179	P	
KZA	Kzyl-Agach	45.37	78.73	496	174	T	
MRT	Markatau	45.28	80.10	525	162	T	
MDO	Medeo	43.17	77.05	741	186	T	
MKR	Mukry	44.78	78.20	558	179	T	
NGN	Namangan	41.00	71.67	1098	209	P	
NRN	Naryn	41.42	75.80	948	191	P	
ORT	Ortomerke	42.95	78.77	763	176	T	
PDG	Podgornaya	43.33	79.48	727	171	T	
PRZ	Przhevalsk	42.29	78.43	835	178	P	
RYB	Rybachye	42.43	76.12	833	191	T	
TGM	Tegermen	43.38	79.68	724	169	T	
TLG	Talgar	43.23	77.23	733	185	P	ChISS
	STATIONS TO THE WEST						
ABL	Alyk-balyk	53.02	68.71	741	302	T	
ALB	Ala-bota	53.63	70.92	651	314	T	
ART	Arti	56.40	58.60	1488	307	P	
BAY	Bayan-Ayl	50.82	75.55	211	303	T	
BRV	Borovoye	53.06	70.28	650	307	P	
CHK	Chkalovo	53.75	70.72	669	314	T	
DZK	Dzhukek	52.95	70.61	625	307	T	
KKB	Kashkarbay	53.09	69.07	723	304	T	
KKR	Kar-Karalinsk	49.33	75.38	200	256	T	
KRD	Krasny Kordon	52.96	69.03	719	303	T	
KUS	Kustanay	53.15	63.40	1082	296	T	
MAK	Makinka	52.57	70.62	604	304	T	
SVE	Sverdlovsk	56.80	60.60	1394	311	P	
VED	Vedenevka	52.63	69.50	675	301	T	
VOS	Vostochnaya	52.72	70.97	591	306	T	
ZRN1	Zerenda-1	52.93	69.05	716	303	T	ChISS
ZRN2	Zerenda-2	52.88	69.15	708	302	P	ChISS

Table 3

		Number of stations use					est. sigma:		real error:		waves
Date	Time	#	E	S	W	N	(lat	long)	(lat	long)	used
							km	km	km	km	
61-Oct-11	07:40:00	9	1	8	-	-	2.6	32.4	8.9	0.8	*Pn*
61-Oct-11	07:40:00	11	2	8	1	-	2.2	12.6	10.1	-4.0	avr
65-Jul-29	03:05:00	8	2	6	-	-	1.2	8.1	1.2	-0.4	*Pn*
65-Jul-29	03:05:00	8	2	6	-	-	2.2	19.1	5.0	-4.4	avr
65-Oct-14	04:00:00	5	2	3	-	-	3.4	14.8	-2.9	-3.0	*Pn*
65-Oct-14	04:00:00	5	2	3	-	-	5.0	47.1	11.3	-5.3	avr
66-May-07	03:58:00	2	-	2	-	-	10.0	(140)	-0.6	(-90)	avr
66-Aug-19	03:53:00	7	-	7	-	-	4.1	(100)	4.4	(100)	avr
67-Jan-30	04:02:00	8	1	7	-	-	3.6	31.8	-14.9	1.7	*Pn*
67-Jan-30	04:02:00	8	1	7	-	-	2.3	26.6	-5.5	1.1	avr
68-Oct-21	03:52:00	3	-	1	1	1	14.5	39.5	4.2	-8.6	*Pn*
68-Oct-21	03:52:00	3	-	1	1	1	8.6	23.0	-3.5	-4.0	avr
68-Nov-12	07:30:00	6	-	4	1	1	13.1	57.9	1.1	37.4	*Pn*
68-Nov-12	07:30:00	6	-	4	1	1	8.0	51.9	-9.4	-9.8	avr
70-May-27	04:03:00	3	-	1	1	1	4.1	5.6	8.6	3.6	*Pn*
70-May-27	04:03:00	3	-	1	1	1	5.8	10.7	9.4	-1.7	avr
72-Jul-06	01:03:00	2	-	1	1	-	10.8	4.8	0.3	-0.5	*Pn*
72-Jul-06	01:03:00	2	-	1	1	-	10.6	4.5	2.2	1.1	avr
72-Dec-28	04:27:00	9	2	1	5	-	2.3	3.5	8.2	-2.1	*Pn*
72-Dec-28	04:27:00	10	3	1	6	-	6.2	16.0	6.6	0.1	avr
74-Dec-07	06:00:00	6	-	3	3	-	1.9	5.9	-2.2	-9.0	*Pn*
74-Dec-07	06:00:00	8	-	3	5	-	8.3	23.1	4.7	5.8	avr
78-Sep-20	05:03:00	3	1	1	1	-	5.0	5.2	-8.1	-0.6	*Pn*
78-Sep-20	05:03:00	3	1	1	1	-	0.3	1.7	-0.8	-2.6	avr
79-Sep-27	04:13:00	7	1	1	4	1	4.7	6.0	14.3	-0.1	*Pn*
79-Sep-27	04:13:00	7	1	1	4	1	2.8	3.8	8.8	-0.7	avr
79-Nov-30	04:53:00	4	1	1	2	-	6.5	10.8	-8.1	3.0	*Pn*
79-Nov-30	04:53:00	4	1	1	2	-	6.6	12.0	-3.9	3.2	avr
79-Dec-21	04:42:00	5	-	1	3	1	5.7	10.2	-10.9	1.3	*Pn*
79-Dec-21	04:42:00	5	-	1	3	1	6.0	10.2	-13.1	0.7	avr
80-Sep-25	06:21:13	6	2	1	3	-	6.3	6.0	17.4	-2.5	*Pn*
80-Sep-25	06:21:13	6	2	1	3	-	7.3	6.0	22.7	-2.1	avr
80-Dec-26	04:07:09	2	1	1	-	-	10.8	4.8	-16.7	11.1	*Pn*
80-Dec-26	04:07:09	2	1	1	-	-	10.8	4.8	-3.3	5.4	avr
87-Sep-18	02:32:10	3	2	1	-	-	16.1	52.0	-4.3	8.2	avr

Table 4

Date	Time	est. location: (lat, deg	long) deg	est. sigma: (lat, km	long) km	Number of stations used: #	E	S	W	N
65-Mar-27	06:30:00	49.85	77.94	4.2	12.2	3	1	2	-	-
66-Oct-29	03:58:00	49.64	78.05	7.0	4.9	4	1	2	1	-
66-Nov-19	03:58:00	49.84	78.09	4.8	16.6	5	2	3	-	-
66-Dec-26	17:39:38	49.40	78.75	8.0	15.0	10	2	7	1	-
67-Sep-02	04:04:00	49.79	78.02	1.3	7.9	4	-	4	1	-
68-Oct-29	03:54:00	49.86	78.15	4.0	23.1	7	-	5	1	1
69-Apr-13	04:04:00	49.61	77.93	2.9	8.1	4	1	3	-	-
69-Nov-27	05:02:00	49.79	78.25	4.7	8.7	3	-	1	2	-
71-Jan-29	05:03:00	49.77	78.11	3.6	15.2	5	-	4	1	-
71-Apr-09	02:33:00	49.88	78.02	5.3	9.5	5	1	2	1	1
73-Mar-23	06:30:00	49.76	79.84	10.0	12.0	2	1	1	-	-
73-Dec-31	04:03:00	49.75	78.04	4.8	7.7	8	1	3	3	1
75-Oct-05	04:27:00	49.81	78.10	2.0	5.3	7	-	3	4	1
76-Mar-20	04:03:39	50.02	77.37	15.0	12.0	8	-	4	3	1
76-Aug-04	02:57:00	50.04	77.91	6.9	7.4	4	1	1	1	1
77-Nov-27	03:57:00	49.78	78.03	0.9	3.8	4	1	3	-	-
78-Jul-31	08:00:00	49.68	78.33	17.3	25.0	3	1	2	-	-
79-May-24	04:07:00	49.96	78.81	4.8	11.0	4	1	2	-	1
79-Sep-14	07:33:00	50.05	78.53	6.8	14.3	3	-	2	1	-
79-Sep-15	04:07:00	49.75	78.41	11.5	21.6	4	1	2	1	-
80-Jul-13	08:10:00	50.00	78.39	8.5	15.6	4	1	2	1	-
80-Sep-20	10:40:01	49.88	78.81	1.5	5.6	3	1	2	-	-
80-Sep-30	05:57:12	49.97	78.05	8.6	20.2	5	1	2	1	1
80-Sep-30	05:57:17	50.02	78.15	13.7	17.8	4	1	2	1	-
80-Nov-06	17:42:58.5	50.15	78.80	2.0	4.0	3	1	2	-	-
81-Jun-05	03:22:20.5	49.80	78.86	7.9	15.5	4	1	2	-	1
81-Jul-05	03:59:18	49.85	78.90	6.3	10.5	4	1	2	-	1
81-Sep-30	12:55:10	50.00	78.80	3.5	6.4	4	1	2	-	1
81-Nov-19	05:57:14	50.20	78.71	10.0	10.0	4	1	3	-	-
82-Jun-11	10:59:07	50.00	78.62	4.1	12.9	4	1	2	-	1
82-Jul-12	10:29:18	49.82	78.24	10.2	39.5	3	-	2	-	1
82-Sep-04	05:47:17	50.10	78.56	18.4	26.1	3	1	2	-	-
82-Sep-15	04:33:19	49.84	79.02	2.5	5.0	4	1	2	-	1
83-Jul-28	03 41 28	50.01	78.15	5.7	13.7	4	1	2	-	1
84-Jun-23	02:57:16	49.93	79.01	2.2	4.5	3	1	2	-	-
85-Jul-11	02:57:02	49.82	78.02	10.0	20.5	2	1	1	-	-
87-Sep-16	07:30:01	49.85	78.79	6.7	12.7	8	1	5	1	1
88-Sep-26	07:45:02	49.93	78.90	18.0	16.0	8	2	4	1	1
88-Dec-28	05:28:08	50.22	77.89	51.8	13.1	8	3	3	2	-

Table 5

		est. location:		est. sigma:		Number of stations used:				
Date	Time	(lat,	long)	(lat,	long)	#	E	S	W	N
		deg	deg	km	km					
64-Jun-06	00:00:00	49.80	(77.40)	7.8	100.0	6	-	6	-	-
64-Aug-18	06:00:00	49.81	(79.10)	8.5	100.0	2	-	2	-	-
65-Feb-04	06:00:00	49.80	(78.90)	6.4	40.0	4	-	4	-	-
87-Jun-29	04:55:08	50.10	78.96	18.0	16.0	2	2	-	-	-

Table 6

Date	Time	Station	phases	ΔD	direction
61-Jun-05	03:50:00	MIX	avr-4	3	North
69-Apr-04	03:57:00	TLG	avr-3	6	North
74-Sep-27	07:34:00	TLG	avr-3	30	North
81-May-28	04:08:	UKN	avr-2	13	West
85-Jun-27	11:57:00	UKN	avr-2	10	West
89-Oct-20	13:22:45	BRV	avr-2	21	West

Table 7

		est. location:		est. sigma:		Number of stations used:				
Date	Time	(lat,	long)	(lat,	long)	#	E	S	W	N
		deg	deg	km	km					
66-Jun-03	09:21:10	51.68	75.10	6.5	13.0	3	1	2	-	-
67-Jul-16	4:07	51.80	78.90	25.0	3.0			1		
81-Mar-31	07:51:30	47.97	(80.00)	10.0	50.0	5	-	5	-	-
84-Aug-26	03:32:57	50.38	71.64	-	-	2	2	-	-	-
same event	alt. location:	55.60	95.70	-	-	2	2	-	-	-
80-Oct-26	11:49:44	far from STS		(ΔD = 813 km)		1	-	1	-	-
83-Feb-13	03:02:09	also far: (ΔD = 277 or 340 km)				1	1	-	-	-

Table 8

			FIVE DIFFERENT MAGNITUDES				
Date	Time	K	M(K)	M(CHISS)	NORSAR	HFS	ISC
61-Jun-05	03:50:00	10.5	4.09				
61-Oct-11	07:40:00		4.81				
62-Feb-02	08:00:00	14.0	5.63				5.5
64-Jun-06	00:00:00	11.0	4.31				
64-Aug-18	06:00:00	8.5	3.21				
65-Feb-04	06:00:00	12.5	4.97				
65-Mar-27	06:30:00	8.4	3.17				
65-Jul-29	03:05:00	10.7	4.19				4.5
65-Oct-14	04:00:00	10.7	4.16				
66-Oct-29	03:58:00	9.0	3.43				
66-Nov-19	03:58:00	8.7	3.30				
66-Dec-26	17:39:38	10.7	4.18				
67-Jun-03	09:21:10	11.7	4.62				
67-Sep-02	04:04:00	10.3	4.00				
68-Oct-21	03:52:00	10.2	3.96				
68-Oct-29	03:54:00	10.8	4.22				
68-Nov-12	07:30:00	10.6	4.13				
69-Apr-04	03:57:00	9.2	3.52				
69-Apr-13	04:04:00	11.3	4.44				
69-Nov-27	05:02:00	10.3	4.00				
70-May-27	04:03:00	10.3	4.02	3.80			
71-Jan-29	05:03:00	11.1	4.35				
71-Apr-09	02:33:00	9.6	3.69				
72-Dec-28	04:27:00	11.4	4.46				
73-Mar-23	06:30:00	9.5	3.65		3.7		
73-Dec-31	04:03:00	10.6	4.13		4.0		
74-Sep-27	07:34:00	10.5	4.09		3.9		
75-Oct-05	04:27:00	10.7	4.18		4.0		
76-Aug-04	02:57:00	10.5	4.09		3.8		4.1
77-Nov-27	03:57:00	9.9	3.83		3.4		
78-Jul-31	08:00:00	10.2	3.96		3.9		
79-May-24	04:07:00	10.3	4.00		3.9		3.9
79-Sep-14	07:33:00	10.8	4.22		4.4		
79-Sep-15	04:07:00	8.8	3.34	3.90	3.8		4.6
80-Jul-13	08:10:00	10.2	3.96	4.30		5.0	
80-Sep-20	10:40:01	9.6	3.69	4.06	3.8		
80-Sep-30	05:57:12	-			3.8		3.8
80-Sep-30	05:57:17	10.7	4.18		4.4		4.4
80-Nov-06	17:42:58	9.6	3.69		3.9		
81-Mar-31	07:51:30	12.2	4.84				
81-May-28	04:08:28	7.7	2.86				
81-Jun-05	03:22:18	10.4	4.05	4.34	4.0		
81-Jul-05	03:59:14	10.1	3.91	4.27		4.6	
81-Sep-30	12:55:10	10.2	3.96		4.3		
81-Nov-19	05:57:14	9.6	3.69		4.0		
82-Jun-11	10:59:07	10.3	4.00	4.21	4.1		
82-Jul-12	10:29:18	10.6	4.13	4.26	3.9		
82-Sep-04	05:47:17	9.5	3.65		3.6		
82-Sep-15	04:33:19	10.7	4.18	4.40	4.2		
83-Feb-13	03:02:09	9.9	3.83				
83-Jul-28	03:41:28	10.7	4.18	4.25	4.3		
84-Jun-23	02:57:16	11.1	4.35		4.4		
84-Aug-26	03:32:57	8.3	3.12				
85-Jun-27	11:57:00	8.5	3.21				
85-Jul-11	02:57:02	10.2	3.96		3.5		
87-Jun-29	04:55:08	8.5	3.21				
87-Sep-16	07:30:01	10.4	4.05	4.28			4.3
88-Sep-26	07:45:04	10.7	4.18				4.3
88-Dec-28	05:28:09	9.5	3.65				

Table 9

Year	UNEs: from Russian sources	UNEs: located, & in seismology literature	Chemical Explosions: reported by Saybekov (1993): Surface (over 10 tons)	Sub-Surface (over 10 tons)	Total/year (Chem Ex)	Possible additional explosions (this study)
1961	1	1				1
1962	1	1				0
1963	0	0				0
1964	7	4				2
1965	11	10				2
1966	17	12				2
1967	16	14				1
1968	18	14				1
1969	14	10				3
1970	11	9		1	1	0
1971	15	11				2
1972	14	12		1	1	0
1973	9	6		3	3	2
1974	14	13	1	2	3	1
1975	14	9		1	1	1
1976	15	12	1	2	3	1
1977	16	11	1		1	1
1978	18	18	1		1	1
1979	18	16		3	3	3
1980	17	13		4	4	5
1981	12	12		4	4	5
1982	10	10	2	3	5	4
1983	12	11	1	1	2	1
1984	13	14	4	2	6	1
1985	12	6	1		1	2
1986	0	0				0
1987	17	15	2	1	3	2
1988	12	11	1	1	2	1
1989	9	7	—	—	—	0
	343	**282**	**15**	**29**	**44**	**45** (Chemical or Nuclear)

Table 10

Date	Time	Lat	Long	Δlat/long		mag	site	P(site)	type	P(type)	
		°	°	km	km						
61-Jun-05	03:50:00	49.80	78.08	-	-	4.27	Deg	1.00	ChE	1.00	
64-Jun-06	00:00:00	49.79	78.00	5	20	4.31	Deg	0.99	UNE	0.99	
64-Aug-18	06:00:00	49.81	78.10	8	25	3.21	Deg	0.99	UNE	0.99	
65-Feb-04	06:00:00	49.78	78.12	8	18	4.88	Deg	0.95	UNE	0.95	
65-Mar-27	06:30:00	49.82	78.00	5	8	3.17	Deg	0.95	UNE	0.95	
66-Oct-29	03:58:00	49.74	78.07	8	8	3.43	Deg	0.99	UNE	0.99	
66-Nov-19	03:58:00	49.70	78.20	6	12	3.32	Deg	0.99	UNE	0.99	
66-Dec-26	17:39:38.5	49.52	78.71	8	8	4.19	SW from Bal		EQ	1.00	
67-Sep-02	04:04:00	49.79	78.02	5	5	4.00	Deg	0.99	UNE	0.99	
68-Oct-29	03:54:00	49.84	78.14	8	12	4.19	Deg	0.99	UNE	0.99	
69-Apr-04	04:57:00	one	station	-	-	3.52	Deg	0.90	UNE	0.90	
69-Apr-13	04:04:00	49.70	77.92	8	12	4.23	Deg	0.99	UNE	0.99	
69-Nov-27	05:02:00	49.79	78.40	10	30	4.00	Deg	0.70	UNE	0.70	
71-Jan-29	05:03:00	49.77	78.11	5	8	4.35	Deg	0.99	UNE	0.99	
71-Apr-09	02:33:00	49.88	78.02	5	8	3.69	Deg	0.99	UNE	0.99	
73-Mar-23	06:30:00	49.94	79.06	3	20	3.66	Bal	0.90	UNE	0.90	
73-Dec-31	04:03:00	49.75	78.04	5	10	4.12	Deg	0.99	UNE	0.99	
74-Sep-27	07:34:00	49.98	79.00	12	50	4.08	Bal	0.70	UNE	0.50	
75-Oct-05	04:27:00	49.81	78.10	4	5	4.18	Deg	0.99	UNE	0.99	
76-Aug-04	02:57:00	49.87	77.70	15	18	4.08	Mrz	0.90	UNE	0.90	
77-Nov-27	03:57:00	49.80	78.06	3	7	3.83	Deg	0.99	UNE	0.99	
78-Jul-31	08:00:00	50.27	78.19	8	10	3.96	N from Deg		ChE	0.80	or UNE
79-May-24	04:07:00	49.94	78.79	8	10	4.02	Bal	0.90	UNE	0.90	or ChE
79-Sep-14	07:33:00	49.95	78.84	5	8	4.20	Bal	0.90	UNE	0.70	or ChE
79-Sep-15	04:07:00	49.94	78.82	10	5	3.36	Bal	0.95	UNE	0.70	or ChE
80-Jul-13	08:10:00	49.91	78.84	5	5	3.97	Bal	0.99	UNE	0.99	
80-Sep-20	10:40:01.5	49.96	78.88	5	5	3.69	Bal	1.00	UNE	0.90	or ChE
80-Sep-30	05:57:12	49.95	78.40	12	8		between B&D		UNE	0.70	or ChE
80-Sep-30	05:57:17	49.95	78.40	12	12	4.20	between B&D		UNE	0.70	or ChE
80-Nov-06	17:42:58.5	50.14	78.76	10	15	3.68	NW from Bal		EQ	1.00	
81-May-28	04:08:30	one	station	-	-	2.86	Deg	0.30	UNE	0.50	
81-Jun-05	03:22:18	49.84	78.72	12	20	4.08	Bal	0.50	UNE	0.50	or ChE
81-Jul-05	03:59:14	49.87	78.99	15	18	3.88	Bal	0.90	UNE	0.50	or ChE
81-Sep-30	12:55:10	49.94	78.90	10	15	3.96	Bal	1.00	ChE	0.90	or UNE
81-Nov-19	05:57:15	50.11	78.95	12	15	3.69	N from Bal		ChE	0.70	or UNE
82-Jun-11	10:59:06	49.93	78.50	12	20	4.00	between B&D		ChE	0.90	or UNE
82-Jul-12	10:29:18	49.90	77.90	20	40	4.15	N from Deg		ChE	0.90	or UNE
82-Sep-04	05:47:17	50.06	78.56	10	10	3.64	between B&D		ChE	0.90	or UNE
82-Sep-15	04:33:17	49.85	78.85	20	40	4.18	Bal	0.50	ChE	0.80	or UNE
83-Jul-28	03:41:25	50.07	78.60	12	12	4.17	between B&D		ChE	0.90	or UNE
84-Jun-23	02:57:16	49.92	78.93	6	10	4.34	Bal	1.00	UNE	0.50	or ChE
85-Jun-27	11:57:04	one	station	-	-	3.21	Deg	0.20	UNE	0.20	or ChE
85-Jul-11	02:57:02	49.78	77.90	10	15	3.94	Deg	0.50	UNE	0.80	or ChE
87-Jun-29	04:55:11.5	one	station	-	-	3.21	Deg	0.40	UNE	0.70	or ChE
87-Sep-16	07:30:01	49.86	78.73	15	12	4.06	Bal	0.50	UNE	0.70	or ChE
88-Sep-26	07:45:01	50.08	78.80	12	15	3.91	N from Bal		ChE	0.50	EQ 0.4
88-Dec-28	05:28:09.5	49.80	78.06	4	5	4.16	Deg	1.00	UNE	1.00	
89-Oct-20	13:22:45	one	station	-	-	3.63	Bal	0.30	Collapse?		

Table 11

Date	Time	Lat °	Long °	Δlat km	Δlong km	# records used	# sta to S	# sta to W&E	Total # of arrivals for loc.	K	# sta for K	mag	Comment
61-Jun-05	03:50:00	49.80	78.08	-	-	1	1	-	4	10.5	1	4.09	Deg; ChE before first UNE
61-Oct-11	07:40:00	49.77	78.00									4.81	Deg; first Soviet UNE; Boch.
62-Feb-02	08:00:00	49.78	78.00							14.0	4	5.63	Deg; UNE; Boch.
64-Jun-06	00:00:00	49.79	78.00	5	20	2	5	1	11	11.0	3	4.31	Deg; UNE
64-Aug-18	06:00:00	49.81	78.10	8	25	1	2	-	5	8.5	1	3.21	Deg; UNE
65-Feb-04	06:00:00	49.78	78.12	8	18	1	4	-	6	12.5	1	4.97	Deg; UNE; obscured by Aleutian eq.
65-Mar-27	06:30:00	49.82	78.00	5	8	1	2	1	6	8.4	2	3.17	Deg; UNE
65-Jul-29	03:05:00	49.78	78.00							10.7	3	4.19	Deg; UNE; Boch.
65-Oct-14	04:00:00	49.99	77.64							10.7	2	4.16	Mrz; UNE; 1100 tons; Boch.
66-Oct-29	03:58:00	49.74	78.07	8	8	-	2	2	10	9.0	3	3.43	Deg; UNE
66-Nov-19	03:58:00	49.70	78.20	6	12	1	4	2	9	8.7	2	3.32	Deg; UNE
66-Dec-26	17:39:38.5	49.52	78.71	8	8	3	8	3	27	10.7	3	4.19	S of Bal; Eq
67-Jun-03	09:21:10	51.70	75.40							11.7	3	4.62	Off Test Site to NW; ChE; 4 sta.
67-Jul-16	04:07:09	50.70	76.50							10.5	1	4.08	Off Test Site to NW; ChE or Eq; 4 sta.
67-Sep-02	04:04:00	49.79	78.02	5	5	3	3	1	9	10.3	2	4.00	Deg; UNE
68-Oct-21	03:52:00	49.73	78.49							10.2	2	3.96	UNE crater shot; 200 tons; Boch.
68-Oct-29	03:54:00	49.84	78.14	8	12	1	5	2	14	10.8	3	4.19	Deg; UNE
68-Nov-12	07:30:00	49.71	78.46							10.6	3	4.13	Three UNE crater shots; Boch.;
68-Nov-12	07:30:00	49.71	78.46						2nd of three concurrent shots				all three shots are E of Deg &
68-Nov-12	07:30:00	49.71	78.46						3rd of three concurrent shots				SW of Bal; 200 tons each
69-Apr-04	04:57:00	one	station	-	-	1	1	-	3	9.2	1	3.52	Deg; UNE
69-Apr-13	04:04:00	49.70	77.92	8	12	-	3	1	13	11.3	3	4.43	Deg; UNE
69-Nov-27	05:02:00	49.79	78.40	10	30	1	1	2	8	10.3	1	4.00	Deg; UNE
70-May-27	04:03:00	49.73	78.10							10.3	3	4.01	Deg; UNE; Boch.
71-Jan-29	05:03:00	49.77	78.11	5	8	2	5	1	14	11.1	2	4.35	Deg; UNE
71-Apr-09	02:33:00	49.88	78.02	5	8	1	3	4	16	9.6	1	3.69	Deg; UNE
72-Dec-28	04:27:00	49.74	78.11							11.4	2	4.62	Deg; UNE; Boch.
73-Mar-23	06:30:00	49.94	79.06	3	20	-	2	-	5	9.5	3	3.66	Bal; ChE
73-Dec-31	04:03:00	49.75	78.04	5	10	1	3	5	13	10.6	3	4.12	Deg; UNE
74-Sep-27	07:34:00	49.98	79.00	12	50	-	3	-	6	10.5	3	4.08	Bal; ChE
75-Oct-05	04:27:00	49.81	78.10	4	5	2	4	3	15	10.7	5	4.18	Deg; UNE
76-Mar-20	04:03:36	50.00	77.25	8	15	8	4	4	17	13.0	5	5.19	W of Deg; Eq
76-Aug-04	02:57:00	49.87	77.70	15	18	1	1	4	10	10.5	3	4.08	Mrz; UNE
77-Nov-27	03:57:00	49.80	78.06	3	7	-	4	1	11	9.9	3	3.83	Deg; UNE
78-Jul-31	08:00:00	50.27	78.19	8	10	-	5	1	14	10.2	5	3.96	N of Deg; ChE or UNE
79-May-24	04:07:00	49.94	78.79	8	10	1	2	2	14	10.3	3	4.02	Bal; ChE
79-Sep-14	07:33:00	49.95	78.84	5	8	-	2	1	8	10.8	2	4.20	Bal; ChE
79-Sep-15	04:07:00	49.94	78.82	10	5	1	1	2	6	8.8	2	3.36	Bal; ChE
80-Jul-13	08:10:00	49.91	78.84	5	5	-	2	2	11	10.2	3	3.97	Bal; ChE
80-Sep-20	10:40:01.5	49.96	78.88	5	5	-	2	2	9	9.6	3	3.69	Bal; ChE
80-Sep-30	05:57:12	49.95	78.40	12	8	1	2	3	10	-	-		between Bal & Deg; ChE
80-Sep-30	05:57:17	49.95	78.40	12	12	1	2	4	12	10.7	2	4.20	between Bal & Deg; ChE
80-Oct-26	11:49:44	43.00	96.00										Far from Test Site; 3 sta.
80-Nov-06	17:42:58.5	50.14	78.76	10	15	-	4	1	12	9.6	3	3.68	NW of Bal; ChE
81-Mar-31	07:51:30	47.80	81.00							12.2	3	4.84	Off Test Site to SE; ChE or Eq; 5 sta.
81-May-28	04:08:30	one	station	-	-	-	-	1	2	7.7	1	2.86	Deg; UNE
81-Jun-05	03:22:18	49.84	78.72	12	20	1	2	2	10	10.4	3	4.08	Bal; ChE
81-Jul-05	03:59:14	49.87	78.99	15	18	1	2	2	12	10.1	3	3.88	Bal; ChE
81-Sep-30	12:55:10	49.94	78.90	10	15	-	2	2	12	10.2	3	3.96	Bal; ChE
81-Nov-19	05:57:15	50.11	78.95	12	15	-	3	1	11	9.6	4	3.69	N of Bal; ChE
82-Jun-11	10:59:06	49.93	78.50	12	20	1	2	2	13	10.3	4	4.00	between Bal & Deg; ChE
82-Jul-12	10:29:18	49.90	77.90	20	40	1	2	1	12	10.6	3	4.15	N of Deg; ChE or UNE
82-Sep-04	05:47:17	50.06	78.56	10	10	1	2	1	10	9.5	3	3.64	between Bal & Deg; ChE
82-Sep-15	04:33:17	49.85	78.85	20	40	-	2	2	14	10.7	3	4.18	Bal; ChE
83-Feb-13	03:02:09	39.50	74.00							9.9	3	3.83	Far from Test Site; 4 sta.
83-Jul-28	03:41:25	50.07	78.60	12	12	1	2	-	4	10.7	3	4.17	between Bal & Deg; ChE
84-Jun-23	02:57:16	49.92	78.93	6	10	1	6	1	24	11.1	7	4.34	Bal; ChE
84-Aug-26	03:32:57	50.40	71.60							8.3	2	3.12	Far from Test Site; 2 sta.
85-Jun-27	11:57:04	one	station	-	-	-	-	1	2	8.5	1	3.21	Deg; ChE or UNE
85-Jul-11	02:57:02	49.78	77.90	10	15	-	1	1	6	10.2	2	3.94	Deg; UNE
87-Jun-29	04:55:11.5	one	station	-	-	-	-	2	5	8.5	1	3.21	Deg; UNE
87-Sep-16	07:30:01	49.86	78.73	15	12	-	5	3	21	10.4	5	4.06	Bal; ChE
88-Sep-26	07:45:01	50.08	78.80	12	15	2	5	8	32	10.7	4	4.16	N of Bal; ChE
88-Dec-28	05:28:09.5	49.80	78.06	4	5	2	3	6	24	9.5	4	3.63	Deg; UNE; Ringdal (1990)
89-Oct-20	13:22:45	one	station	-	-	-	-	1	2	-	-	-	Deg; ChE or UNE cavity collapse?

Table 12

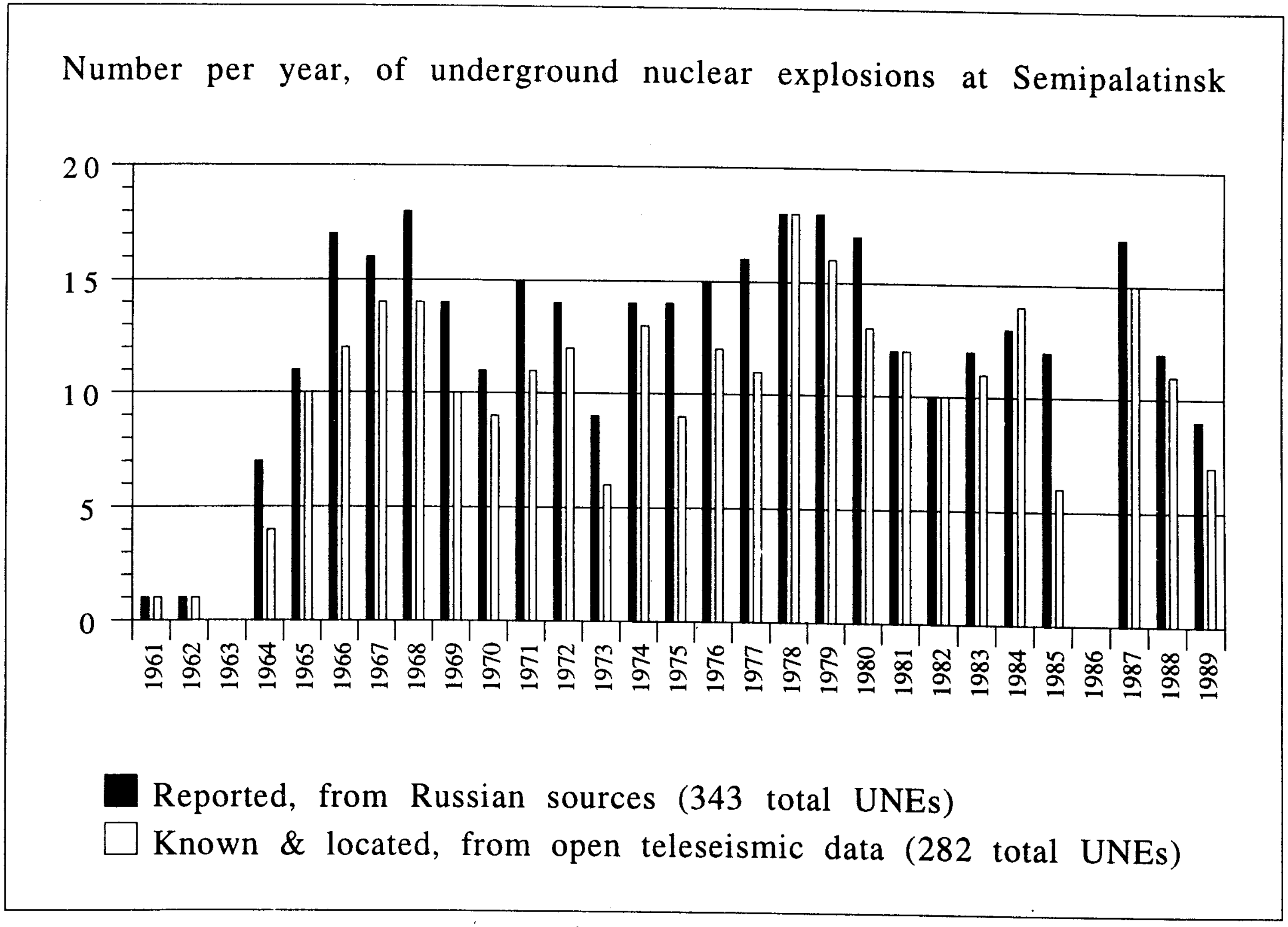
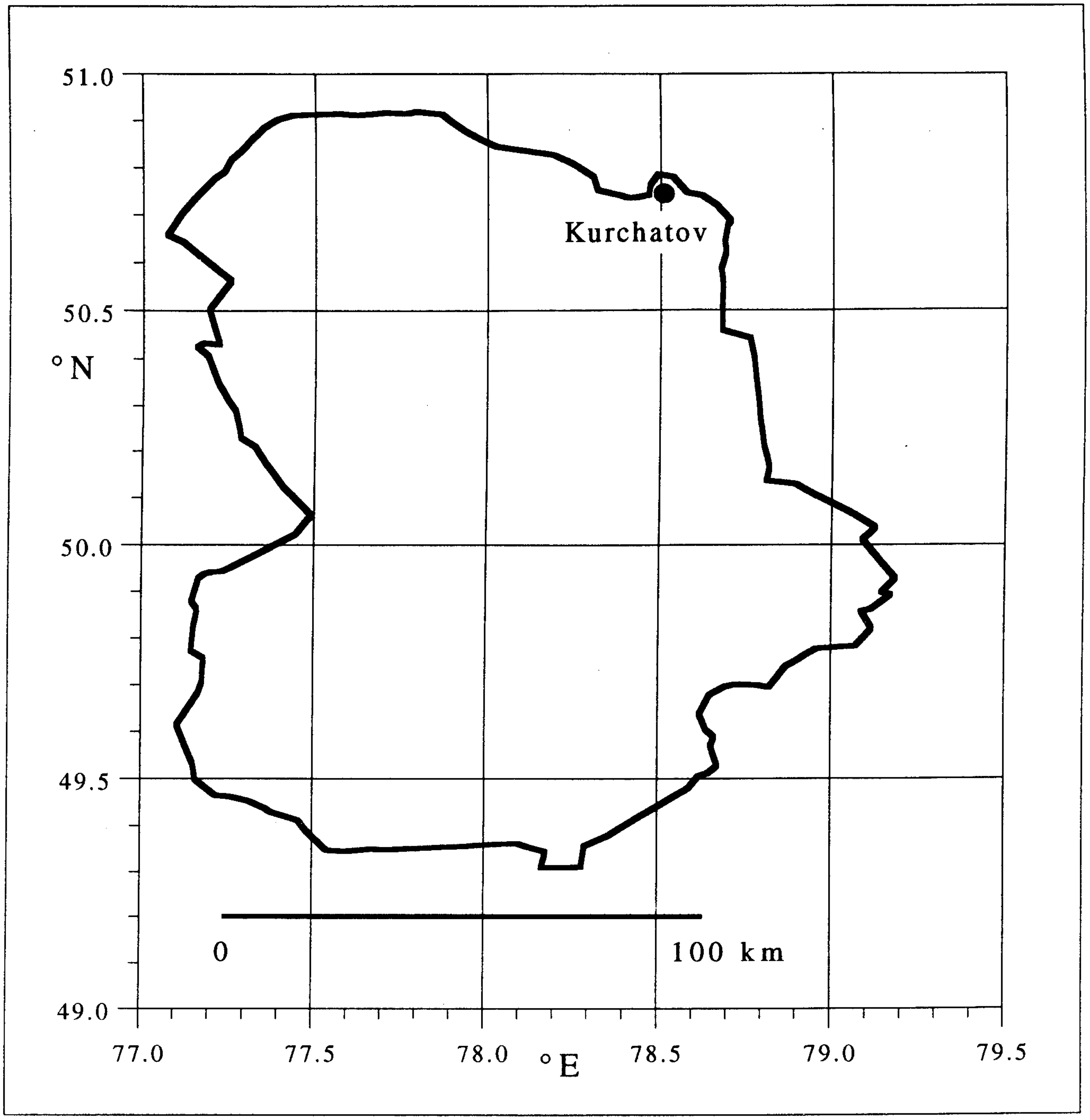

Number per year, of underground nuclear explosions at Semipalatinsk
20
15
10
5
0
1961
1962
1963
1964
1965
1966
1967
1968
1969
1970
1971
1972
1973
1974
1975
1976
1977
1978
1979
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
Reported, from Russian sources (343 total UNEs)
Known & located, from open teleseismic data (282 total UNEs)

Figure 1



The boundaries of the Semipalatinsk Test Site, East Kazakhstan

Figure 2

52 stations at regional distances from the Semipalatinsk Test Site

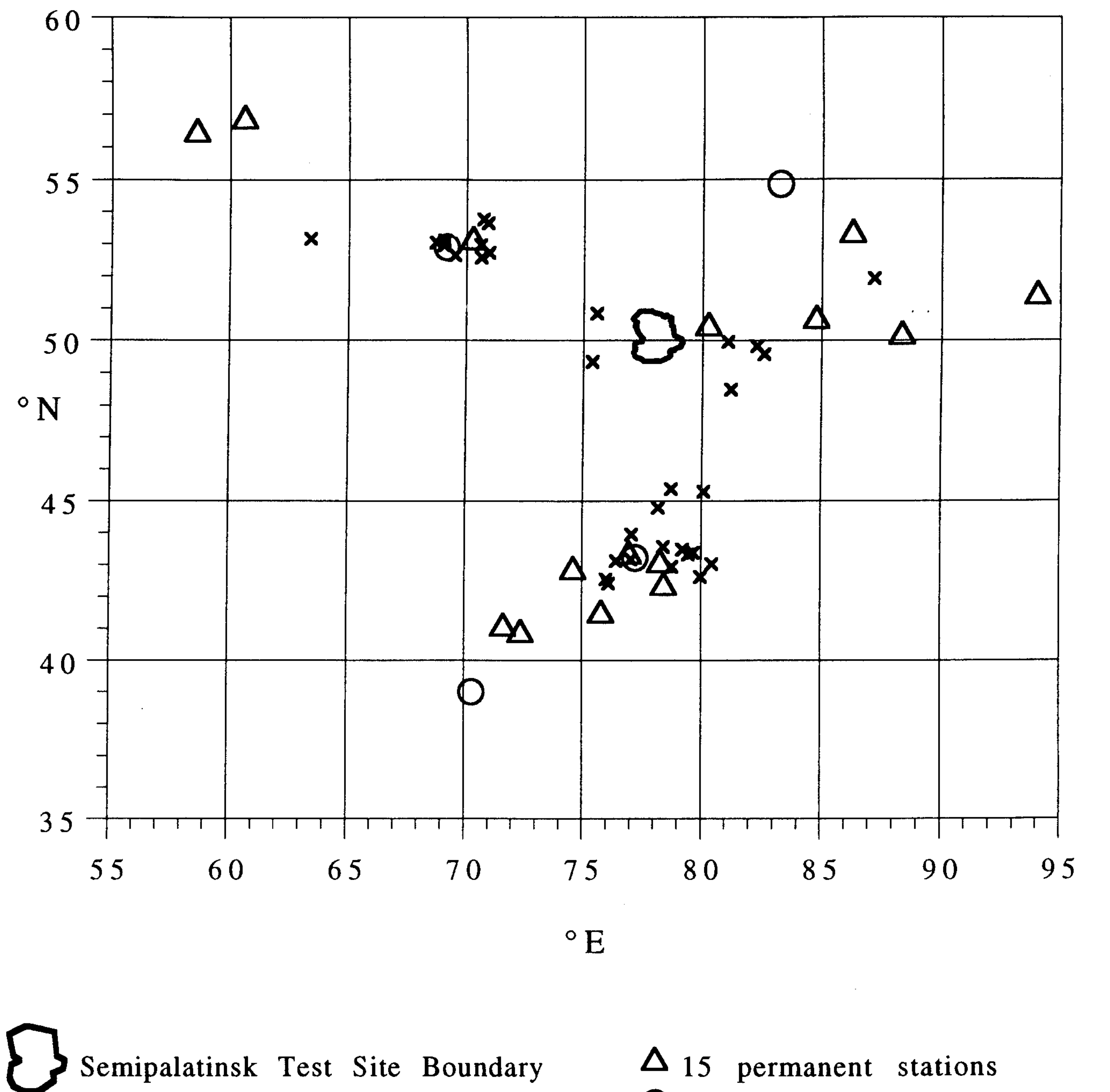
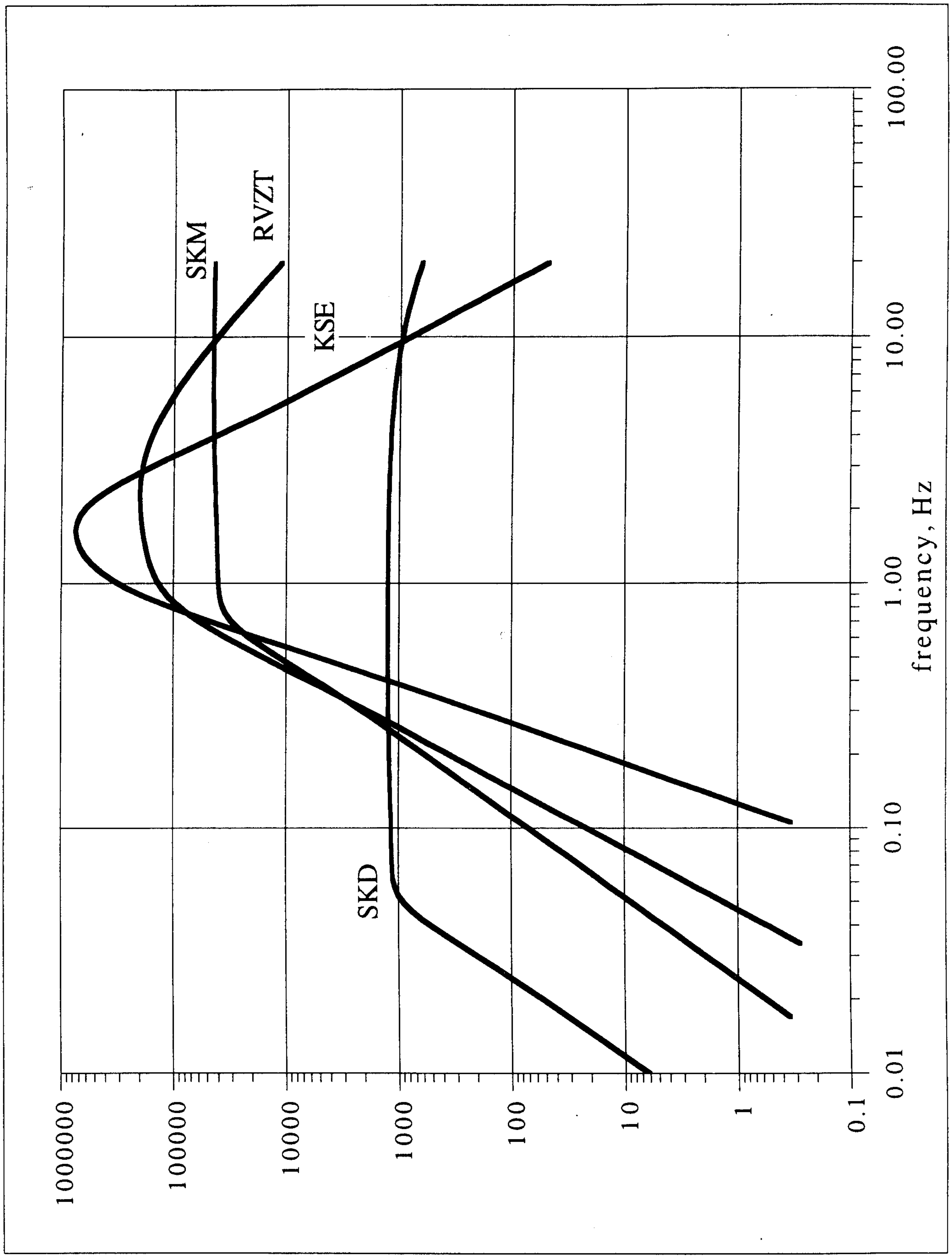


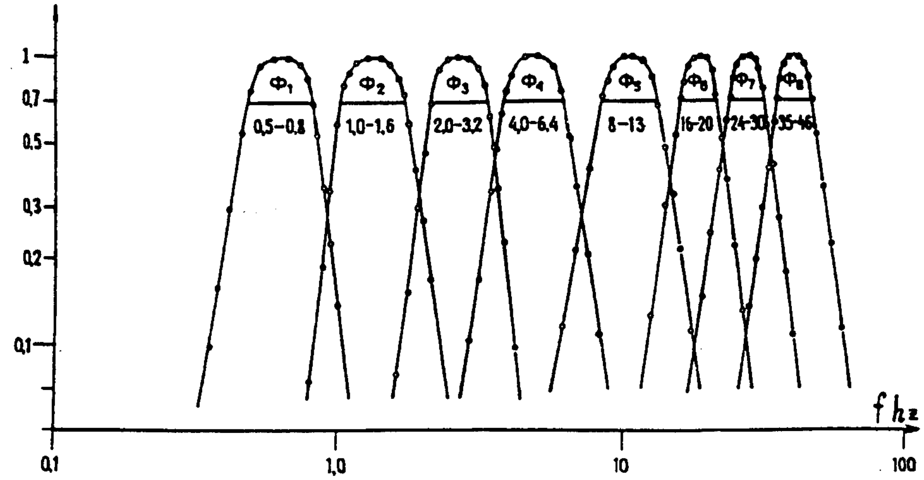
Figure 3



SKM
RVZT
KSE
SKD
1000000
100000
10000
1000
100
10
1
0.1
0.01
0.10
1.00
10.00
100.00
frequency, Hz

Figure 4a

ChISS amplitude response



ChISS impulse response

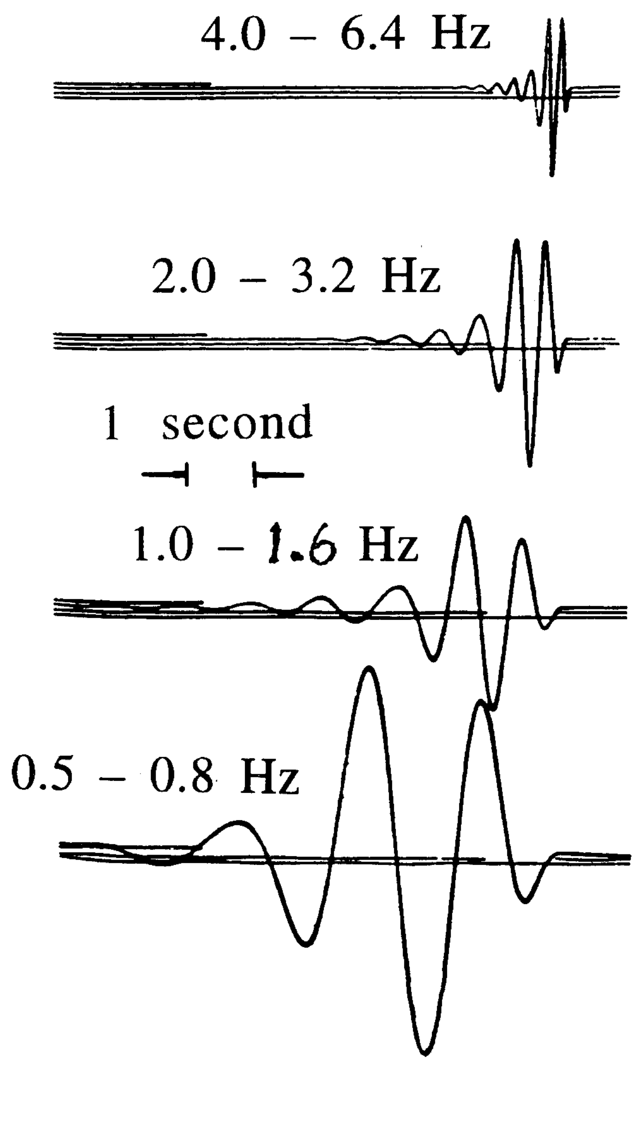


Figure 4 b

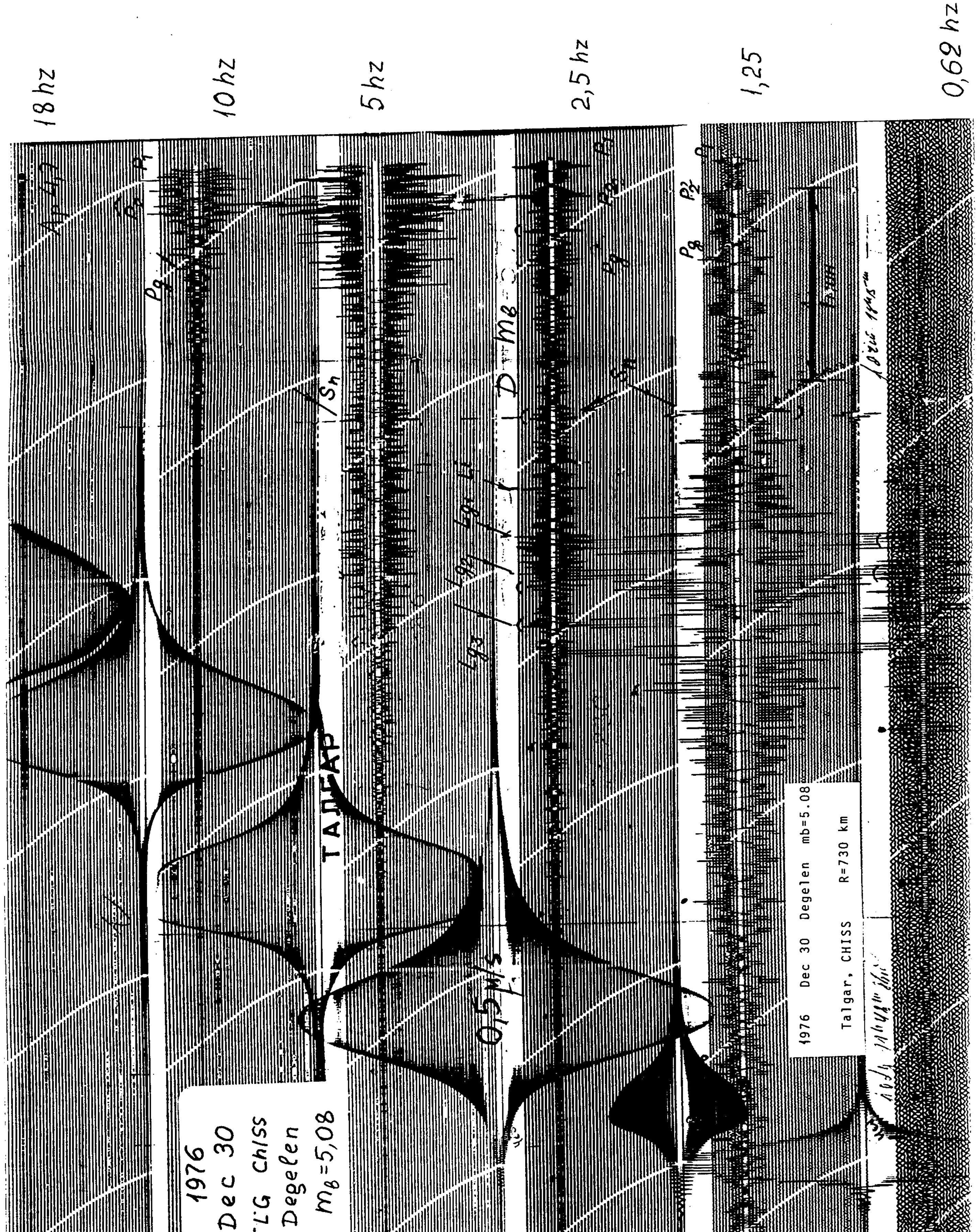

18hz
10hz
5hz
2,5hz
1,25
0,62hz
1976
Dec 30
TLG CHISS
Degelen
m_B=5,08
ТАЛГАР
0,5 M/S
1976 Dec 30 Degelen mb=5.08
Talgar, CHISS R=730 km

Figure 5a

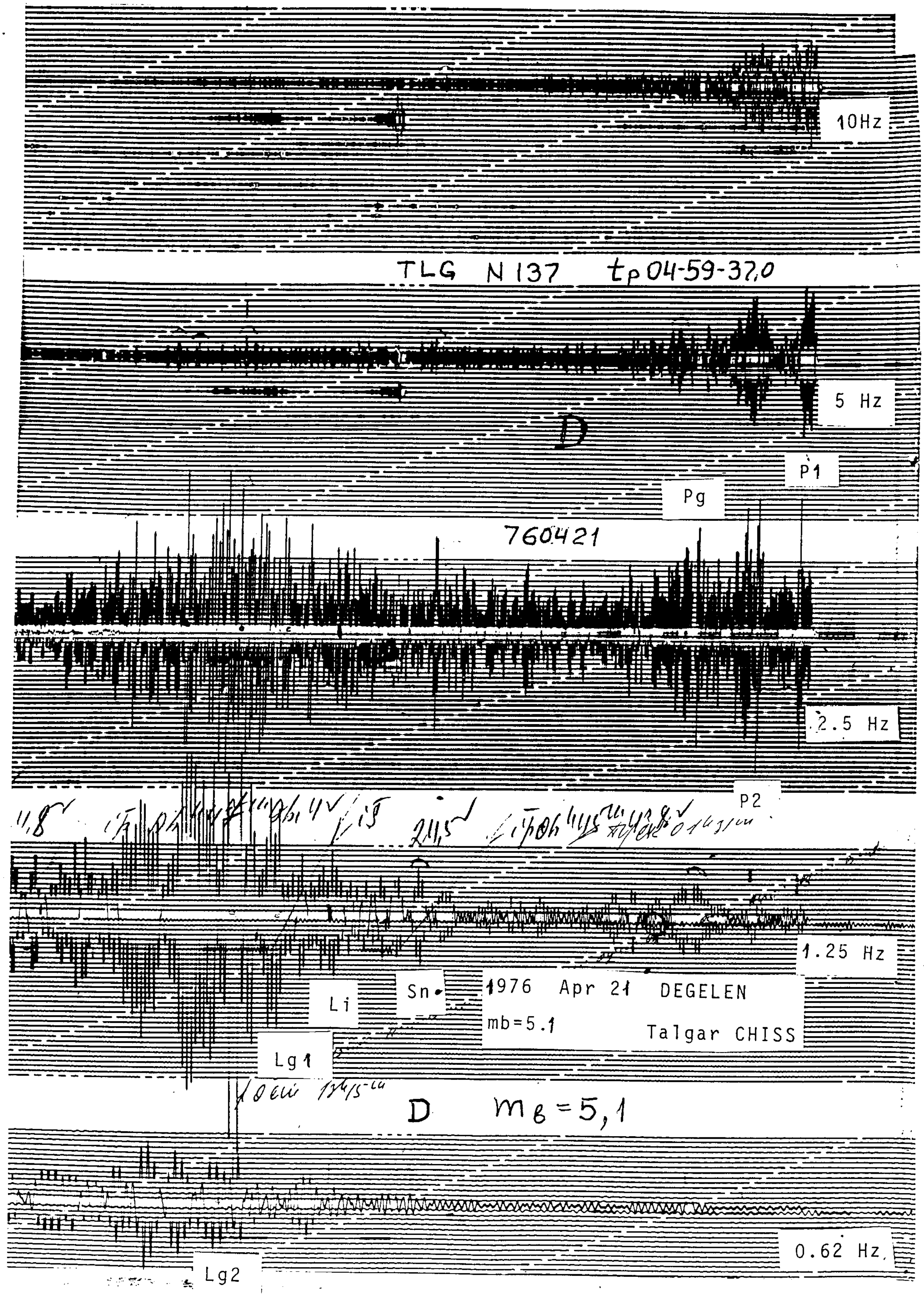

10Hz
TLG N 137 tp 04-59-37,0
5 Hz
D
P1
Pg
760421
2.5 Hz
P2
1.25 Hz
Li
Sn
1976 Apr 21 DEGELEN
mb=5.1
Talgar CHISS
Lg1
D mв=5,1
0.62 Hz
Lg2

Figure 5b

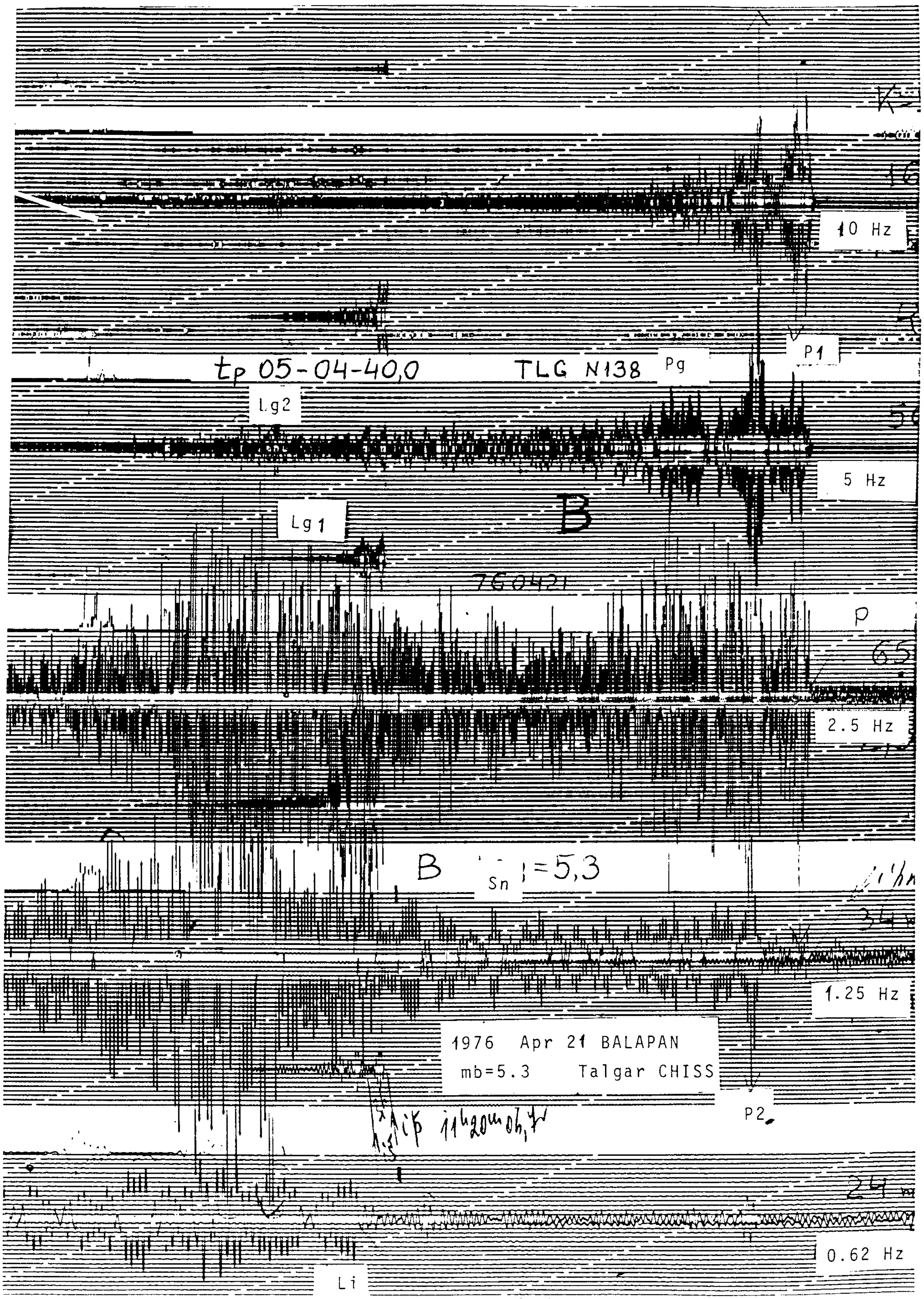

10 Hz
tp 05-04-40,0
TLG N138
Pg
P1
Lg2
5 Hz
B
Lg1
760421
P
2.5 Hz
B
Sn
=5,3
1.25 Hz
1976 Apr 21 BALAPAN
mb=5.3 Talgar CHISS
P2
0.62 Hz
Li

Figure 5c

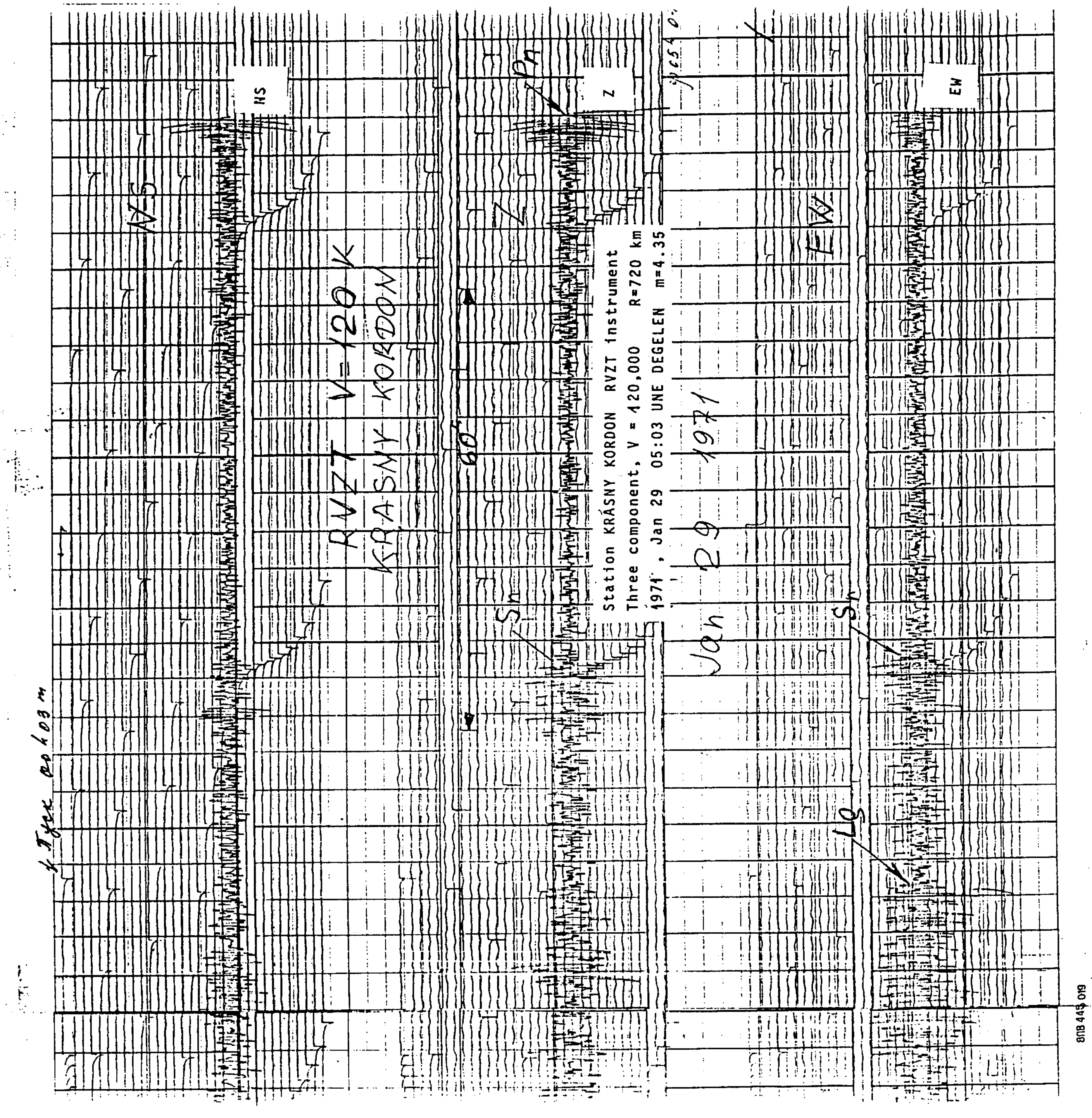
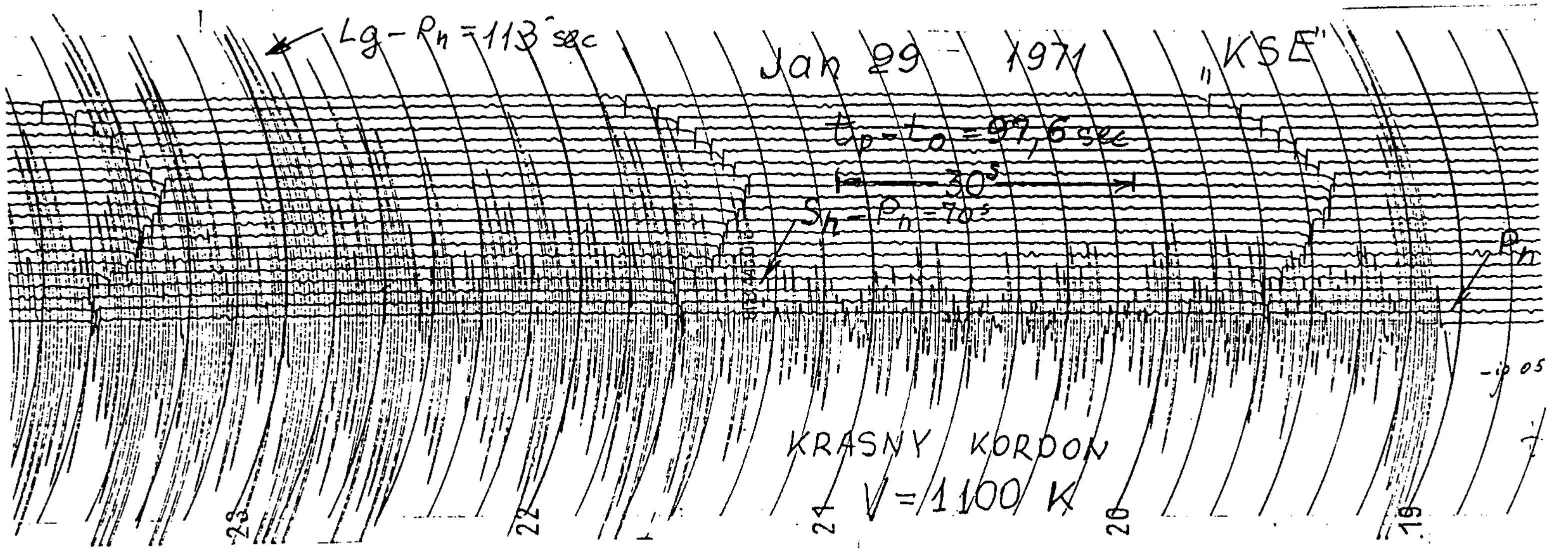
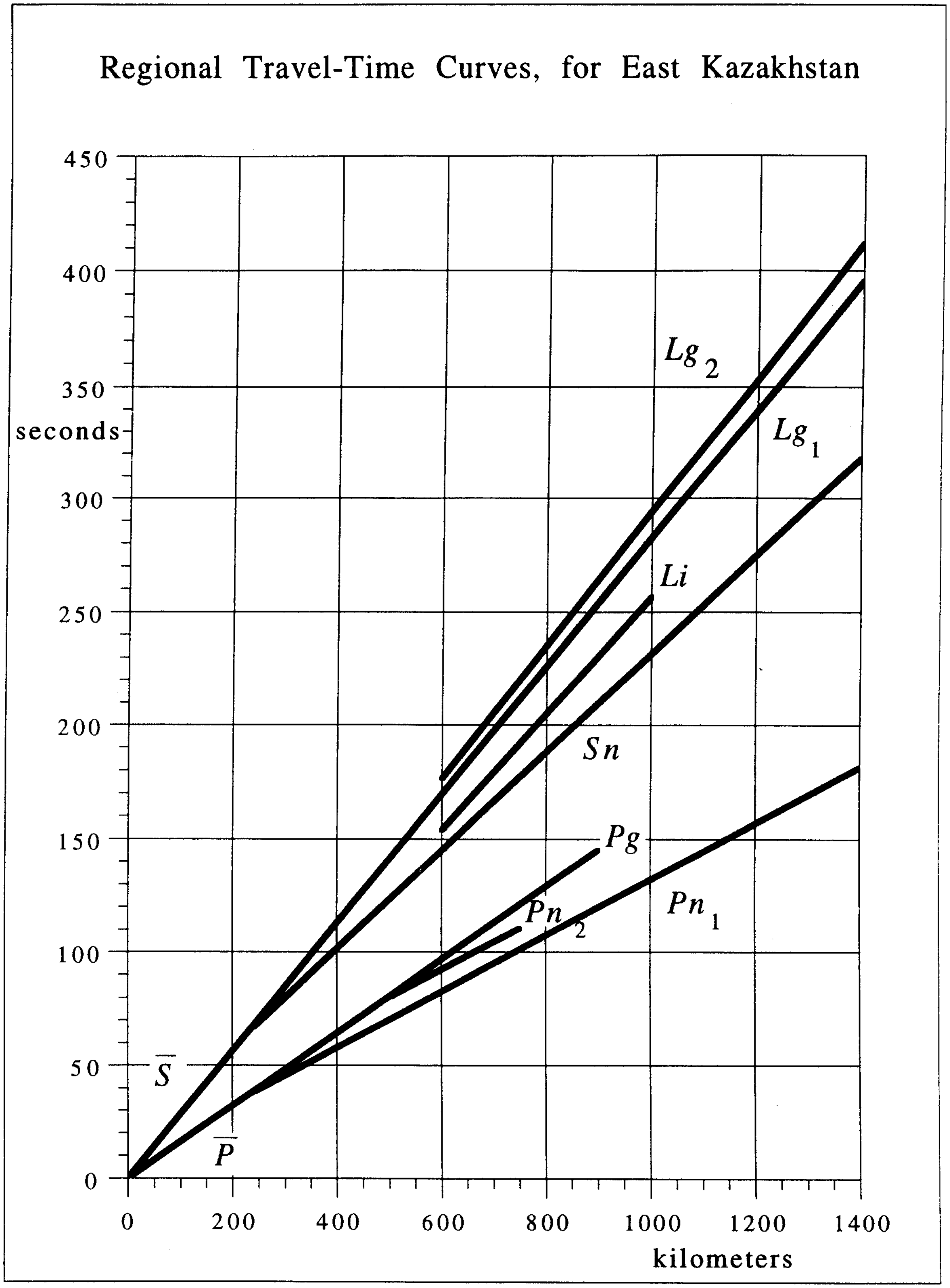

Station KRÁSNY KORDON RVZT instrument
Three component, V = 120,000 R=720 km
1971 , Jan 29 05:03 UNE DEGELEN m=4.35
NS
Z
EW
RVZT V-120 K
KRASNY KORDON
Jan 29 1971
Pn
Sn
Lg
60s

Figure 6a



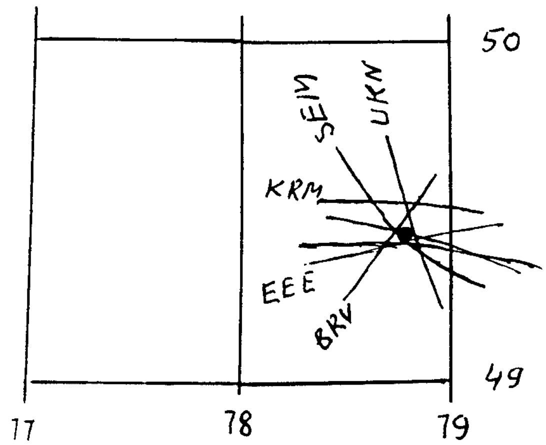
Station Krasny Kordon "KCE" instrument
Vertical, 0.6 - 1,1 sec V = 1,100,000
1971 Jan 29 05:03 UNE Degelen m=4.35
R = 720 km

Figure 6b

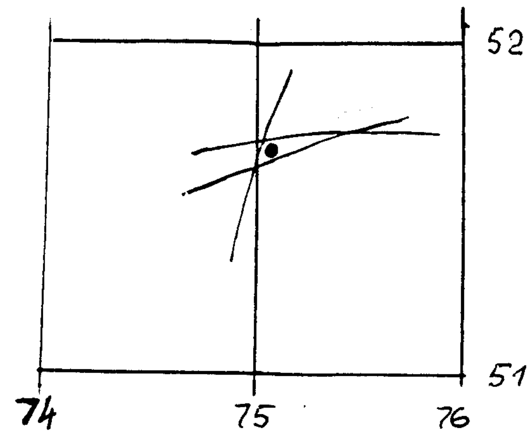


Regional Travel-Time Curves, for East Kazakhstan
450
400
350
seconds
300
250
200
150
100
50
0
0
200
400
600
800
1000
1200
1400
kilometers
Lg 2
Lg 1
Li
Sn
Pg
Pn 2
Pn 1
S̄
P̄

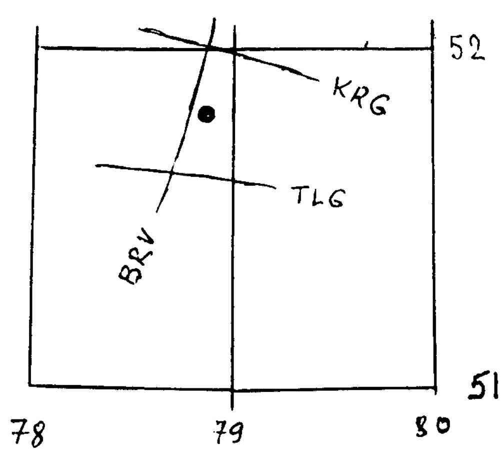
Figure 7



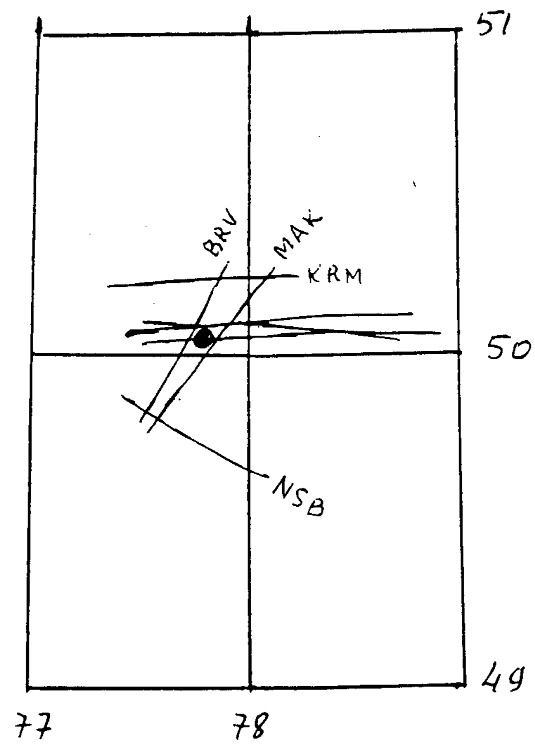
1966-Dec-26 (49.40°, 78.75°)
(8 km, 15 km)



1967-Jun-03 (51.68°, 75.10°)
(6.5 km, 13 km)

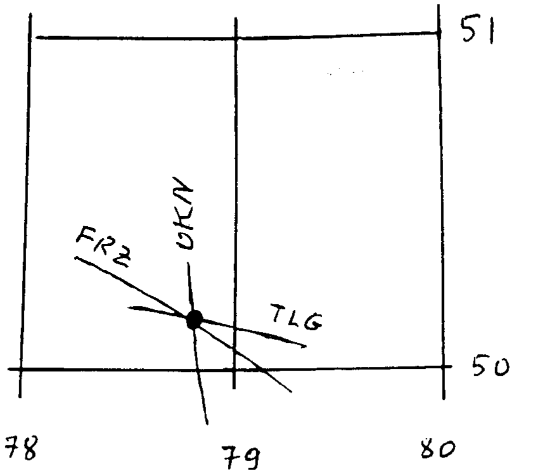


1967-Jul-16 (51.80°, 78.90°)
(10 km, 25 km)

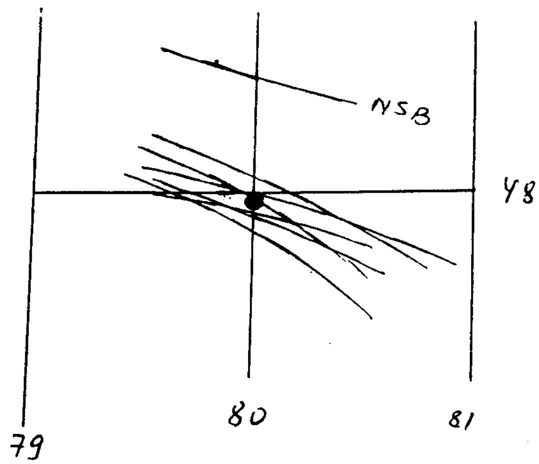


1976-Mar-20 (50.02°, 77.37°)
(15 km, 12 km)

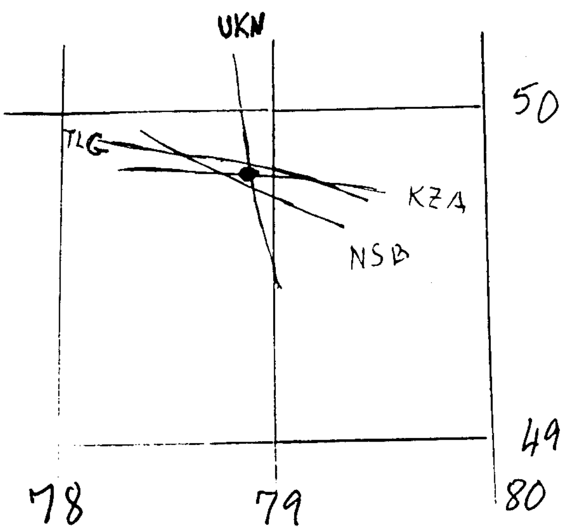
Figure 8 (1 of 3)



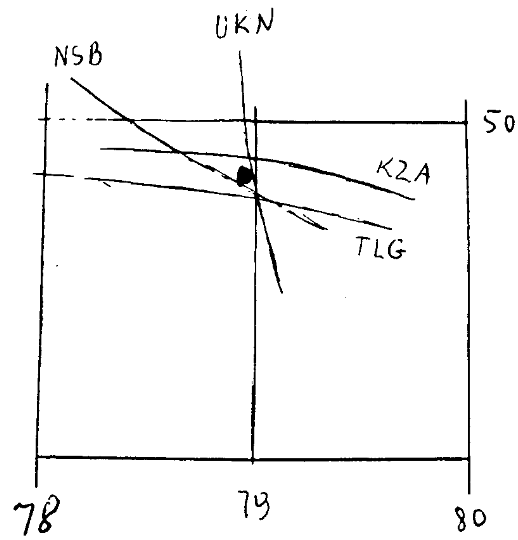
1980-Nov-06 (50.15°, 78.80°)
(2 km, 4 km)



1981-Mar-31 (47.97°, 80.00°)
(10 km, 50 km)



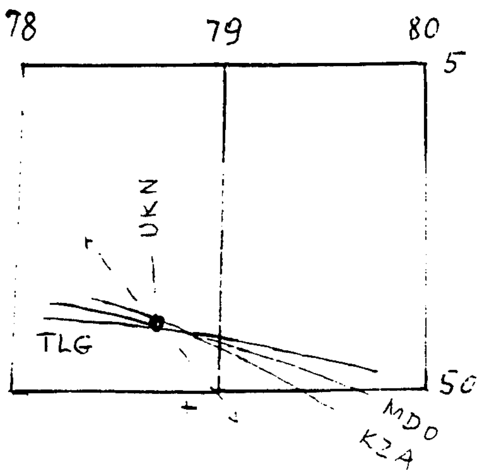
1981-Jun-05 (49.80°, 78.86°)
(7.9 km, 15.5 km)



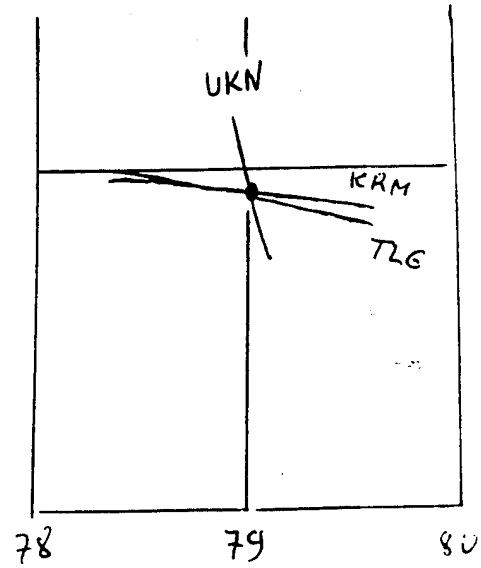
1981-Jul-05 (49.85°, 78.90°)
(6.3 km, 10.5 km)

Figure 8 (2 of 3)

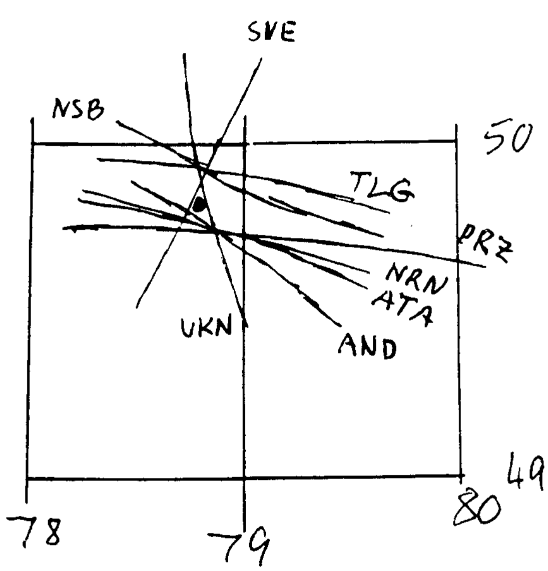
←--→ trace of possible epicenter if change t_0 (origin time)



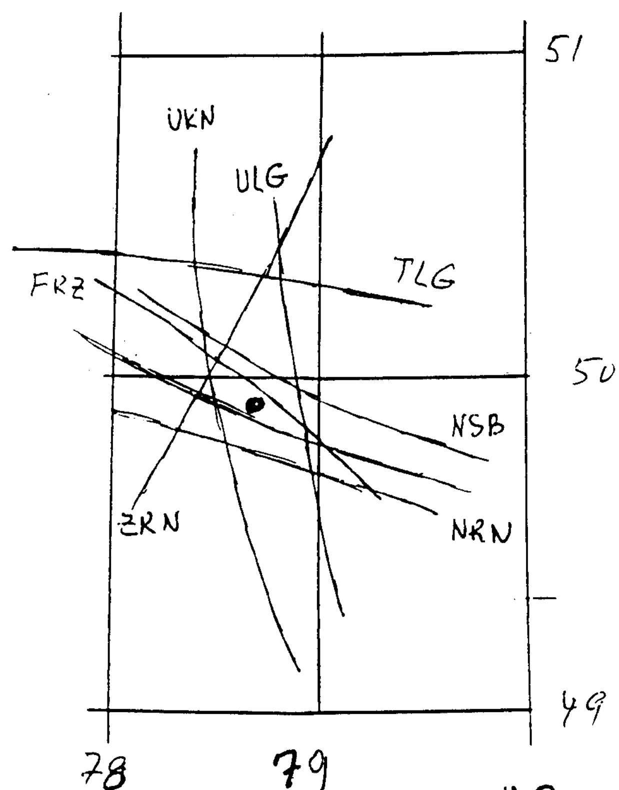
1981-Nov-19 (50.20°, 78.71°)
(10 km, 10 km)



1984-Jun-23 (49.93°, 79.01°)
(2.2 km, 4.5 km)



1987-Sep-16 (49.85°, 78.79°)
(6.7 km, 12.7 km)



1988-Sep-26 (50.10°, 78.96°)
(18 km, 16 km)

Figure 8 (3 of 3)

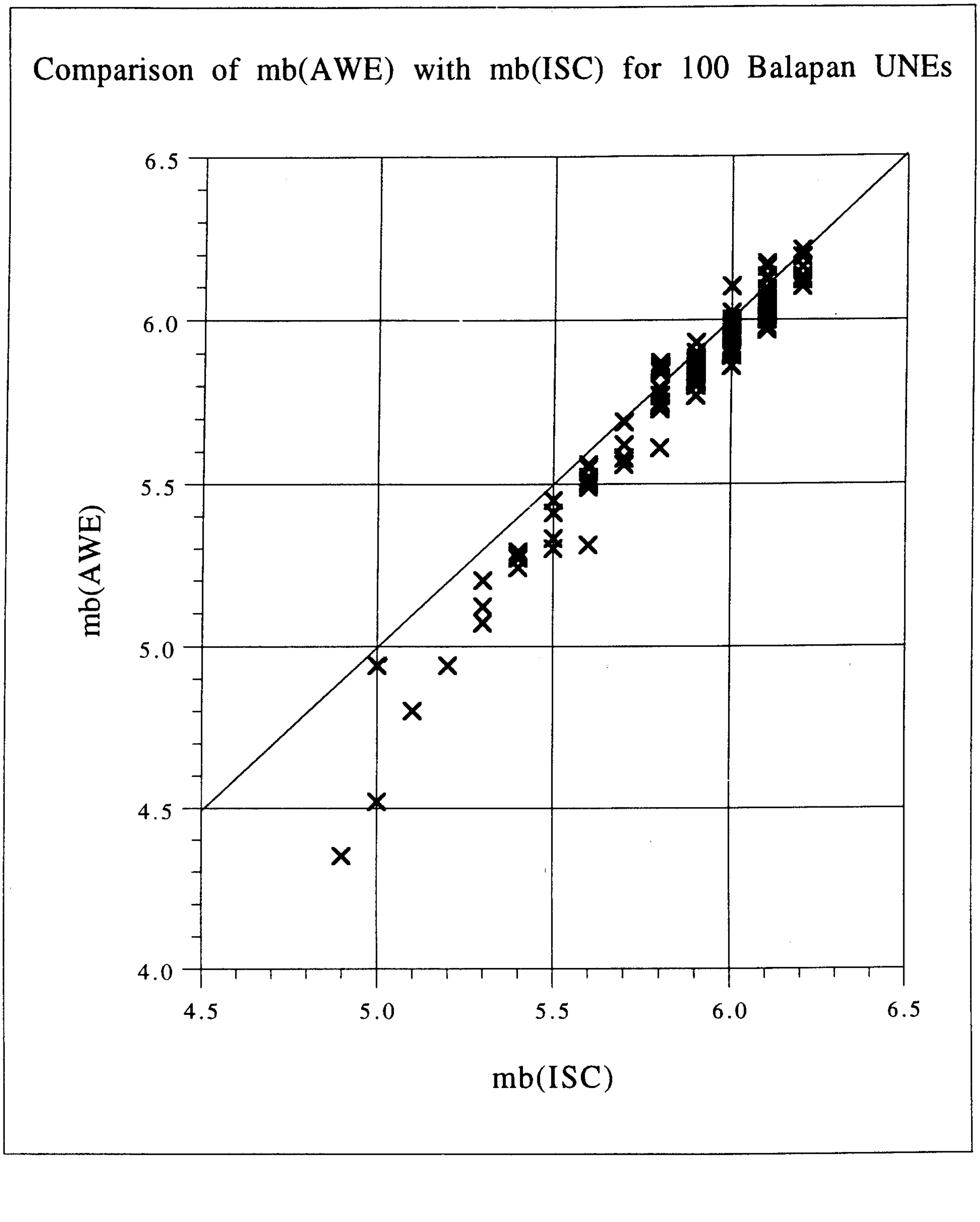

Comparison of mb(AWE) with mb(ISC) for 100 Balapan UNEs
mb(AWE)
6.5
6.0
5.5
5.0
4.5
4.0
4.5
5.0
5.5
6.0
6.5
mb(ISC)

Figure 9a

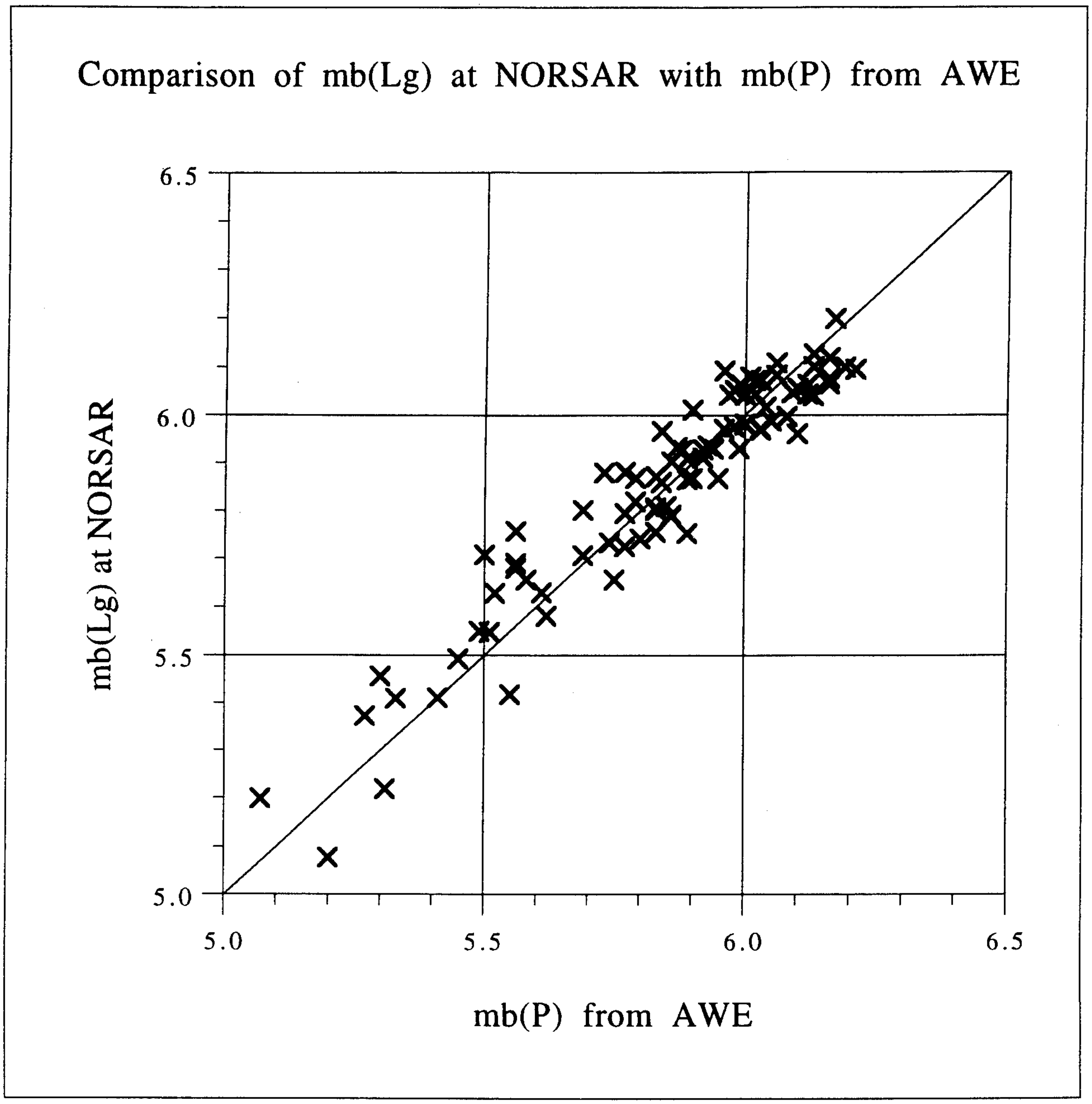

Comparison of mb(Lg) at NORSAR with mb(P) from AWE
mb(Lg) at NORSAR
mb(P) from AWE
6.5
6.0
5.5
5.0
5.0
5.5
6.0
6.5

Figure 9b

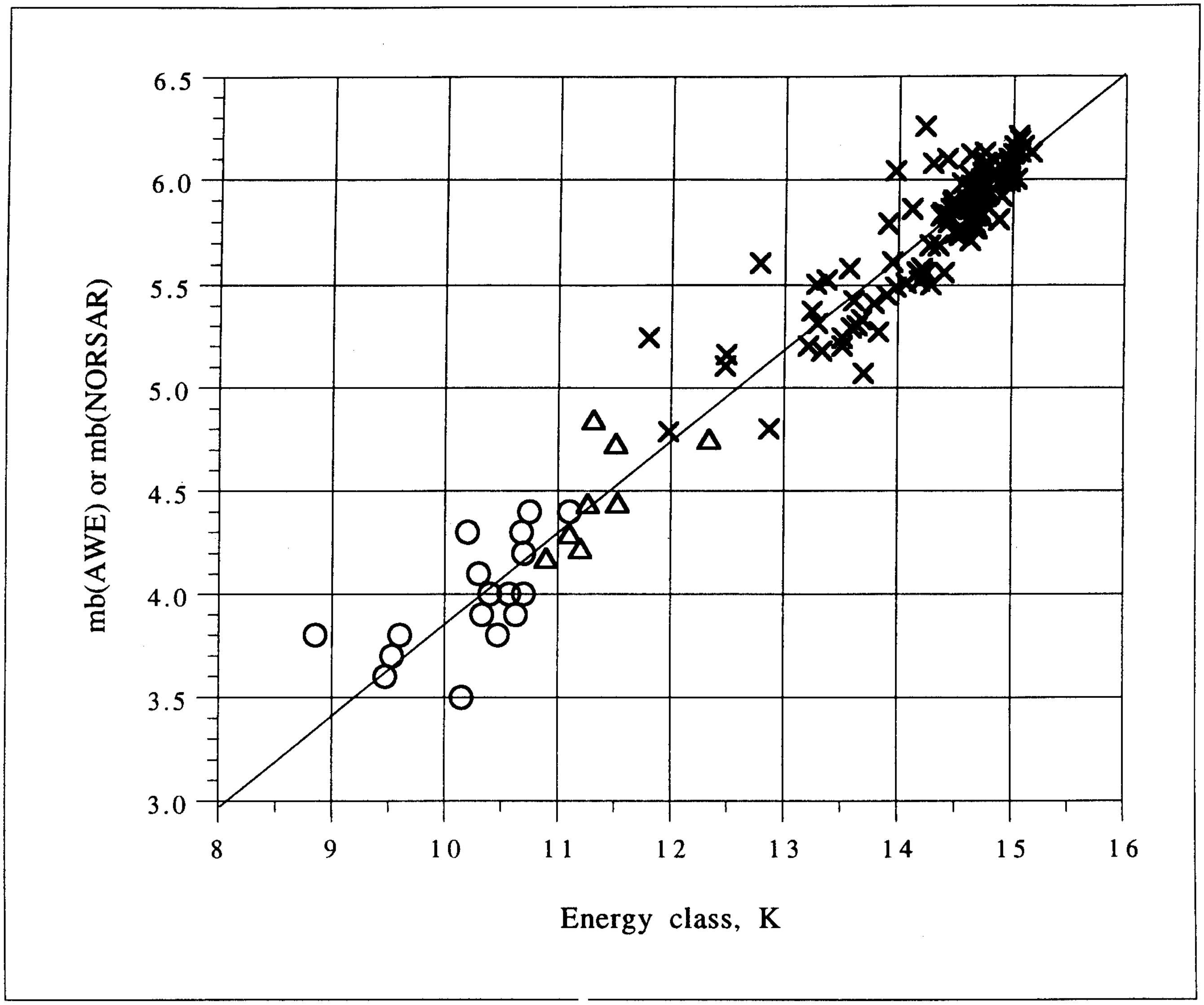

6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
mb(AWE) or mb(NORSAR)
8
9
10
11
12
13
14
15
16
Energy class, K

Figure 9c

m(AWRE) = 1.17m(CHISS) - 1.02

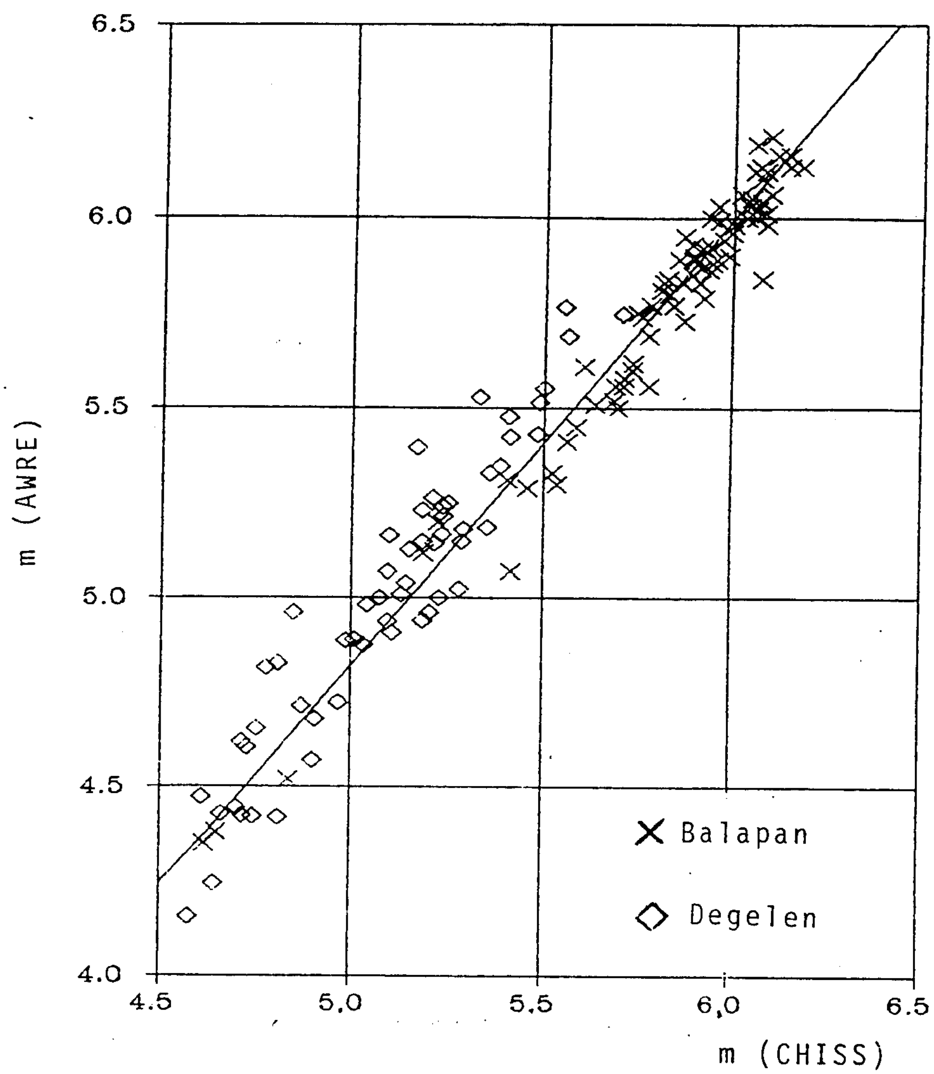
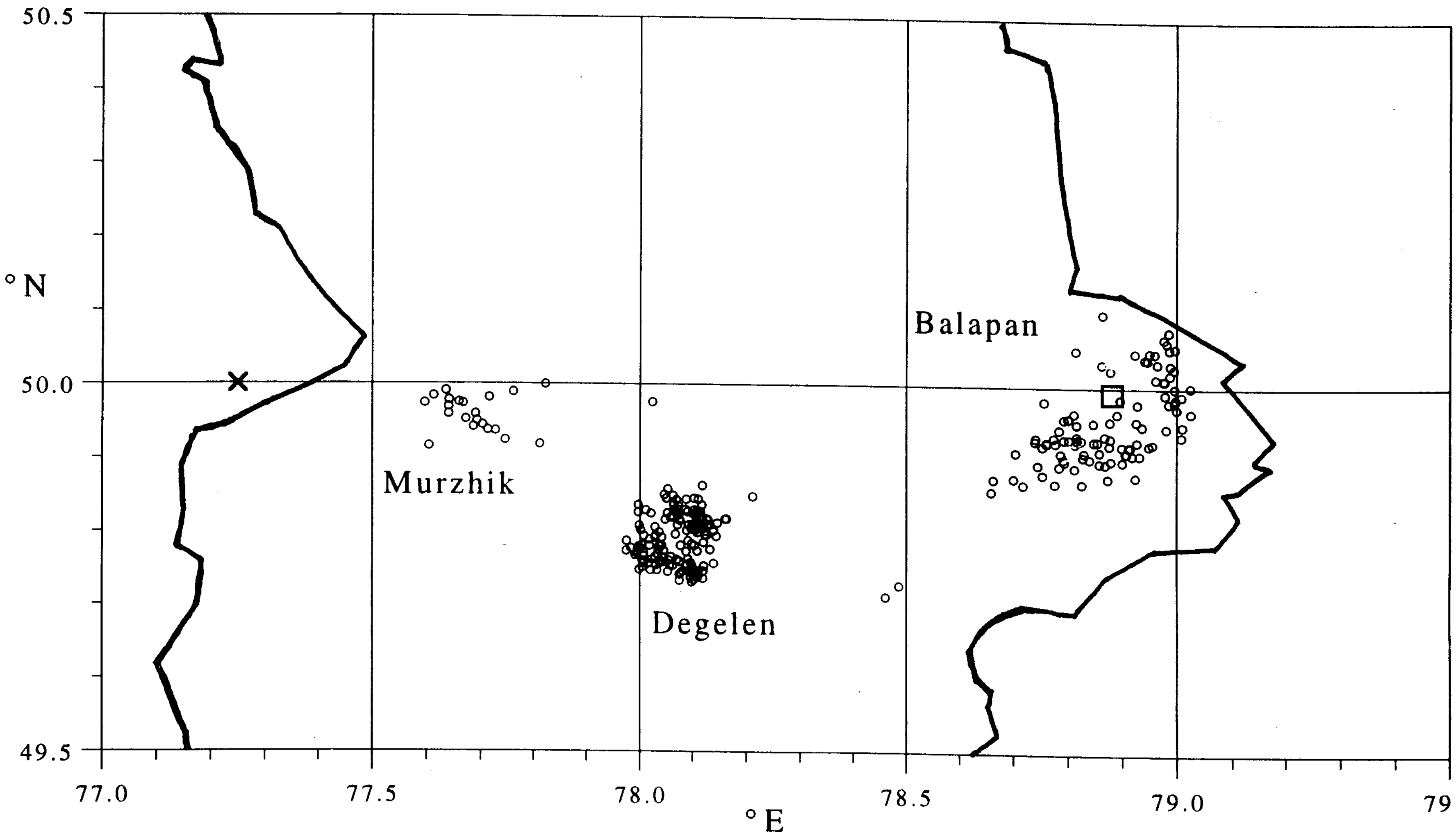


Figure 9d

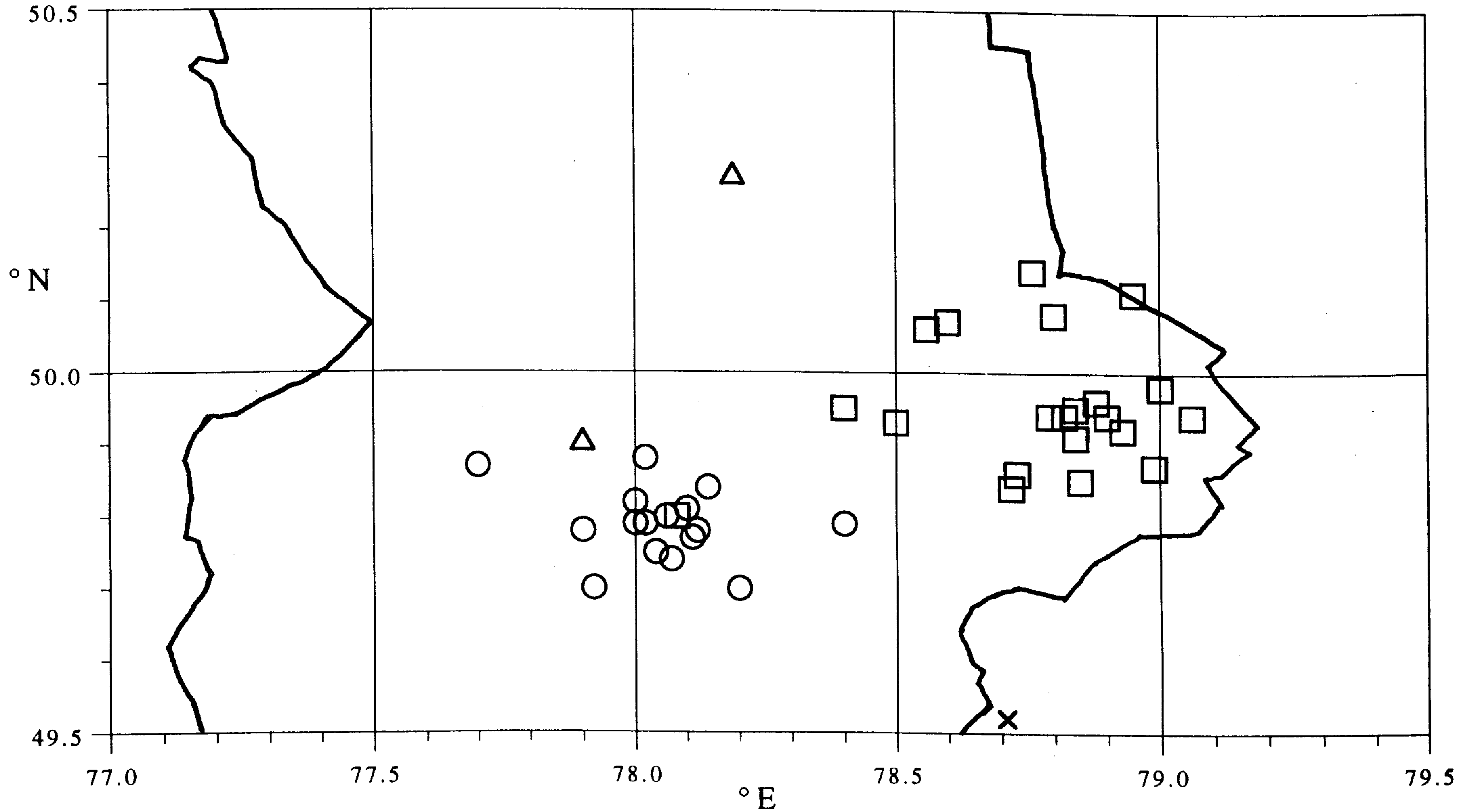
282 known & located presumed UNEs at the Semipalatinsk Test Site



1 known & located earthquake (76-Mar-20, cross); 1 chemical explosion (84-Sep-15, square)

Figure 10

43 previously unknown or unlocated seismic events on/near the Semipalatinsk Test Site



18 UNEs (circles); 22 ChEs (squares); 2 UNEs or ChEs (triangles); and 1 Eq (cross)

Figure 11

Seismic events of this study, within 300 km of the Semipalatinsk Test Site

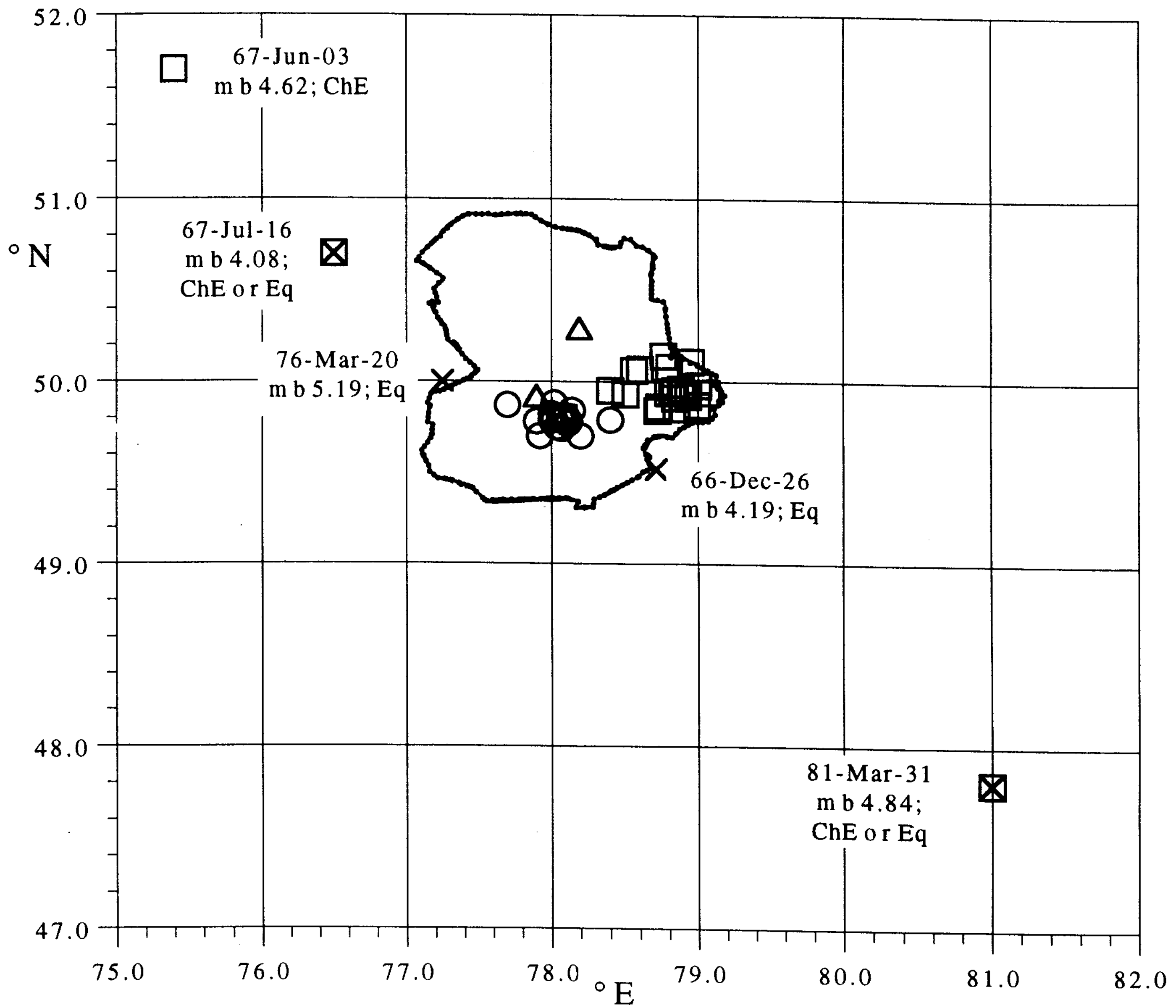


Figure 12

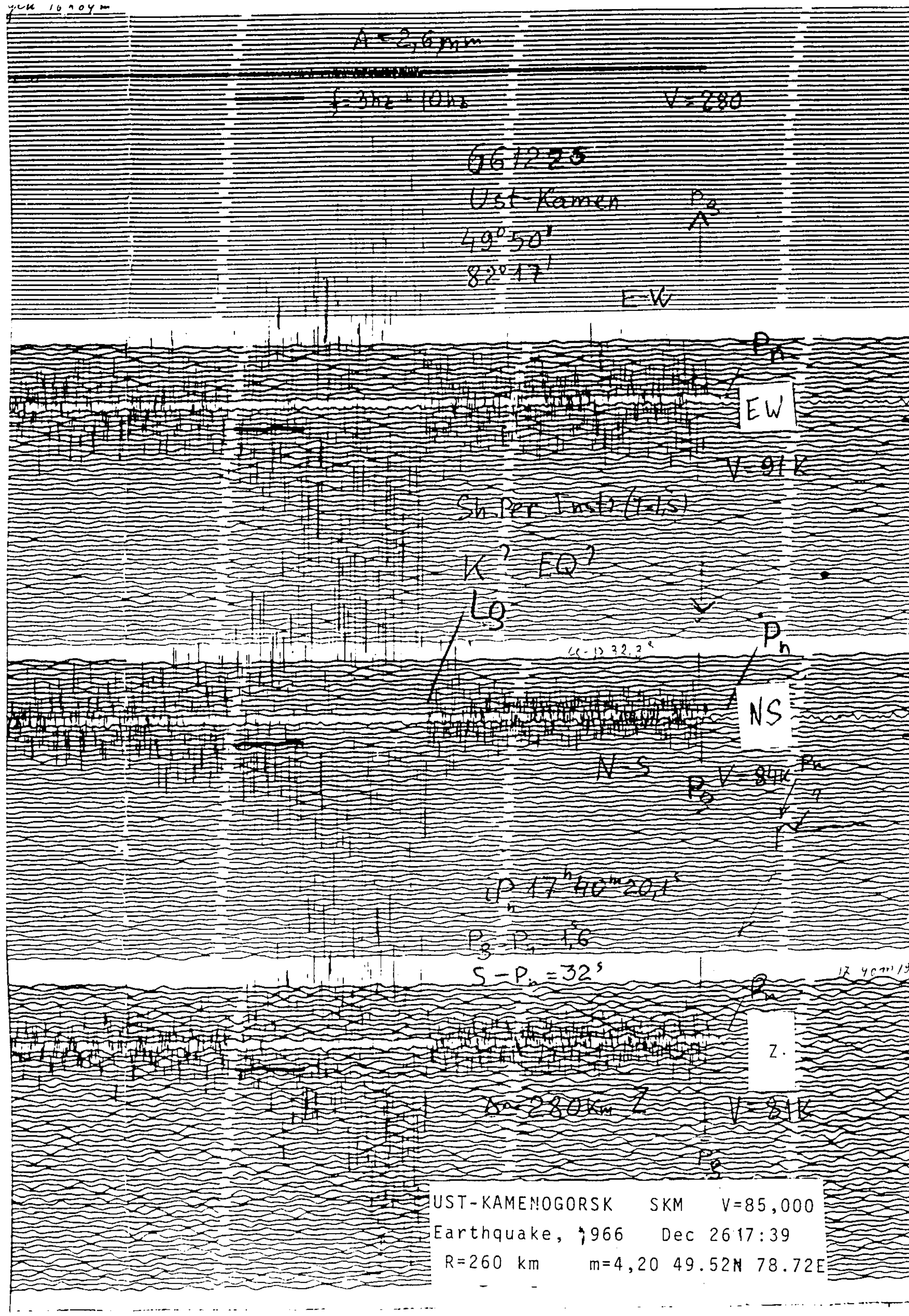

A = 2,6 μm
f = 3hz ÷ 10hz
V = 280
661225
Ust-Kamen
49°50'
82°17'
E-W
Pn
EW
V = 91K
Sh Per Inst (T=1,5)
K? EQ?
Lg
Pn
NS
N-S
Pg
V = 84K
iPn 17h40m20,1s
Pg - Pn = 1,6
S - Pn = 32s
Pn
Z
Δ~280 Km Z
V = 81K
Pg
UST-KAMENOGORSK SKM V=85,000
Earthquake, 1966 Dec 26 17:39
R=260 km m=4,20 49.52N 78.72E

Figure 13a

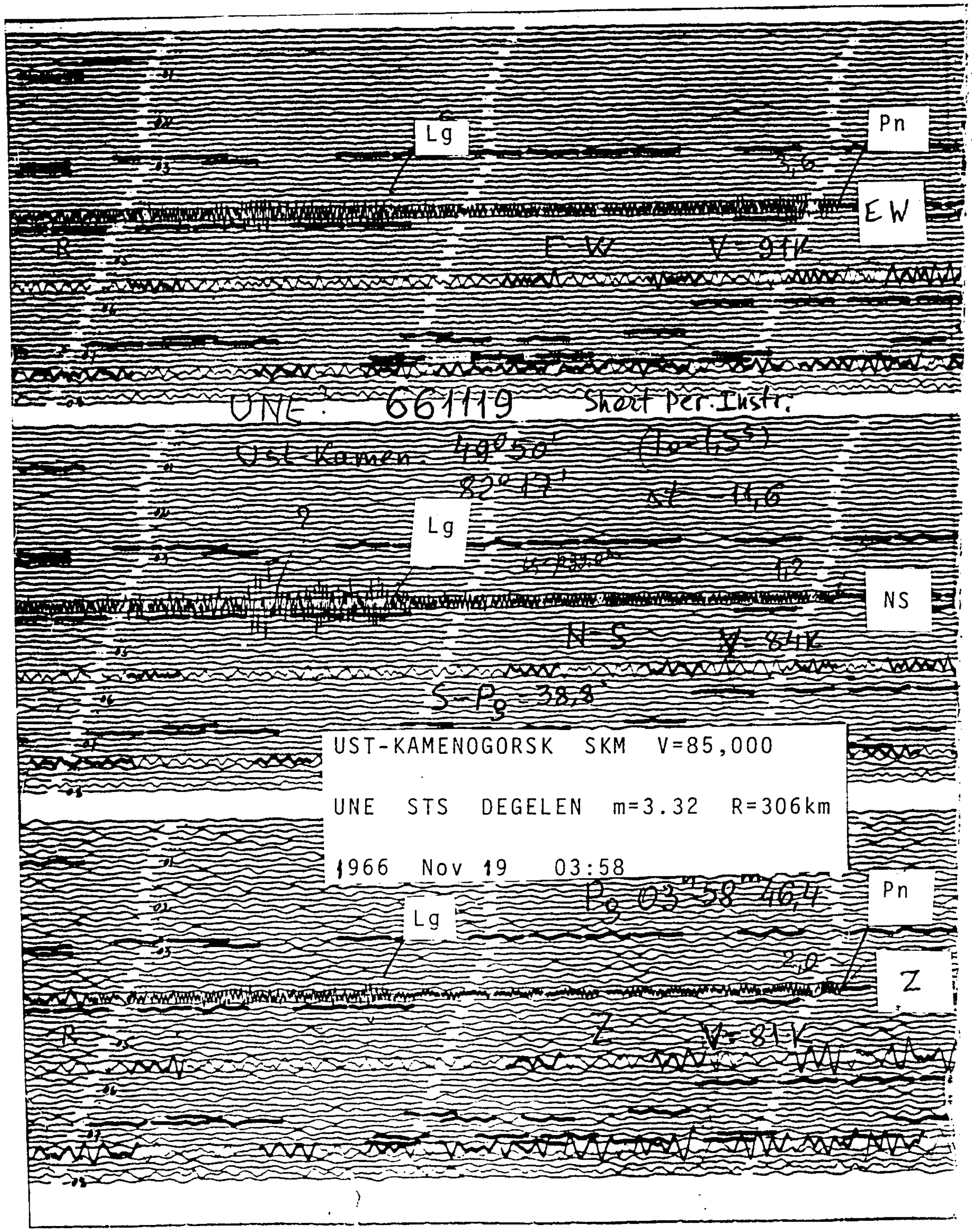

Lg
Pn
EW
Lg
NS
UST-KAMENOGORSK SKM V=85,000
UNE STS DEGELEN m=3.32 R=306km
1966 Nov 19 03:58
Lg
Pn
Z

Figure 13b