

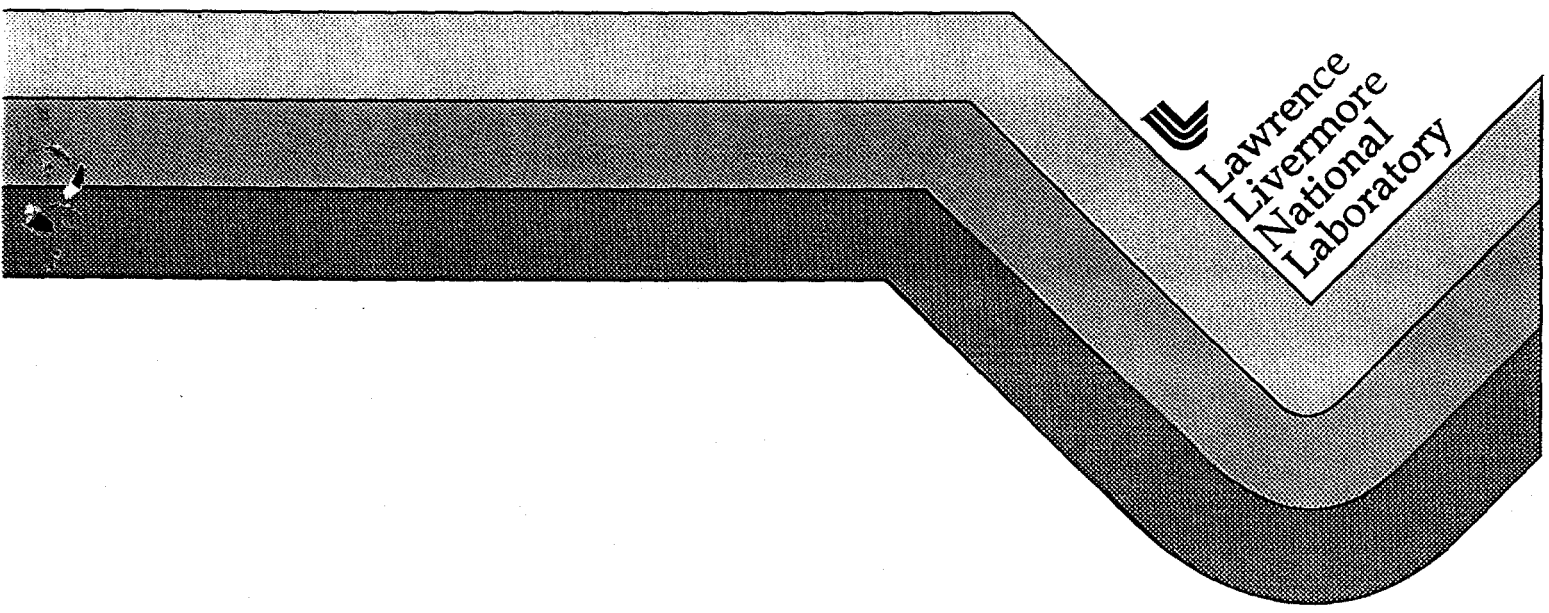
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**RUSSIAN ACADEMY OF SCIENCES JOINT INSTITUTE OF PHYSICS
OF THE EARTH COMPLEX SEISMOLOGICAL EXPEDITION**

**INVESTIGATIONS INTO SEISMIC DISCRIMINATION BETWEEN
EARTHQUAKES, CHEMICAL EXPLOSIONS AND
NUCLEAR EXPLOSIONS**

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JOINT INSTITUTE OF PHYSICS OF THE EARTH
COMPLEX SEISMOLOGICAL EXPEDITION

R E P O R T

INVESTIGATIONS INTO SEISMIC DISCRIMINATION BETWEEN
EARTHQUAKES, CHEMICAL EXPLOSIONS AND
NUCLEAR EXPLOSIONS.

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ABSTRACT.

In this report we describe some results of investigations on a problem of discrimination between nuclear explosions, chemical explosions and earthquakes, carried out in the Complex Seismological Expedition of the Joint Institute of Physics of the Earth of the Russian Academy of Sciences. Records of underground nuclear explosions from the Semipalatinsk test site, and from region the Pre-Caspian depression, and also records of nearby chemical explosions and earthquakes were processed. We analysed records of permanent and temporary stations, located mainly in the North Tien Shan, northern Kazakhstan and Urals regions.

We studied the influence of regional conditions on the effectiveness of seismic monitoring of nuclear explosions. Various amplitude criteria of the discrimination between explosions and earthquakes are considered. We analyzed possibilities to discriminate different source types using spectral-temporal characteristics of seismograms. The nature of some wave types, recorded at regional distances, is investigated. We consider possibilities of discrimination between nuclear and chemical explosions and earthquakes using analysis of characteristics of irregular waves. We outline future investigations, connected with the study of the unique set of seismograms kept in the OSE.

CONTENTS.

INTRODUCTION.....	6
1. INSTRUMENTATION USED IN THE CSE AND SYSTEM OF INVESTIGATIONS.....	9
1.1. Instrumentation.....	9
1.2. Seismic stations.....	12
1.3. Materials used.....	13
2. INFLUENCE OF REGIONAL CONDITIONS ON EFFICIENCY OF SEISMIC MONITORING.....	17
2.1 Calibration curve by surface waves for northern Tien Shan stations.....	19
2.2. Calibration curves for P-waves for the northern Tien Shan stations.....	21
2.3. Calibration functions for S- and L_g -waves for the northern Tien Shan stations.....	23
2.4. Regional variations of the amplitude level for waves of various types.....	24
3. RELATIONS BETWEEN AMPLITUDES OF VARIOUS WAVE TYPES AS CRITERIA OF DISCRIMINATION BETWEEN EXPLOSIONS AND EARTHQUAKES.....	28
3.1. Correlation of amplitudes of S- and P-waves...	28
3.2. Correlation of amplitudes of P_n - and P_g -waves.....	30
3.3. Correlation of amplitudes in various groups of longitudinal waves at distances more	

than 1000 km.....	31
3.4. Correlation of S-wave amplitudes.....	31
3.5. Correlation of L_g - and P-wave amplitudes.....	32
3.6. Amplitude correlation LgH/LgV	33
3.7. Correlation between amplitudes of longitudinal and surface waves (criterion m-M).....	34
3.7.1. Processing of the experimental data.....	35
3.7.2. Significance of the data.....	37
3.7.3. Methods of determining magnitude.....	41
3.7.4. Frequency response of the seismic channels.	43
3.8. Time of amplitude level increase from the first arrival to P-wave maximum.....	44
4. SPECTRAL-TEMPORAL CRITERIA OF IDENTIFICATION OF EXPLOSIONS AND EARTHQUAKES.....	47
4.1. Predominant periods of seismic waves.....	47
4.2. Spectral-temporal criteria of identification of explosions and earthquakes.....	53
4.2.1. Method of distinguishing parameters.....	56
4.2.2 Method of module envelopes.....	57
4.2.3. Contour properties of the ChISS seismograms.	59
4.2.4. Description of the spectral-temporal algorithm of discrimination of earthquakes and underground nuclear explosions.....	65
4.3. Complexing the discriminating criteria.....	69
5. DISCRIMINATION BETWEEN EARTHQUAKES, CHEMICAL EXPLOSIONS AND NUCLEAR EXPLOSIONS BY CHARACTERISTICS OF REGULAR AND IRREGULAR SEISMIC WAVES.....	71
5.1. On the nature of some wave groups recorded at	

regional distances.....	72
5.1.1. Common characteristics of seismograms.....	73
5.1.2. Interpretation of the experimental data.....	82
5.2. Analysis of records of underground nuclear explosions from the Semipalatinsk test site, close chemical explosions and earthquakes.....	89
5.2.1. Analysis of experimental data.....	93
5.3. Analysis of records of the underground nuclear explosions from the Pre-Caspian depression.....	95
5.4. Discussion.....	98
CONCLUSIONS.....	103
REFERENCES.....	109
APPENDIX.....	123
FIGURE CAPTIONS.....	137
FIGURES.....	151

INTRODUCTION.

Lately the world community has agreed on the necessity of global monitoring of possible nuclear explosions. For explosions with a power more than 10 kT this problem can be easily solved with existing national seismic networks. But for reliable monitoring of weaker events (down to 0.5 kT) it is necessary to develop seismic networks that allow us to record seismic events at regional distances (less than 2500 km). Wave fields at regional and teleseismic distances are quite different. Characteristics of various wave groups, such as P_n , P_g , S, S_n and L_g , recorded at regional distances, are very sensitive to peculiarities of the earth's structure. In the first instance it concerns the problem of discrimination of nuclear explosions, chemical explosions and earthquakes. Applying the results obtained in one region to some new areas can lead to fundamental mistakes.

In this respect materials of the Complex Seismological Expedition (CSE) of the Russian Academy of Sciences, obtained during more than 30-years' investigations are of great value. Indeed, the high-sensitivity CSE stations have been installed close to the nuclear test sites in the former Soviet Union, the Chinese test site Lop Nor, and the Indian test site Srinagar. The CSE stations recorded industrial nuclear explosions all over the territory of the former Soviet Union, including regions where there were only a

small number of regular seismic stations or they were none altogether. It is also important to consider the possibility of nuclear testing in some other countries- Pakistan, Iran, Iraq, North Korea, etc. These areas are largely inaccessible for detailed seismic investigations.

It is also worth noting that during their operation the CSE high-sensitivity stations recorded thousands of relatively weak chemical explosions, either in various areas of the former Soviet Union, or outside its border. A huge volume of experimental data, accumulated by the CSE, gives a unique opportunity for addressing all of the problems of nuclear explosion monitoring - detection, location, discrimination, and identification of these events. In this report, we describe some results of investigations in only one area of nuclear explosions monitoring, which have not previously been published.

A major goal of this work is the discrimination of nuclear explosions, chemical explosions and earthquakes, based on analysis of the experimental data, obtained by the CSE.

The report consists of an introduction, 5 main parts and conclusions. In the first part of the report we describe seismic instruments used in the Expedition and the observation system. The second part is devoted to a study of the influence of regional conditions on efficiency of nuclear monitoring systems. In the third part we consider various amplitude criteria for discrimination between nuclear explosions, chemical explosions and earthquakes. In

the fourth part we investigate possibilities of discrimination between various source types by spectral-temporal characteristics of the seismograms.

The fifth part in some sense stands by itself. In this part we at first analyze the nature of some wave groups, recorded at regional distances. On the basis of our conclusions we consider the possibility of discrimination between explosions and earthquakes by analysis of nontraditional wave types. For this reason in fifth part we describe separately observation system and experimental data used.

In the conclusions we sum up the results of the work accomplished, and also outline of further investigations, connected with analysis of the unique experimental data accumulated by the CSE.

The report consists of 227 pages, including 108 pages of text, 77 figures and 14 tables.

The following CSE employees took part in this work:

Kopnichev Yu.P.-professor and director of the CSE.

Aptikaev F.F.-leading scientist.

Antonova L.V.- senior scientist.

Khalturin V.I.-leading scientist.

Sokolova I.N.-junior scientist.

Aptikaeva G.F.-engineer.

Krivosheeva L.A.-engineer.

Bondar' E.P.-laboratory assistant.

Zhernokleva T.A., Linnik V.V. and Starochenko S.G. took part in the production of this report.

1. INSTRUMENTATION USED IN THE CSE AND SYSTEM OF INVESTIGATIONS.

1.1. Instrumentation.

The instrumentation used at the CSE stations essentially differs in amplitude-frequency characteristics (AFC) from that used at American stations.

To study regional seismicity, ground displacement seismometer were broadly deployed by the CSE, as well as by other institutions in the former Soviet Union. In the short-period range curves 1, 2, and 3 in Fig. 1.1 correspond to these channels. Initially the SKM-III seismometers (modernized Kirnos seismometer) had such characteristics; below we will denote by this symbol all seismometers, whose characteristics are close to those, independent of the actual device type.

Differences in low-frequency slopes of the frequency responses are connected with the natural period of the pendulum. For example, in West Siberia the seismometer pendulums are set at the period $T_0=2.0$ sec (curve 2 in Fig. 1.1), in East Siberia they are set at the period $T_0=1.74$ sec. Until 1963 many CSE stations have responses of type 1. Since 1963 they have gradually begun to be equipped by channels with frequency response 2 (with the seismometer pendulum set at period $T_0=1.5$ sec).

Until 1969 magnification of these channels was close to $V=50$ thousand. Since 1969 the CSE has begun large-scale

research on determining the microseism level all over the territory of the former Soviet Union. This allowed us to carefully choose sites for seismic station installation and to increase the magnification of the channels equipped with amplifier units. The maximum magnification for all three channels was about 240000.

For the purpose of detecting seismic sources, first of all at teleseismic distances, stations of the Expedition were equipped with narrow-band short-period channels CSE-1, CSE-2, CSE-3 (vertical component only). In Fig. 1.1 frequency responses Nos. 4, 5, 6 correspond to such channels. The frequency response No. 6 is most successful one. It was constructed as a result of processing digital records of explosions and microseism noise. Now this response is a principal one used in the CSE for recording of teleseismic signals. The central frequency of this channel, depending on station conditions varies from 0.75 to 1.0 sec. In most favorable conditions the magnification of this channel reaches 2 million.

For recording the low-frequency waves we used at the main stations a three-component sensor of SK type (Kirnos seismometer) with frequency response No.1 (Fig. 1.2). This instrument was a standard one in the former Soviet Union. In order to compare results obtained by instruments with different frequency bands, an instrument with frequency response No. 2 (Fig.1.2) was operated at the Talgar station simultaneously with an SK seismometer. This frequency response was used in a typical seismometer SKD-0, which was

constructed later. The magnification of these long-period channels varied from 1000 to 2000.

In addition to these, during some time narrow-band long-period devices with responses, close to No. 3 response (Fig.1.2) was operated at some CSE stations. The central period of such channels varied from 18 to 30 sec, and magnification - from 20 thousand to 30 thousand.

We also used other experimental devices. The most interesting devices are frequency-selective seismic stations (ChISS), which recorded seismic signals in narrow-frequency bands with a width about $2/3$ octave [Zapol'skiy, 1971; Rautian and Khalturin, 1978]. Usually ChISS- stations have 7 vertical channels, but in some cases recording was carried out by a ladder number of channels, from low-frequencies (0.03 Hz) to high frequencies (up to 300 Hz). Some experiments with three-component ChISS-stations were conducted.

In this work we used 5-channel ChISS-stations (Fig. 1.3). The frequency bands of these channels, which are numbered from low to high frequencies, are correspondingly 0.27-0.40 Hz, 0.62-0.92 Hz, 1.1-1.7 Hz, 2.2-3.4 Hz and 4.6-7.0 Hz.

Lately we began to use three-component short-period instruments in the CSE with frequency response, close to No. 1 in Fig. 1.1, with recording on magnetic tape and automatic digitization unit.

The CSE has long-term experience of recording local seismic events with telemetered system RTS-AN and also with

British and American telemetered systems. The Soviet telemetered network consisting of 6-7 stations have been used during about 15 years near the city of Almaty (Kazakhstan). Some devices have been situated in deep boreholes, which allowed us to considerably increase the magnification at these stations. The frequency responses of the borehole channels were close to response No.2 in Fig. 1.1.

A few year ago a digital software-operated seismic system PUSK-2, functioning in a triggered regime has been installed at the Talgar station. A detailed description of the magnetic recording systems and digital station PUSK-2 is presented in a report [Kopnichev et al., 1995]. Below we describe only some results of the data processing using seismograms obtained by the seismic channels of the SKM, SK, CSE and ChISS types.

1.2. Seismic stations.

Since 1969 the CSE seismic stations have been installed only after detailed investigations of the microseismic noise level in an area of proposed station installation.

At permanent stations, for example, in Talgar, in Garm etc. the seismic devices were installed in tunnels. At temporary stations, which operated for 1-3 years, but sometimes more than 20 years, seismometers were installed in shallow excavations on bedrock with a concrete pier. The excavations were closed by two covers.

In carrying out this report we used experimental data obtained mainly by the CSE stations situated in the northern Tien Shan and northern Kazakhstan, and also in the central Urals region (one station). Locations of these stations are shown in Table 1.A (see Appendix).

Stations equipped also with intermediate-period instruments, are marked by asterisks in this table. ChISS-devices were used at two stations - Talgar and Garm. We used the Talgar station as the main one. A detailed description of the Talgar station is placed in the report [Kopnichev et al., 1995].

1.3. Materials used.

For addressing problems described in parts 2-4 of this report we processed the records obtained by short-period (SKM), intermediate-period (SK) and ChISS- instruments. For addressing problems described in part 5, we also used the records obtained by narrow-band channels (CSE).

Data on earthquakes and explosions were received from the International seismological Centre bulletin, the seismological bulletin of the USSR stations, the bulletin of Institute of Seismology (Kazakhstan), and the bulletin of the Talgar station.

The choice of the epicentral distance range was stipulated by the necessity of obtaining criteria for

discrimination between earthquakes and explosions, which occurred within the former Soviet Union and were recorded by the CSE stations. In most cases epicentral distances varied from 400 to 2500 km.

We used the following experimental material:

1. Records of underground nuclear explosions from the Semipalatinsk Test Site (STS), a list of which is shown in Table 2.A;

2. Seismograms of industrial nuclear explosions, produced in various areas of the former Soviet Union (Table 3.A);

3. Records of underground nuclear explosions in salt, produced in some regions of Russia and Kazakhstan (Table 4.A);

4. Seismograms of chemical explosions in two quarries, located to the north and north-east of the Talgar station (the Sayak quarry on the northern bank of Lake Balkhash and a quarry near the Kyzyl-Agach station);

5. Records of chemical explosions at distances about 750 km, the locations of which weren't determined (their list is in Table 1.1).

6. Records of underground nuclear explosions from the STS and earthquakes at epicentral distances up to 1000 km from the northern Tien Shan array of CSE stations. Epicenters of these events were to the north (explosions), northeast, east-northeast, south and southwest from these stations. These earthquakes were picked out to study the regional variations of wave propagation of various wave

groups (Table 5.A).

Table 1.1. Chemical explosions

Date	Origin time		Magnitude
	h	m	
			m (SKM)
07/31/78	08	00	5.1
05/24/79	04	07	4.5
11/06/80	17	43	3.9
06/05/81	03	22	4.1
11/30/81	12	55	4.5
11/19/81	05	57	3.8
07/12/82	10	29	4.0
09/15/82	04	33	4.8
07/28/83	03	41	4.8
09/15/84*	06	15	4.8
06/26/84	02	57	4.7
11/16/87	07	30	4.8
11/26/88	07	45	4.4

* Explosion in the Balapan area, STS

Fig. 1.4 is a map showing the locations of the seismic stations, test sites, quarries, epicenters of the industrial explosions and earthquakes presented in Table 5.A. (Some

part of the industrial explosions, presented in Table 3.A, is outside of the map area). For earthquakes used for construction the magnitude calibration curves and for the discrimination between explosions and earthquakes, a list is not presented due to the large data volume (about 1000 events). Epicenters of these earthquakes aren't shown either in Fig. 1.4. Data for these events are presented in the ESSN and ISC bulletins (1978-1993).

2. INFLUENCE OF REGIONAL CONDITIONS ON EFFICIENCY OF SEISMIC MONITORING.

It is known that regional seismo-geological conditions fundamentally affect all the tasks of seismic monitoring. It is possible to divide the problem of seismic monitoring of nuclear explosions into four main tasks:

1. Detection - establishment of the occurrence of a seismic source;
2. Location - estimation of the geographical coordinates, depth and origin time;
3. Discrimination - establishment of the nature of the source (nuclear explosion, chemical explosion or earthquake);
4. Identification - evaluation of the parameters of the source.

For example, for earthquakes the following parameters are evaluated: seismic moment, geometrical size of the source, orientation of the source in space, mean displacement, stress-drop, etc. For explosions it is possible to consider TNT equivalent, grouping of the charges in space and time, burial depth, chamber type (borehole or tunnel), parameters of the surrounding medium (bedrock, sedimentary rocks, water, etc.).

The tasks described are closely connected to each other. For example, if we determined a relatively large

depth of the seismic source, we can conclude, that it is not an explosion. The problem of discrimination is most closely connected with the task of calibration. A classical example of discrimination between nuclear explosions and earthquakes is by the criterion of magnitudes, determined by surface and body waves - (M_s and m_b respectively).

It is well-known that amplitude characteristics of various wave groups vary with epicentral distance, these differences having a regional character. For this reason the calibration problems must be solved before development methods for the discrimination of earthquakes and explosions. Sometimes even after detailed study of the data obtained we can not determine the reason for variations of the structure of the wave field - either differences in source type or differences in structure of the medium in the test site area and adjacent areas. Such cases are encountered if test site area is located in an aseismic region. In any case solving all the problems of the seismic monitoring should begin from the study of regional characteristics of the seismic wave fields. Such works have previously been conducted in the study area [Nersesov and Rautian, 1964; Antonova and Khalturin, 1967; Antonova et al., 1968; Gupta et al., 1972; Ruzaikin et al., Gupta and Burnett, 1981; Kaazik et al., 1990, etc.].

Below we describe some results of our detailed investigations, which have special significance for solving these problems of seismic monitoring such as the detection, discrimination and calibration of seismic sources in the

region of the northern Tien Shan and adjacent areas.

2.1 Calibration curve by surface waves for northern Tien Shan stations.

It has been established that surface waves are most stable wave groups. Magnitude estimations by the M scale are characterized by 2.5-3.0 times smaller standard deviation, than magnitudes by m scale (for SKM instruments). In addition, the M values depend to a smaller extent on type of seismometer used and methods of data processing. For example, the M_S values, determined by the seismic services of the USA, and Russia (ESSN) and by the international seismological center (ISC) on the average coincide with a standard deviation about 0.1 magnitude unit. Henceforth we will denote the magnitude determined by surface waves by the letter M without indexes. Nevertheless, systematic regional deviations of the M values take place [Instruction..., 1982]. To increase the accuracy of the magnitude estimations and reliability of source discrimination we constructed a calibration curve for the estimation of M values using the vertical component of Rayleigh waves on records of the northern Tien Shan seismic stations.

We used data from 7 permanent seismic stations, equipped with either SK or SKM instruments. Shchel' Dal'nyaya, Talgar and Almaty stations are situated along the northern slope of the Zailiyskiy Alatau ridge; Przheval'sk, Kadzhisay, Rybach'ye stations are in the Issyk-Kul

depression; the Frunze station is situated in the Chu depression. The maximum distance between stations is about 300 km (Frunze and Przheval'sk). In some cases we also analyzed seismograms recorded by the CSE stations (Charyn, Chilik, Orto-Merke), located in the eastern part of the Zailiyskiy Alatau ridge, which were equipped only with SKM instruments (Fig. 1.4).

We considered earthquakes at epicentral distances to 2500 km with source depths not more than 60 km. We excluded from consideration earthquakes from the Caspian Sea region, because these events are characterized by underestimated M values.

Let us describe the main results of the surface wave study in the region under consideration. At small epicentral distances (up to 450 km) amplitudes of the surface waves attenuate by the following law: $\lg(A/T)_{\max} \sim -1.05 \lg \Delta(\text{km})$, which is considerably weaker attenuation than that usually used in the ESSN relation $\lg(A/T)_{\max} \sim -1.66 \lg \Delta(\text{km})$. At larger distances the CSE and ESSN calibration curves quickly approach one another together and coincide on average.

For the vertical (M_V) and horizontal (M_H) components we found the relation $M_H = M_V + 0.1$. Henceforth we will denote the value M_H by the symbol M , especially as we include a corresponding correction into the calibration curve for the vertical component (Table 6.A).

A comparison of the magnitude estimations by intermediate-period and long-period instruments showed that at all epicentral distances the relation

$M(\text{SKD-0}) = M(\text{SK}) + 0.005$, is valid at least in the range $4.0 \leq M \leq 7.2$. As to the use of narrow-band instruments (types 3 and 4 in Fig. 1.2), correct estimations are possible only in the teleseismic zone; at regional distances M values are understated.

The value $(A/T)_{\text{max}}$ for the Rayleigh waves practically does not depend on the source depth, while the source is in the Earth's crust (down to a depth of about 50 km). For greater depths the value $(A/T)_{\text{max}}$ decreases in comparison with the calculated one approximately by the relation

$\lg(A/T) \sim -1.72 \lg(h)$, where h is the hypocenter depth. We did not find any influence of the parameter h on the period of the Rayleigh wave corresponding to the maximum A/T value: $T(\text{sec}) = 8.1 \pm 1.8$ for $h \leq 60$ km.

Instruments of the SK type for the northern Tien Shan stations allow us to record the earthquakes with $M=3.0$ at distances to 450 km, with $M=4.0$ - over the entire all distance range considered.

2.2. Calibration curves for P-waves for the northern Tien Shan stations.

When measuring amplitudes of body waves we considered maximum deviations from the zero line. Our results show that this a mode slightly improves data convergence in comparison with methods of amplitude measurement as one half of the extent of whole oscillation (peak-to-peak).

We measured the amplitudes in the initial part of

record of corresponding wave group in 20 sec intervals for earthquakes with $M \leq 7.5$. For stronger events the time interval was increased to 1 min. We constructed magnitude calibration curves separately for P_n - and P_g -waves. Earthquakes were calibrated using the more precise M scale. Then we reduced the amplitude charts $(A/T)_{\max}$ as a function of distance to the arbitrary level $M=5.0$, taking into account relations between the scales M and m . After determining the form of the $(A/T)_{\max}$ curve, we calculated a calibration function (a value m for which this curve was constructed is known). We also carried out an analogous procedure when constructing calibration functions for other wave groups.

For comparison we carried out analogous work using data from Altai-Sayan stations of the CSE at distance range 1500-2000 km. We showed, that magnitudes m for Altai-Sayan stations are systematically underestimated on average by approximately 0.3 magnitude units. We established fundamental variations in the shape of the curves as a function of the distance. Magnitude calibration functions for P_n - and P_g -waves obtained for the northern Tien Shan stations equipped by the instruments SKM are presented in Table 6.A. Magnitude values using data obtained by the SK instruments are larger on average 0.37 ± 0.07 magnitude units. We observed these differences to increase with increasing magnitude.

2.3. Calibration functions for S- and L_g -waves for the northern Tien Shan stations.

At the end of the distance range considered (1800-2000 km) regular shear waves (S) are reliably observed only on the horizontal component. Waves of the L_g -type prevail at the entire distance range under consideration and for this reason they are of particular interest for solving the tasks of seismic monitoring. An advantage of using these waves is that there is a smoother variation of the amplitude level with distance (abrupt variations are absent). As for body waves, we constructed the calibration curves for waves of the S- and L_g -types separately (Table 6.A). Comparison of the curve for L_g -waves with the curve presented by Vanek et al. [1964], which has been obtained for different stations and for earthquakes from other regions, showed their coincidence at distances up to 900 km. At larger distances the L_g -wave attenuation for the northern Tien Shan is significantly weaker. In the distance range 900-2500 km the amplitude level is lower by approximately seven times. At the same time Vanek et al. [1964] have found that such an amplitude decrease is already observed at distance 1400 km. Thus, the "range of influence" for the northern Tien Shan stations is larger than for the European stations. At the same time for the northern Tien Shan stations the L_g -waves are strongly attenuated when crossing the Hindu Kush and the Kun Lun mountain belts. For this reason L_g -waves are not observed on records of the northern Tien Shan stations for

earthquakes from Tibet, Himalaya, Afghanistan and northern India.

Standard deviations for the S- and L_g -waves amplitudes are approximately the same as for P-waves. At the same time, at distances greater than 1000 km small differences are observed, which indicated an absence of a perfect similarity of velocity structure for the longitudinal and shear waves.

2.4. Regional variations of the amplitude level for waves of various types.

Some criteria for the discrimination seismic sources are based on differences in correlations of the amplitude levels for various wave types. For example, one might possibly expect that an explosion, being a symmetrical source, doesn't radiate the shear waves and Love waves. Thus differences in radiation patterns for earthquakes and explosions would be observed.

At the same time strong regional variations of the attenuation of various waves exist, which can significantly change the correlations of originally radiated wave amplitudes. To illustrate this let us consider the character of the attenuation of the waves P_n , P_g , S_n and L_g as a functions of direction for 12 northern Tien Shan stations, equipped with instruments of the SKM type. We analyzed earthquake records of energy classes $K=9.7-14$ ($3.8 < m_B < 5.8$) in the distance range 250-1000 km. Basic data on these events are shown in Table E.A (see Fig. 1.4). In addition,

we considered records of explosions from the Semipalatinsk Test Site (STS), as shown in Table 2A.

We measured the amplitudes and periods for the longitudinal waves on the vertical component, and for the S_n - and L_g -waves - on both horizontal components (in this case we used the larger of the two amplitudes). In the cases when S_n -wave could not be picked out from the background of P-coda, we measured amplitudes at the section of the seismogram, where S_n -waves should be observed according to the travel time curves. The amplitudes measured were normalized to the level, corresponding to the value $K=11$ ($m_B=4.6$). Using these data, we constructed station curves for each epicentral zone, in which we included station corrections determined by distant earthquakes. These corrections diminish the influence of systematic errors, connected with unprecise instrument calibration, various conditions of the seismometer installations (in tunnels or on the surface, etc.). Then we averaged various station charts (Fig. 2.1-2.4).

Let us briefly describe the similarities and differences of the azimuthal charts. For P_n -waves the amplitude curves, as a function of azimuth, have largest divergences (either in their form or their level) in comparison with the other waves. They have the maximum level for the northern direction (explosions), and a minimum - for the southwest direction (earthquakes). Differences in absolute level reach 1.0 or even 1.5 log. units. The charts for the E-NE and SW directions differ less in their level,

nevertheless the divergences reach 0.5-0.7 log. unit. The smallest, but still significant divergences are observed between the charts for explosions (N) and earthquakes (E-NE direction). Extrema of the charts have various "depth", they not always coincide by the epicentral distances.

For the P_g - and S_n -wave charts differences in both form and level are considerably lower. For the P_g - waves the maximum differences in the level are observed between charts for the E-NE and SW directions; they reach 0.5 log. unit. As to the form, there are no clearly expressed maxima and minima here, though in the range 650-800 km the charts become gently sloping. For S_n -waves the maximum differences in the level are only 0.2 log. unit.

The amplitude charts for the L_g -waves show good similarity in form and relatively small (0.2 log. unit) differences in level for the E-NE and SW directions. The chart for explosions differs insignificantly from charts for earthquakes by the level, but strongly by the form. It has a well - expressed maximum at distances where the charts for earthquakes became gentle or they have a small minimum.

Thus, we showed that in the northern Tien Shan region stable anomalies of the amplitude characteristics of various wave groups are observed for earthquakes. Consequently, more abrupt anomalies of this a kind for the northern direction (explosions) can be explained by peculiarities either of the sources, or of the media structure, predominantly in the upper mantle. Note that when recording at various stations these anomalies are revealed in a different manner. For

example, the relative level of the P_n -waves is very high at the Kyzyl-Agach, Talgar, Chilik, Charyn, Narynkol and Rybach'ye stations. At the Fabrichnaya and Ili stations the P_n -wave level by explosions and earthquakes is quite comparable, at least, for similar azimuths.

From the other side, abrupt azimuthal anomalies are observed also for earthquakes. It is interesting that at relatively short distances azimuthal diagrams are sharply changed either by the form, or by the level (Fig. 2.5). In this figure, data only for P_n - and L_g -waves for the Talgar station and nearby stations are shown. Note that for some stations we obtained estimations of the amplitude level not for four, but for five directions. Since earthquakes were not recorded in immediate proximity to the STS, we can not be sure, that we discriminate explosions and earthquakes by correlations the amplitude level but not seismological conditions in various regions.

3. RELATIONS BETWEEN AMPLITUDES OF VARIOUS WAVE TYPES AS CRITERIA OF DISCRIMINATION BETWEEN EXPLOSIONS AND EARTHQUAKES.

3.1. Correlation of amplitudes of S- and P-waves.

We considered the correlation of the amplitudes on records of the SKM corrected for the frequency response. S-wave amplitudes were measured on the horizontal component, and P-wave amplitudes on the vertical component.

In Fig. 3.1 a total distribution of $\lg(A_S/A_P)$ for quarry blasts at distances of 250-550 km is shown. Almost all the blasts were produced in two quarries, situated to the north and to the north-east of the Talgar station (Fig. 1.4). For comparison, in Fig. 1.4 the $\lg(A_S/A_P)$ distribution is shown for earthquakes at the same epicentral distances, but from the other directions, because earthquakes are rare in the quarry areas. In this and other charts the experimental data (points and circles) are approximated by the Laplace function. Despite expectations, the S-wave amplitudes for the explosions are slightly larger than for the earthquakes, though these differences do not exceed $1/3$ of one standard deviation. Another unusual circumstance is that the standard deviation was significantly larger for the explosions than for the earthquakes.

Note that in the other regions this criterion for discrimination of quarry blasts and earthquakes works rather

effectively [Deneva et al., 1989]: when $\lg(A_S/A_P) > 0.4$ the sources are not explosions. Perhaps the reason is connected either with differences in media structure or with different types of instruments. Deneva et al. [1989] note that using the spectral ratios of the longitudinal and shear waves is a promising direction for future investigations.

In Fig. 3.2 analogous distributions for underground nuclear explosions from the STS and for earthquakes for the same distance range (500-1000 km) are shown. We obtained results close to the results for the quarry blasts. The only difference is that at the distances considered the amplitudes of S- and P-waves for earthquakes are equal on average.

Thus, the ratio of the amplitudes of shear and longitudinal waves can not be considered as a criterion of discrimination of blasts and nuclear explosions from earthquakes in the North Tien Shan at distances up to 1000 km neither for the blasts, nor for the nuclear explosions.

In Fig. 3.3 distributions of $\lg(A_S/A_P)$ for nuclear explosions in salt and for earthquakes at distances of 900-2300 km are shown. As long as distance range for the nuclear explosions in salt is greater than for explosions from the STS, we estimated a preliminary change of $\lg(A_S/A_P)$ with distance. For the explosions this value decreases with distance by the relation $\lg(A_S/A_P) \approx -1.95 \lg \Delta$. Note that the data for the nuclear explosions from STS correspond well to this relation. For the earthquakes a relation $\lg(A_S/A_P) \approx -1.75 \lg \Delta$ was obtained. It is possible that this

difference is related to the longer periods of P-waves from earthquakes (for this reason these waves attenuate more slowly with distance). The other possibility is connected with different epicentral zones. Finally, changing values of A_S/A_P for explosions and earthquakes may be incidental, resulting from insufficient amounts of data or by processing errors. We chose the same relation for A_S/A_P for the explosions and earthquakes: $\lg(A_S/A_P) \approx -1.85 \lg \Delta$. In Fig. 3.3 a distribution of deviations from an averaging line is shown. Mean values of the distributions correspond to $\Delta = 1600$ km.

It follows from these charts that the ratio of the amplitudes A_S/A_P at distances of 900-2300 km is not an effective criterion. The maximum difference between distribution curves for the explosions and earthquakes corresponds to $\lg(A_S/A_P) = -0.3$. In this case approximately 82% of the earthquakes are eliminated with 18% false alarms.

3.2. Correlation of amplitudes of P_n - and P_g -waves.

P_g -waves stand out well at distances up to 1000 km. Ratios of amplitudes P_g/P_n for explosions and earthquakes are similar. In addition, standard deviations for the corresponding distributions are large ($\delta = 0.26$ log.unit) for the explosions and even larger for the earthquakes. Thus, the value of this ratio can not be used as criterion to discriminate the explosions and earthquakes, at least for the northern Tien Shan stations.

3.3. Correlation of amplitudes in various groups of longitudinal waves at distances more than 1000 km.

Since we do not regard these groups to be some determined P-wave types, we pick out them in a formal manner. We denote waves with higher apparent velocities than those of the P_g -waves, and with maximum amplitudes observed on the vertical component, by a symbol 1P. At distances more than 1000 km they were usually waves of the P_n type. We denote waves with apparent velocities less than those of P_g -waves, but larger than that of S-waves, by a symbol 2P.

In Fig. 3.4 distributions of $\lg(A_{2P}/A_{1P})$ for explosions in salt and for earthquakes at distances of 1200-2000 km are shown. Here we used records of the Talgar, Borovoye, Zerenda, Bayanaul and Karkaralinsk stations. We can see that ratio of the maximum amplitudes A_{2P}/A_{1P} is not really an effective criterion for discrimination. The maximum distance between distribution curves for the explosions and earthquakes corresponds to $\lg(A_{2P}/A_{1P})=0.28$. In this case about 77% of the earthquakes are eliminated with of 23% false alarms. As long as these explosions originated in various regions, we can infer that this criterion can be used for the other epicentral zones as well.

3.4. Correlation of S-wave amplitudes.

One may suppose that differences in directions of

strength acting at sources for explosions and earthquakes can lead to differences in levels of amplitudes for S_H - and S_V -waves. But we did not find any significant differences. The amplitude levels on components compared were equal on average. The standard deviations for the explosions and the earthquakes were also approximately the same ($\delta \approx 0.12$ log.unit). Thus, this parameter can not be considered as a criterion for discrimination at least for the northern Tien Shan stations.

3.5. Correlation of L_g - and P-wave amplitudes.

We measured the maximum amplitudes of L_g - and P-waves. We carried out measurements of L_g -wave amplitudes on the horizontal component, and P-wave amplitudes on the vertical component. Whereas epicentral distance significantly affects our results for the explosions, we processed the data for the underground nuclear explosions from the STS separately from those from the salt dome areas. Fig. 3.5 shows distributions of $\lg(A_{L_g}/A_p)$ for the explosions from the STS and, for earthquakes at the same distance range ($\Delta=500-1000$ km). We can see that both curves have similar parameters. Using the value A_{L_g}/A_p for this distance range as a criterion for the earthquakes is found to be ineffective. Note that Murphy and Bennet [1982] showed a low effectiveness of this criterion at the distance range considered in the other regions. However, they pointed out discrimination by spectral analysis of these wave types was

highly effective.

In Fig. 3.6a analogous distributions for explosions in salt and for earthquakes in the distance range 1200-2300 km are shown. At these distances the data variance for both the explosions and for the earthquakes is significantly less than it is at shorter distances. The parameter A_{Lg}/A_p can be used as a criterion for discrimination at such distances. The maximum distance between the distribution curves corresponds to a value $\lg(A_{Lg}/A_p)=0.4$. In this case approximately 72% of the earthquakes are eliminated by a lapse 28% of the explosions. This criterion can be used together with other criteria.

Note that Blanford [1980] obtained a contrary result: in that study the ratio A_{Lg}/A_p is less for earthquakes than for explosions. Probably in some cases this parameter discriminates differences in epicentral zone structure, rather than the nuclear explosions and earthquakes.

3.6. Amplitude correlation LgH/LgV .

Fig. 3.6b shows distribution of $\lg(LgH/LgV)$ for all types explosions and earthquakes in the distance range 290-3100 km. As long as waves of the same type are considered, their amplitude ratios depend little on magnitude or on epicentral distance. The other advantage of this method is that Lg waves often dominate at regional distances.

3.7. Correlation between amplitudes of longitudinal and surface waves (criterion m-M).

One of major methods for discrimination is based on surface and body waves. After a meeting of experts in Stockholm the number of publications devoted to this criterion abruptly increased. Recently however quantitative estimates of effectiveness of this criterion, determined by various authors, are quite different. It is worth noting that an abundance of formulae have been presented in various publications [Gutenberg, 1945; Fillippo and Marcelli 1949; Vanek and Zatopek, 1955; Gutenberg and Richter, 1956; Stelzner, 1961; Romney, 1964; Fisher 1964; Flinn and Engdahl, 1965; Antonova et al., 1968; SIPRI, 1968; Basham, 1969; Bath, 1969; Liebermann and Pomeroy, 1969; Bune et al., 1970; Pasechnik, 1970; Basham and Whitham, 1971; Gordon, 1971; Dahlman et al., 1971; Gupta et al., 1972; Bune and Golubeva, 1973; Polikarpova, 1973; Seggern, 1973; Basham and Horner, 1973; Springer and Hannon, 1973; Kondorskaya et al., 1974; Khalturin, 1974; Golenetskaya and Medvedeva, 1974; Ulomova, 1974; Prozorov and Hudson, 1974; Elvers, 1975; Hudson and Douglas, 1975; Bungum and Tjostheim, 1976; CCD/558, 1978; Kebeasy et al., 1979; Hattori, 1980; Husebye and Mykkeltveit, 1981; Stevens and Day, 1985; Nowroozi, 1986; et al.].

We investigated factors which can significantly influence the accuracy of this criterion. In our opinion,

the major factors are as follows:

- imperfection of mathematical processing of experimental data;
- small amount of data;
- regional peculiarities of media structure;
- peculiarities of methods of magnitude estimation;
- frequency response of the apparatus used.

3.7.1. Processing of the experimental data.

We will show that differences in formulae describing dependences between the values m and M is to a considerable extent connected with an incorrect method of data processing. Usually a relation is looked for in the form of a linear correlation:

$$m=a+bM \quad (3.1)$$

Most investigators take one of the regression equations as a desired correlation. Such an approach is equivalent to a statement that scatter in the experimental data is connected with errors in determining only one of the compared values. In earlier works, when the magnitude M was a basic characteristic of seismic source energy, this value was used as an independent variable. Consequently, these investigations looked for the regression of m by M . Such the regression leads to underestimations of the values of a and b . The more variation and less range of change in the compared values, the larger the regression coefficient is underestimated.

Later, the magnitude m became the more common characteristic, and correspondingly investigations began to determine more often the regression of M by m . In this case, after the equation obtained is transformed to the form (3.1), overestimated values of the coefficient b are determined. Since the variance of the magnitude estimations for explosions is smaller than it is for earthquakes, errors of the coefficient b in the correlation (3.1) for the explosions also will be smaller. For this reason the regression lines $m=m(M)$ for explosions and for earthquakes in general (by using the regression) are not parallel.

In the papers cited above, we found 62 values of coefficient b in the equation (3.1). The distribution of this coefficient, as one would suppose, has two peaks.

For more accurate estimates we picked out 16 equations, obtained using the regression of m by M ($m=a+bM$, which implies, that only the m value may have errors). In the first case b has an average value of 0.52 ± 0.07 , and in the second case $b=0.89 \pm 0.17$.

Comparing the standard deviations of b values, it is possible to conclude that when determining the m value the errors are approximately 2.4 times as large as they are when determining the M value.

To decrease the errors connected with the mathematical processing of the seismic data, some authors use the method of orthogonal regression [Antonova et al., 1968; Aptikaev, 1969; Prozorov and Hudson, 1974]. To use this method it is necessary to know the ratio of the errors of values

compared. According to our estimates, for the regional seismic network the standard deviation for the M value for earthquakes is slightly less than 0.1, and is about 0.25 for the m value. Thus, the $\delta m / \delta M$ ratio probably equals 2.5, which closely coincides with the estimation above.

In Fig. 3.7 data showing the discussed correlation of $M(SK)$ and $m(SK)$ for earthquakes at distances not exceeding 2500 km from the center of the north Tien Shan seismic array are presented. We did not consider the earthquakes with epicenters in the Caspian sea because on average underestimated M values correspond to these events. Source depths did not exceed 70 km. We considered 586 earthquakes. We processed the data using the method of orthogonal regression by various assumption about the correlations between the errors of determining the m and M values ($k = \delta m / \delta M$):

By $k=0$ (regression M by m) $M=1.47m(SK)-2.9$,

By $k=2.5$ (the best approximation) $M=1.6m(SK)-3.65$,

By $k=\infty$ (regression m by M) $M=1.7m(SK)-4.15$.

In this case, differences are not so considerable. The reasons are as follows: firstly, we considered a limited number of epicentral zones and the compact network of the seismic stations, and secondly, we eliminated data from area of the low M values, which boundary is shown in Fig.3.7 by a dotted line.

3.7.2. Significance of the data.

To obtain reliable results experimental data should be statistically significant in all considered ranges of magnitudes and epicentral distances. However it is difficult to take this factor into account. For example, loss of weak signals leads to overestimating magnitude values. For records of surface waves the slope of the averaging line is changed. Some authors attribute the nonlinearity of the function $m(M)$ completely to the loss of part of the surface waves records [Husebye and Mykkeltveit, 1981]. We support this point of view. Elvers [1974] and Husebye and Mykkeltveit [1981] have developed methods to take into account the loss of the weak signals by some part of seismic stations and methods to increase efficiency of the criterion $(m-M)$ by "negative evidences". Using the method of orthogonal regression does not eliminate the errors connected with the statistical insignificance of the data. It is possible to weaken this effect by excluding insignificant data from consideration. The data insignificance can be easily discovered by an abrupt change of median line directions by columns and rows.

Fig. 3.7 shows that the median line by columns (the continuous thin line) sharply changes its direction at $M=4.1$, stretching parallel to the horizontal axis. For the median line by rows (dashed line) a change of direction to the vertical axis, is not observed. This means that at least by $m \geq 4.0$ the magnitudes m in our sample are significant ones. To remove errors connected with the loss of significance by M value, we drew a line through the "bend"

of the median line perpendicular to the supposed direction of the desired stright line (dotted line in Fig. 3.7). It is impossible to take into account the data below this boundary outlined. In Fig. 3.8 an obvious case of insignificant data for both variables (m and M) is shown.

Analogous analysis was carried out for underground nuclear explosions (Fig. 3.9.). Distance ranges were slightly greater (the Novaya Zemlya test site is at a distance of about 3500 km from the northern Tien Shan stations). Also included in this sample are explosions from the STS, industrial explosions in the territory of the FSU, including explosions in salt, and a few explosions from the Chinese test site Lop Nor. Fig. 3.9 shows, that the chart $M=M(m)$ has the same slope as for earthquakes: $M=1.6m(SKM)-4.85$. In this Figure one can see that at distances of 750 km surface waves from the explosions are not recorded by the SK-seismometers with a magnification of about 1000 by $M=2.9-3.2$ (depending on the level of microseisms). This threshold may be decreased using frequency, polarization, and velocity filtering by array analysis.

Note that equations connecting magnitudes m and M for earthquakes ($M=1.6m(SKM)-3.65$) and for explosions ($M=1.6m(SKM)-4.85$) obtained by analysis of data from stations in the northern Tien Shan are essentially different from equations obtained in other regions. Many authors have mentioned the dependence of the correlation of m - M on peculiarities of the media structure in the regions of

sources and stations [Savino et al., 1971; Landyрева, 1974; Instructions..., 1982 etc.].

We also estimated coefficients in the equation $m=a+bM$ for 9000 earthquakes from 45 regions using data of the ISC bulletins, and also for smaller areas by records from the ESSN stations. The results obtained support the dependence of the coefficients of the equation on the propagation medium. One can judge the values of these variations by the results presented in Table 3.1. These estimations are obtained by processing the experimental data using the method of the orthogonal regression with the constraint $\delta m/\delta M=2.5$.

Table 3.1. Values of the coefficients in the correlation $m(SKM)=a+bM$ by data of the ESSN network.

Region	a	b	Range of the significant magnitudes (m value)
Aleutian Islands	2.50	0.60	4.9-6.2
Kamchatka	1.00	0.67	4.6-6.0
Kuril Isl.	2.75	0.52	5.2-6.5
Japan	2.40	0.69	5.0-6.5
Philippines	2.35	0.61	5.2-6.5
Indonesia	2.10	0.69	5.0-6.7
China	1.10	0.82	4.5-6.0

Thus, the values of the coefficients depend on the stations and epicentral zones which predominate in a sample of data.

3.7.3. Methods of determining magnitude.

In many countries, new modifications of magnitude scales, including calibration functions, station and regional corrections and methods of measurements on the seismograms have been developed to increase the accuracy of magnitude determination. We know more than 100 papers devoted to these problems. The characteristics of the local magnitude calibration curves for the various wave types in the regions of Central Asia and Kazakhstan are described in Section 2.

Methodical techniques of magnitude estimation can also influence the final results. For example, Basham and Horner [1973] considered the values m and M for explosions; the method of determining these magnitudes was especially developed for the purpose of calibration. A peculiarity of the method consists in using only the amplitudes of signals. Disregarding the visible periods improves the repeatability of the data for explosions in various media. They also considered the correlation of the magnitudes m and M , estimated by the methods described above. Of course, the equations obtained differ from the results of other authors.

The other essential difference in the techniques of

seismogram processing is connected with a choice of measurement range and time interval. Some seismologists use the maximum amplitude value, divided by corresponding visible period. Others use the maximum value A/T for the entire time interval under consideration. Clearly, $A_{\max}/T \leq (A/T)_{\max}$.

Lastly, differences in the choice of time interval for magnitude determination are essential for our purposes. At CSE, we use the maximum value A/T for events with $m < 7$ in the 25 sec interval after the first arrival. The NEIS measures amplitudes in a 5-sec interval after the first arrival. This difference in methods leads to systematic underestimation by the NEIS of earthquake magnitude by 0.3-0.4. For explosions this difference does not exceed 0.15.

Miyamura [1983] also pointed out that maximum P-waves amplitudes are often reached later than the time interval adopted for magnitude measurement in the USA.

Fig. 3.10 shows the distribution of deviations of the experimental data from the best-fit straight lines to $M=M(m)$ for earthquakes and explosions. An asymmetry of the distribution for earthquakes can be observed. One can see the efficiency of the $m-M$ criterion, for all explosions, $M < 1.6m(\text{SKM}) - 4.05$. In this case about 8% of the signals are false alarms. Note that efficiency of these criteria will be slightly higher if we pick out earthquakes with shallow focal depths, in accordance with the accuracy of the depth determinations. In this case, the distance between the distribution curves for the earthquakes and explosions

probably will increase forwards the M axis, and the standard deviation will diminish.

3.7.4. Frequency response of the seismic channels.

The estimations of discrimination efficiency presented earlier are related to magnitude m , determined using short-period instruments of the SKM type. Nevertheless, the efficiency of this criterion can be increased using more short-period instruments for measuring the m values with corresponding lowering of the calibration accuracy. By our estimation the use of shorter-period Benioff seismometers leads to the underestimation of the m value: $m(\text{SKM}) - m_B < 0.15$ for explosions and $m(\text{SKM}) - m_B \approx 0.30$ for earthquakes. Thus, only by short-period filtering can the efficiency of this method be significantly increased.

For the Talgar station we compared the magnitude estimations using records of the SKM- seismometers with periods $T_0 = 1.5$ sec and $T_0 = 1.2$ sec (in Fig. 1.1. these correspond to frequency responses No. 2 and No. 3). We did not find systematic differences in the magnitude values for explosions when using these seismometers. For the earthquakes the magnitude values m are higher on average for more broad-band seismometers: $m(T_0 = 1.5 \text{ sec}) = 1.02m(T_0 = 1.2 \text{ sec}) + 0.1$. For example, according to the formula presented, at $m = 3$ the difference in the m values is about 0.15. This difference increases with increasing magnitude.

In principle, it is possible to increase the efficiency of this criterion by using also the change of the frequency response of the long-period channel. But we did not carry out such an investigation due to an absence of long period apparatus which would allow us to synthesize filters with various characteristics.

3.8. Time of amplitude level increase from the first arrival to P-wave maximum.

As our investigations show, the time T_r of the amplitude increase from the first P-wave arrival to the maximum amplitude in this wave group proved to be a useful criterion at teleseismic distances. The distributions of T_r for earthquakes and explosions are shown in Fig. 3.11. For explosions from the Novaya Zemlya test site (NZTS) a value $\lg T_r(\text{sec})$ as an average equals 0.3 and the standard deviation is 0.34 log. unit. The mean distance from this test site to the North Tien Shan stations is 3500 km.

For the industrial explosions, including those in salt, we considered only records from the Talgar station. The epicentral distances were 900-3100 km. A large number of these explosions corresponds to the distance range of 1700-3100 km. We considered 56 industrial explosions and 55 earthquakes. A distribution of the $\lg T_r$ value for the industrial explosions is described by parameters $\lg T_r(\text{sec}) = 0.42 \pm 0.40$. The corresponding distribution for the earthquakes is characterized by parameters

$\lg T_r(\text{sec}) = 0.87 \pm 0.40$. The maximum distance between the distribution curves corresponds to the value $\lg T_r(\text{sec}) \approx 0.65$. In this case about 72% earthquakes are eliminated by 28% explosions miss. It also follows from this chart, that for about 9% of the earthquakes the maximum P-wave amplitudes are observed for $T_r > 25$ sec. One should take this factor into account when developing methods of magnitude estimations.

Note, that the effectiveness of this criterion can be increased by studying the influence of such characteristics as distance and magnitude on the T_r value. We reduced the magnitude influence by limiting the magnitude range and narrowing the epicentral distance range. Previous investigations of the effects of these factors have been made before [Zapolsky et al., 1974; Landyrev et al., 1974].

As it is seen in Fig. 3.11, the differences in the T_r values decrease at smaller epicentral distances, while the variance increases. At distances less than 1000 km the distribution of the T_r value is discrete and corresponds to various P-wave types for nuclear and chemical explosions, including quarry blasts.

In the Degelen area, $\lg(T_r(\text{sec})) = 0.27 \pm 0.17$, for 23 of the 96 explosions considered, $\lg(T_r(\text{sec})) = 1.07 \pm 0.03$ for 56 explosions and $\lg(T_r(\text{sec})) = 1.38 \pm 0.01$ for 17 explosions. These T_r values correspond to the wave groups P_{n1} , P_{n2} and P_g .

In the Balapan area $\lg(T_r(\text{sec})) = 0.27 \pm 0.08$ for 9 events from 21 explosions and $\lg(T_r(\text{sec})) = 1.09 \pm 0.03$ for 12 events. For the North Tien Shan stations P_g -waves for the explosions

at the Balapan test site are always smaller than P_n waves.

For the Murzhik area the P_{n1} wave was longer only in two cases with $T_r=1.8$ sec and $T_r=2.2$ sec. The P_{n1} wave was longer in 8 cases with $\lg T_r(\text{sec})=1.1\pm0.05$. In four cases the maximum amplitudes corresponded to the P_g -wave with $\lg T_r(\text{sec})=1.41\pm0.07$.

An analogous situation exists for chemical explosions at distances of about 750 km: for the 16 records considered the times of amplitude increase were in two cases 2.4 sec and 2.5 sec, in twelve cases $\lg T_r(\text{sec})=1.04\pm0.03$ (10.9 sec), and in two cases $T_r = 33$ sec and 37 sec.

For earthquakes, the T_r value is on average, larger than for explosions. This is probably because earthquake sources are usually deeper, than explosions. This leads to appearance of large number of secondary waves, including those related to the Earth's surface. An explosion can be considered as a point source, while earthquake source usually has a considerable size, comparable with wave length of waves radiated. Finally, explosions can be considered as the source of instantaneous action, while an earthquake source is more like an integration of subsources. Thus, in the general case seismic waves produced by earthquakes are more long and complicated, than those produced by explosions.

4. SPECTRAL-TEMPORAL CRITERIA OF IDENTIFICATION OF EXPLOSIONS AND EARTHQUAKES.

4.1. Predominant periods of seismic waves.

Comparison of visible periods corresponding to peak amplitudes of different seismic phases from explosions and earthquakes is the simplest type of spectral criteria for discriminating earthquakes and explosions. The broader the frequency band of recording equipment the more reliable are the criteria working on the basis of visible periods. Although the photographic paper rate in the equipment of the SK type is four times lower than that of the SKM type (30 and 120 mm/sec respectively), resolution from the seismograms differs only by a factor of two: the minimal period measured from the SKM seismograms is 0.2 sec, and that from the SK seismograms is 0.4 sec. Sometimes, when ambient seismic noise is low and the signal has a sinusoidal-like shape, the threshold of resolution may be lower, and when the noise is high - the threshold should increase. Magnitude correction was used to reduce the error of the period measurements. From the data recorded at Talgar station, the periods of longitudinal waves from explosions increase with magnitudes as $\text{dlg}T(\text{sec})/\text{dm}=0.10$ in the range from 700 to 3000 km from the epicenter. According to this relationship, all the estimates were reduced to a magnitude of $m=5.0$ because it is predominant in the set of explosions

considered here.

Visible periods in P-waves from earthquakes almost do not depend on distance as measured by the SKM type equipment [Antonova and Khalturin, 1966; Antonova et al., 1968]. The visible periods of P-waves from earthquakes with magnitude $M=5.0$ are of $\lg T_p(\text{SKM})=0.084 \pm 0.160$ in the range from 400 to 1100 km. The periods increase a little beyond 1100 km due to a change of predominant seismic phases. The periods are stable again in the 2000 to 3000 km range: $\lg T_p(\text{SKM})=0.018 \pm 0.10$. Visible periods of P-waves from underground nuclear explosions are much shorter and also depend on distance very weakly as follows from our data as well as from other unclassified sources [Passechnik, 1970].

The SK type seismographs show the same measured visible periods from explosions as the SKM do. As for earthquakes, the periods from SK records are characterized by higher values and higher standard deviations. The period/distance curve from the SKM data is smooth while that from the SK data has peaks. Neglecting these oscillations in the SK curves, one can obtain: $\lg T_p(\text{SK})=0.17 \pm 0.23$. The visible periods increase almost in proportion to distance from $\lg T_p(\text{SK})=0.26$ at 1000 km to $\lg T_p(\text{SK})=0.55$ at 2000 km. The visible periods vary very intensively in the range from 2000 to 3000 km with the highest value being as large as $\lg T_p(\text{SK})=0.68$ at 2300 km and the lowest value being of $\lg T_p(\text{SK})=0.42$ at 2600 km.

Standard deviation of $\lg T$ value at distances below 2000 km can be treated as constant and equal to 0.23. If we

neglect some oscillations in the range from 2000 to 3000 km, one can obtain the following relationship: $\lg T_p(SK) = 0.55 \pm 0.25$. All the data considered above were obtained from the recordings at the Talgar seismic station. Antonova and Khaiturin [1966] presented the results of a study of visible periods as a function of distance for other seismic stations of the Central Asia, Kazakhstan, Siberia as well as other regions. From our data it follows, that the periods of oscillations that change with distance, depth and positions of peaks may vary in a broad range even for stations located in the same region. North Tien-Shan stations recorded some quarry explosions 250 to 500 km away; nuclear explosions at the STS and large-scale chemical explosions conducted in various regions 590 to 890 km away; the bulk of the data on peaceful nuclear explosions including salt explosions are in the range from 1700 to 2300 km. It is worth while processing the data for the explosions separately and not include corrections (different corrections for different stations) for the epicentral distance.

Figure 4.1 displays the distribution of periods of oscillations from 14 explosions detonated at two quarries near Sayak and Kyzyl-Agach (see Fig. 1.4) and 70 earthquakes in the same range from 290 to 430 km.

No magnitude correction was included since the records from the explosions and earthquakes were obtained in the same range from the events with similar magnitudes. The records from the earthquakes, as shown in Figure 4.1, are

"enhanced" by low frequencies. From the 70 earthquakes measured by short-period equipment, four have periods as large as 4 sec, and one has a period even longer than 5 sec. The largest difference between the distribution curves from the quarry blasts and earthquakes is then $\lg T_p = -0.08$. 98 percent of the earthquakes are separated while missing only 7 percent of the explosions. Efficiency of such a criterion can be substantially increased by broadening the equipment response to longer periods.

Nuclear explosions in salt do not differ much from peaceful nuclear explosions in other rock media by periods of longitudinal waves. Thus, they can be studied together. Figure 1.4 presents the epicenters of the explosions and principal information on the explosions is summarized in Tables 3.A and 4.A.

Despite a large distance range (1000 to 3000 km), the distribution of periods estimated from 71 explosions (Figure 4.2) is characterized by a relatively low standard deviation of 0.10. 125 records of earthquakes in a range from 1700 to 2900 km, where most of the explosions occurred, were studied for a comparison. The standard deviation for the earthquakes is much larger of 0.23. The largest difference between the distribution curves for explosions and earthquakes corresponds to $\lg T_p = 0.13$. 95 percent of the earthquakes are separated in this case while missing only 5 percent of the explosions. The efficiency of this criterion may be underestimated since neither distance nor station corrections were included. A standard deviation of $\lg(T)$

obtained for earthquakes at a fixed range from one seismic station (Talgar) has been already estimated, which is 0.13. Since the epicenters of explosions and seismic stations are situated in different regions one can infer that the criterion will work everywhere.

Figure 4.3a shows distributions of $\lg T$ for the following groups of seismic sources:

- underground nuclear explosions at the Degelen area, STS;
- underground nuclear explosions at the Balapan and Murzhik areas, STS;
- chemical explosions;
- SKM measured earthquakes;
- SK measured earthquakes.

All the sources are in the relatively narrow range of 590 to 890 km.

It follows from Figure 4.3a that the periods of oscillations, even with 3-sigma deviation, are all in the band of SKM response. That is why the distributions of visible periods of P-waves are the same from the SK and the SKM records. Visible periods at the SK records from earthquakes in the same range are much larger. It follows from the Figure that the Balapan and the Murzhik explosions generated oscillations with 25 percent longer periods than those of the Degelen. Chemical explosions are of even longer periods (at the same distances).

Frequency content is also not the worst criterion of discrimination between earthquakes and explosions. When measuring P-wave periods from 101 explosions at Degelen by

using the SK seismographs the periods were shorter than 0.8 sec in all the cases, while those from 58 explosions at the Balapan and the Murzhik were in the range from 0.8 to 1 sec only in three cases (~6%). Periods shorter than 0.8 sec were observed only in 6% of the SKM records and 2% of the SK records from earthquakes. Chemical explosions are less well separated with all of the 14 explosions having periods less than 1.1 sec. 15% of the earthquakes have periods at the SK records shorter than 1.1 sec.

The results obtained are in good agreement with those reported by Passechnik [1970]: periods of P-waves from underground and surface explosions at distances less than 1000 km were 0.58 ± 0.10 sec for the SKM seismographs; the SK seismograph periods were almost the same.

Periods of L_g waves also differ for explosions and earthquakes. Earthquakes selected for the study were in the range from 700 to 2300 km because the UNE and industrial explosions detected by the Talgar station were in the same range. Visible periods vs. magnitude and distance are well studied for northern Tien Shan earthquakes as well as for the Talgar station. We studied only SK records at Talgar. This station is characterized by following relationships: $\delta \lg T(L_g) / \delta m = 0.16$, $\delta \lg T(L_g) / \delta \lg \Delta = 1.0$. Experimental estimates of the visible periods were reduced to $m = 5.5$, $\Delta = 1000$ km. The results are as follows (see also Fig. 4.3b)

explosions $\lg T(L_g) = 0.15 \pm 0.08$

earthquakes $\lg T(L_g) = 0.51 \pm 0.14$.

Thus, underground nuclear explosions, including those in

salt, are best discriminated (at fixed magnitude and distance) when $\lg T = 0.28$. 95 percent of the earthquakes are separated in this case while missing only 5 percent of the explosions.

It is worth noting that discrimination of earthquakes and explosions can be done from the SKM records also. For example, for the STS explosions and earthquakes in the same distance range, 90 percent of earthquakes are separated with 10 percent of explosions missing when $\lg T(L_g) = -0.03$.

4.2. Spectral-temporal criteria of identification of explosions and earthquakes

In recent years, specialists in control and monitoring are paying more and more attention to spectral methods of identification. One of the reasons for this is the importance of control of weak sources at regional distances. The smaller the epicentral distance and magnitude of a seismic source the higher frequency spectral content of seismic signal one can suppose. Most of the known identification criteria reflect the fact that spectral and temporal distribution of energy are different between different seismic phases. Thus, the classic magnitude criterion and its modifications characterize the ratio between shares of short-period P-wave energy in the beginning of the seismogram and long-period surface waves energy at later times. It is interesting also that almost all the criteria proposed before are based on one such

ratio, for example, different groups of P-wave, P- and S-waves, P- and L_g-waves, P- and LR-, LR- and LQ-waves, etc. [Taylor et al., 1989]. Even the enumeration of the investigated ratios shows, however, that differences in spectral and time distribution of energy of the waves from underground explosions and earthquakes are characteristic for the whole seismogram. The question, evidently, is how to use these differences altogether. An optimal way is computer processing of broad-band digital waveforms. Multidimensional algorithms of the criteria are elaborated in other studies [Wichert, 1971; Pisarenko et al., 1981; Tjostheim, 1981].

In our investigations, we used analog records of multichannel frequency-selecting seismic station (ChISS). Experience obtained by CSE shows that such stations used at distances up to 2500 km are effective in discrimination of explosions and earthquakes. The algorithm we have developed is an attempt to create a complex spectral and time criterion of discrimination. One of the important features of this algorithm is a description and parametrization of the materials used.

Seismograms can be described quantitatively in various ways. A natural requirement here is decreasing the amount of digital data with the total information saved relevant to the problem under investigation. In the theory of artificial perception, where one of the principal and specific tasks is a formation of a space of informative signs, there are no strict methods of selection and estimation. There are only some intuitive and approximate ways of selecting a

particular sign from these available. This selection determines in principle the ways of solving the main problem of recognition (identification):

- a) formation of a space of informative signs;
- b) determination of characteristics of the images in the space of informative signs (statistical descriptions of separable classes);
- c) construction of a rule for class determination of input objects (decisive rule).

An initial description almost always has some physical meaning and it is natural for researchers to look for discriminators that have a clear physical nature. Sometimes they can be isolated. In practice, however, objects of separable classes in description may be so mixed that it is necessary to use special and sophisticated algorithms of curved separable surfaces which is difficult to use in a sign space of many dimensions. To solve this problem, some transformations of the initial description are usually used (to achieve more compact object locations in the classes, to increase differences between them, and to use more simple separating surfaces) or reduction of the sign space dimension (to use more effective algorithms). Here, we use the first technique.

Seismograms from earthquakes and underground nuclear explosions recorded by ChiSS stations at Talgar and Garm provide the data for this study. Typical responses of the stations are illustrated in Fig. 1.3. Two ways of parametrizing the records are used: the method of

distinguishing parameters, are method of module envelopes.

4.2.1. Method of distinguishing parameters.

Data reduction represents a procedure for distinguishing parameters and quantifying their differences. Peak-to-peak amplitudes at seismic phases P , P_g , S , L_g , and L for selected time/distance curves were the principal parameters. Each record was separated into sections so that peak amplitudes were not left out of the section because of epicenter location errors. Next spectral ratios, $\text{tg } \varphi$, (Fig. 4.4) were compiled to characterize the slope of the logarithmic spectrum of the ChISS records. These are equal to the difference of decimal logarithms of amplitudes of neighboring channels.

Spectral ratios of all the neighboring pairs of channels in all the selected sections were compiled into "code" tables in such a way that sections of records appear in rows and recording channels in columns. Thus, the code tables provide a succinct description of the steepness of ChISS spectra in various record sections. Note, that for various reasons (different time shift of filters, divergence and differentiation of wavetrains at different channels, etc.) the spectral ratios determined by this procedure may characterize spectral steepness in nonsynchronous times, but this nonsynchronism should not be larger than the time section itself. Figure 4.5 shows graphically the code tables. The horizontal axis (time) is divided into intervals

by the number of selected sections or by the number of columns in a code matrix. Numerical values of the spectral ratios are given along the vertical axis. Points in a section, i.e. along columns of the code matrix, and between sections along rows of the matrix are connected by lines.

4.2.2 Method of module envelopes

In our opinion the method of module envelopes is more involved and describes the spectral-temporal field of ChISS seismograms more accurately. Here the same characteristic of logarithmic steepness of spectral slope in a section of discrete time is used, but smoothed values of the envelopes of each channel are used as the parameters.

The smoothing procedure is as follows. A center line was drawn along each channel of the ChISS record. All the positive peaks of the record were marked on transparent paper which then was turned over and negative peaks were added to positive ones. Hence, a summary cloud of points was obtained on the paper where points represent absolute values (modulus) of all the extrema (Fig. 4.6). The points were coded with an accuracy of 0.5 mm in amplitude and 1 sec in time. The envelope of each trace thus coded was averaged by a rectangular window with a length larger than 8 mean periods of the corresponding filter. The peak amplitudes of the records in the band from 0.27 to 0.40 Hz (the first channel) were averaged in a window of 30 sec length, the channel with the frequency band of 0.62 to 0.92 Hz had

window length of 20 sec, and the channels of higher frequency had a window length of 10 sec.

The procedure of initial processing includes also the calculation of standard deviation, logarithms, as well as recovery of true ground motion. Thus, current parameters of a record were the decimal logarithm of an averaged level of the envelope and the corresponding standard deviation. Parameters were sampled (every 5 seconds) from each record. Hence, the averaging was conducted with different amount at overlap: for the first channel the overlap was of $5/6$ of the time window length, $3/4$ for the second, and $1/2$ for the remainder. Figure 4.6 shows an example of original data and the envelopes of $\lg A$ and $\lg(A+\delta)$ for the record of the fourth channel (2.2 to 3.4 Hz) at the Talgar station. CHISS spectra steepnesses were then calculated by differential coding of the amplitudes of the envelopes of neighboring channels at synchronous moments of time.

We note that records from 63 earthquakes and 43 explosions were processed by the method of distinguishing parameters. 50 earthquakes and 23 explosions were less than 1000 km away from recording stations and 13 earthquakes and 15 explosions more than 1000 km away. The method of module envelopes was used for 13 explosions and 11 earthquakes recorded at Talgar (Table 4.1). The earthquakes were selected from a sector of the Zaisan-Pamir region along an arc of 735 km radius centered at Talgar (Fig. 4.7).

Table 4.1. Original information on earthquakes, records of which were processed by module envelopes method

N	Date	Time	N°	E°
	dd mm yy	hh mm ss		
1.	10/01/61	03-07-08	43.5	87.1
2.	11/06/61	12-28-47	37.1	73.1
3.	11/21/61	05-00-03	40.5	70.1
4.	06/26/63	14-09-13	36.4	76.7
5.	11/23/64	06-57-58	41.9	86.1
6.	10/21/65	15-56-33	43.8	87.1
7.	11/17/65	00-17-44	48.5	81.7
8.	08/28/67	21-05-52	36.5	80.1
9.	02/10/67	05-51-02	41.6	86.2
10.	01/13/71	21-52-31	39.0	70.8
11.	04/18/71	07-24-15	39.0	71.4

4.2.3. Contour properties of the ChISS seismograms.

The contour properties of a seismogram are the specific features of the surface represented by the relief of the amplitude of the spectral-temporal field of the seismic process under analysis.

Character of time sections of ChISS seismograms. Let us

consider time sections of a trace of the ChISS record transformed by the method of module envelopes. Figure 4.8 shows some examples of the filtered records for two explosions and two earthquakes.

Despite some similarity in the shape of the envelopes of the explosions and earthquakes, there are some significant differences: low-frequency envelopes of the earthquakes are characterized by higher amplitudes, whereas at high frequencies the situation is opposite. The envelopes of the third and fourth channels are the highest for the explosions, while the envelope of the first channel is highest for earthquakes.

From other specific features important for discrimination of earthquakes and explosions, there is a distinction of differentiated amplitudes of the envelopes of P- and S-wave sections. This difference for the explosions in the first three channels (especially the second) is much higher than for earthquakes. Distinctions of P- and S-wave are also clear. There is a deeper relative minimum of the envelopes for the explosions opposite to that for the earthquakes. This relation suggests that this feature is similar to one which is the basis of a "complexity" criterion at teleseismic distances.

Figure 4.9 shows diagrams of sums of normalized envelopes of an explosion (right) and an earthquake (left). There are two curves in each of the diagrams. The solid line represents the time history of S-envelopes normalized to the envelope of the first channel, and the dashed line is for

S-envelopes normalized to the envelope of the fifth channel. The difference between the explosions and earthquakes is clear. It is expressed in the fact that the curves for the earthquakes do not cross the "zero" line (the solid line is totally below zero, and the dashed line is above zero) whereas both curves of the explosions cross the line (i.e. are in the positive and negative regions of the sum). This feature may be interpreted in a following way: the sum of the envelopes normalized to the first channel shows how much of the spectral density at high frequency is lower or higher than that of the first channel. The sum of the envelopes normalized to the fifth channel characterizes the same relationship but at low frequencies.

Thus, it is clear from figure 4.9 that in the first two minutes (i.e. P and S time intervals) the record of the explosion is of relatively high frequency, and the record of the earthquake has a spectrum with energy at long periods. This difference between explosions and earthquakes is of crucial importance in the frequency band of interest. Surface waves also differ at this point, but less. Long-period records could be used to investigate this idea.

Properties of spectral sections. It is convenient to consider the properties of spectral section through the characteristics of spectral slope steepness in the frequency band. Figures 4.10 through 4.14 show diagrams illustrating the variation in time of slope steepness in different frequency bands (between neighboring channels).

Figure 4.10 illustrates the features of ChISS records from earthquakes and explosions which were processed by the method of module envelopes.

Figure 4.11(a and b) shows similar averaged data obtained by the method of distinguishing parameters for sets of earthquakes and explosions. Figure 4.11a shows the results obtained at the Talgar station from the STS explosions ($\Delta=725$ km) and earthquakes ($\Delta<1000$ km) recorded from the eastern (central diagram) and south-western direction (lower diagram). Figure 4.11b shows similar results obtained at the station at Garm from the STS explosions ($\Delta=1350$ km) and regional earthquakes ($\Delta>1000$ km) without regionalization.

Figure 4.12(a-j) presents time history of summary positive $A(t)$ and negative $B(t)$ slopes of spectra, as well as absolute steepness of spectra $C(t)$: $A(t) = \sum_i \operatorname{tg}(\varphi_i(t))$, $\varphi_i > 0$; $B(t) = \sum_i \operatorname{tg}(\varphi_i(t))$, $\varphi_i < 0$; $C(t) = \sum_i |\operatorname{tg}(\varphi_i(t))|$. Summing is done by channels from $i=1$ to $i=4$ (Figure 4.4). Figure 4.12 shows summary slopes in two ways. The upper diagram displays the curves $A(t)$ and $B(t)$. In this case, the value of $C(t)$ is just the difference between the curves at a given time. The lower diagram shows $A(t)$ and $C(t)$. In this case, $B(t)$ is determined as a difference between the curves at a given time. A slight advantage of the second way is that $A(t)$ and $C(t)$ are both positive.

Figures 4.13 and 4.14 show diagrams of the summary slopes from the method of distinguishing parameters. Figure 4.13 presents the results for events at distance less than

1000 km (station Talgar, STS, earthquakes from eastern and south-western directions; see Fig. 4.7).

Figure 4.14 shows similar results for the Garm station from events beyond 1000 km (the STS and not regionalized earthquakes).

Considering diagrams of spectral ratios, the following tendencies may be revealed independently of the method of processing. The spectral ratios increase with time for the explosions as well as for earthquakes for most of the channel pairs. The lines connecting co-named spectral ratios in different spectral sections are positioned similarly for the explosions and earthquakes: vertically, from down to up, the lines usually coordinated with increasing frequency.

Independent of the nature of an event, the spectral section associated with intensive phases (P_g , S, L_g etc.) are related to the increase of spectral steepness, and relatively "quiet" portions of the records are characterized by low steepness.

The following tendencies on the diagrams of spectral ratios (Fig. 4.12) are important from the discrimination: the area contoured by the curves $A(t)$ and $B(t)$ is large for the explosions. The line of zero slope (the line of maximum of spectrum) crosses this area in such a way that both sides are approximately equal for the explosions, while the upper part is much larger for the earthquakes. It is characteristic that larger portions of the negative slopes are near the beginning of the records with the portion for the explosion being much larger than for the earthquakes.

Comparing the envelopes (Fig. 4.8) and the spectral ratios (Fig. 4.12) it is possible to discuss a position of spectral maximum of a given seismic phase and inversion of sign for steepness of slope. While for the explosions the maximum of the P-wave is usually at the fourth channel and the slope sign changes usually between $4/5$ and $3/4$ spectral ratios, for the earthquakes the maximum of P-wave is on the second channel and the sign change occurs at the $1/2$ to $2/3$ ratios. One can observe a shift of this feature for later phases. When S- and L_g -waves arrive, the spectral maximum is on the third or fourth channel for the explosions, and on the first channel for the earthquakes. Spectra of L-waves and coda waves from the earthquakes are extended to long periods, and the spectral maximum of the explosions is on the second channel. All the above mentioned properties are the sharpest in the summary slope graphs (Fig 4.12).

It is clear, that the largest differences in the spectral sections of the seismograms of the explosions and earthquakes are in the sums of the negative slopes of the initial parts of the seismograms and in the rate of increase of the sum of positive slopes in time, at least for the principal seismic phases (including L-waves). It is clear that these two properties are interrelated; the frequency band is constant and the larger the sum of negative slopes, the lower the sum of positive slopes. Figures 4.13 and 4.14 illustrate this well enough where graphs of averaged summary slopes are compared for events in different regions and at different ranges. At distances less than 1000 km the graphs

show a sharp difference in the sums of slopes of both signs. Earthquakes from the south-west are different from those from the west by twice as large an area of sums of slope steepness at high frequency, and two times lower area of sums of slopes' steepness at low frequency. On the other hand, both sets of earthquakes differ from explosions.

This property is especially sharp for events at larger epicentral distances. Earthquakes having the same summary slopes as explosions at high frequency do not have negative sums at all, whereas for explosions the portion of negative sums decreased only a little in comparison to smaller epicentral distances.

Thus, the analysis of the contour properties of ChISS seismograms from explosions and earthquakes shows that a fundamental distinction between them is a natural shift of spectrum along a seismogram: explosions are characterized by higher frequencies than earthquakes.

4.2.4. Description of the spectral-temporal algorithm of discrimination of earthquakes and underground nuclear explosions.

The results of a study by spectral-temporal method of discrimination. We have shown that:

- the largest differences in steepness of spectra of earthquakes and underground nuclear explosions (UNE) are at the low-frequency slope of L_g - and P -wave spectra in the frequency band investigated; higher frequencies (beyond 10

Hz) are not helpful due to high attenuation and low threshold of their presence in records;

- the efficiency of all the P-wave fragments is almost the same;
- the efficiency of all the discriminators depends on distance;
- the spectral ratios of the short-period component in the initial part of records are the most informative discriminator at distances less than 1000 km;
- low-frequency spectral ratios become more important with distance;
- at distances of 1400 to 1600 km numerical values of all the parameters increase with distance; at larger distances, in the zone studied, the parameters increase only slightly;
- spectral ratios of P-waves change less with distance than those of L_g ;
- the dependence of the spectral ratios on distance obtained from the earthquakes is demonstrated by the data from explosions recorded at two distances (Garm-STS, 1350 km; and Talgar-STS, 735 km);
- the best results in discrimination are obtained by discriminators of the second rank based on relationships of all the channels in the frequency band;
- discriminators summing the whole record are more stable than those using only some isolated parameters.

It is possible to state that in spite of variations in the spectral-temporal properties of the seismic records in the range studied there are fundamental differences between

the UNE and earthquakes, with these differences being over the whole record.

We infer that at the procedures of description considered, comparison and summing of the contour properties of CHISS seismograms can be used as one of the methods to discriminate underground explosions and earthquakes.

Algorithm of discrimination and its modifications. The basis of the proposed algorithms is a representation of records of CHISS stations by envelopes obtained through smoothing. In this procedure, parameters representing the envelopes may be different characteristics: averaged level of the envelopes, averaged level plus standard deviation, averaged sum of amplitudes or their squares (energy) saved in a time window, etc.

Depending on time and spectral properties of discrimination described above we propose two modifications of the discrimination algorithm - "Maina-Vira" based on time and spectral properties, and "Tatsukava" based on spectral ratios.

"Maina-Vira" algorithm. This algorithm is based on the property of discrimination of UNE and earthquakes revealed by the summing normalized envelopes of records discussed previously. Two graphs are obtained as a result of "Maina-Vira" (Fig.4.9), one of which ("Maina") describes the variation in time of the envelope sums normalized to the envelope of the first channel, and the second ("Vira") is a sum of the envelopes normalized to the fifth channel.

The discriminating information is in the behaviour of

the curves taken both separately and together. The "Maina" graph in Figure 4.9 shows that there are no positive sums of normalized envelopes for the earthquakes, and the sum is essentially positive for the underground explosions during at least two minutes. the "Vira" graph shows opposite features - it is totally positive for the earthquakes and there is a sharp minimum in the beginning for the explosions. Relationships of parameters of the curves "Maina" and "Vira" represent quantitative discriminating information.

In practice, it is necessary to consider the curves relative to the level of the seismic noise. So, we have calculated average values and standard deviations of amplitudes of seismic noise in one minute intervals preceding the records at the Talgar station during a two year period (Table 4.2).

Table 4.2. Averaged level of seismic noise at different frequencies from ChISS records at Talgar.

	frequency band, Hz				
	0.27-0.40	0.62-0.92	1.1-1.7	2.2-3.4	4.6-7.0
mean A, nm/sec	6.15	1.38	1.06	1.55	1.82
standard	1.48	0.40	0.2	0.66	0.57

Figure 4.8 displays the averaged level of seismic noise together with the original envelopes from earthquakes and explosions.

The "Tatsukawa" algorithm. In this algorithm, graphs of the variation in time of the sums of positive slopes of spectra and the sums of absolute values are constructed. The graph of the sums of absolute values is higher than this for only positive values. There is an area of negative slopes of spectra between these two contours. Discriminating information is in the area of the negative sums as well as in a rate of increase at the positive sums.

4.3. Complexing the discriminating criteria.

There is no simple criterion for 100-percent discrimination of explosions and earthquakes, as a consideration of Table 7.A shows.

Spectral-temporal criterion apparently gives almost 100-percent discrimination. However there was only a limited set of data used in the analysis (we imply not only an amount of data, but number of stations, test sites, active tectonic zones). Note that the efficiency of discrimination was analyzed by comparison of Laplace curves approximating the experimental data for the explosions and earthquakes. This may compensate to some extent for the nonrepresentativity of the data set.

It is possible to improve the efficiency of

discrimination by successive usage of simple criteria. In other investigations [Dahlman et al., 1978; Sykes and Evernden, 1982] some examples of complex criteria have been shown. For example, successive application of criteria of source depth, location of source in the sea beyond 25 km from a coast, and m-M comparison gives 100-percent discrimination of explosions and earthquakes. The same effect gives complexing the third moment of frequency and a "complexity".

Taking together, the criteria we have developed also can provide high discrimination efficiency. For example, almost 100-percent discrimination can be achieved with our data by successive application of the independent criteria T_p , L_{GH}/L_{GV} , L_g/P , $2P/1P$ for nuclear explosions in salt at distances from 1200 to 2000 km (note that this result may be due to specific geological structure of the crust and mantle in the region of the Pre-Caspian depression where the explosions have been conducted; see section 5). Spectral-temporal criterion also can be complexed with such a criterion as L_{GH}/L_{GV} . Thus, there is an opportunity to improve the efficiency of the spectral-temporal criterion by using not only vertical but also horizontal components of the CHISS station (three-component stations are better).

The criteria considered can also operate together with other criteria which were not described in the report (source depth, location, first motion, etc.).

5. DISCRIMINATION BETWEEN EARTHQUAKES,
CHEMICAL EXPLOSIONS AND NUCLEAR EXPLOSIONS
BY CHARACTERISTICS OF REGULAR AND IRREGULAR
SEISMIC WAVES.

Parameters of the short-period seismic wave field have been widely used for solving the problem of the discrimination between earthquakes and explosions [Gupta and Burnett, 1981; Nuttli, 1981; Evernden et al., 1986; Taylor et al., 1988; Taylor et al., 1989; Baumgardt and Yong, 1990]. Short-period records are most informative for relatively weak events ($m_b < 4.5$) and at regional distances (from a few hundred to several thousand km).

But it is worth noting, that conclusions made by various authors on the effectiveness of these criteria for discrimination of earthquakes and explosions are often contradictory. There are cases when discrimination criteria obtained by analysis of short-period records in one region turned out to be not effective in the other regions.

The reasons for this are connected mainly with the complexity of the wave fields at regional distances and with very strong heterogeneity of the media in the lithosphere and asthenosphere, where most intensive at such distances wave group, are basically spreading.

Recently new data on the nature of some seismic wave groups, in the first instance, Sn- and Lg-coda recorded at

distances up to 3000 km, have been received [Kopnichev, 1985; Kopnichev and Arakelyan, 1988; Kopnichev, 1990]. These data permit more effective study of the short-period wave fields for solving the problem of discrimination of explosions and earthquakes.

Below some results of studying the nature of wave fields at regional distances are briefly described. On the basis of these results we describe a comparative analysis of records of nuclear and chemical explosions and also nearby earthquakes, recorded by high-sensitivity seismic stations of the CSE in some regions of Eurasia.

5.1. On the nature of some wave groups recorded at regional distances.

In this section we describe data, obtained earlier by Yu. F. Kopnichev and A.R. Arakelyan and also some new results.

Materials used. Records of permanent and temporary seismic stations of the CSE, situated in various regions of the former Soviet Union were analyzed (Table 5.1). The stations are equipped with narrow-band vertical seismic channels centered at 1 Hz. More than 2000 seismograms of crustal and deep-focus earthquakes, and also explosions, recorded at distances from several hundred to 2500 km were processed.

Table 5.1

Seismic stations of the CSE,
records of which were used by data analysis.

N	Name	φ° , N	λ° , E
1	Talgar	43.2	77.2
2	Zerenda	52.9	69.2
3	Krasnyy Cordon	52.9	69.0
4	Borovoye	53.0	70.1
5	Vostochnyy	52.7	71.0
6	Chkalovo	53.7	70.7
7	Zelenitza	50.7	28.2
8	Norinsk	51.3	28.5
9	Tikhiy Don	50.1	40.5
10	Severnyy	55.2	60.2
11	Uchkeken	43.8	42.6
12	Maslyanogorsk	53.5	101.6

5.1.1. Common characteristics of seismograms.

Analysis of short-period records at the regional distances has shown that in many Eurasia regions the L_g wave, accompanied by coda, is prevalent on the seismograms, (Fig.5.1). A maximum amplitude level in this wave group can be several times (in some cases - ten times or more) larger, than P_n - and S_n -wave amplitude levels. This type of wave

field is observed when mainpart of the path from the source to the station lies on the ancient platforms - East-European, Siberian, and also on the Kazakh shield, Altai and Sayan, to the north and east of Russia [Kopnischev, 1988]. On envelopes of such records an interval of very strong amplitude attenuation after the maximum of L_g -wave amplitude stands out against the background of the L_g -coda. The interval corresponds to shear waves, multiply reflected from the boundaries of the Earth's crust [Kopnischev, 1985] (Fig. 5.2). This rather long interval, after a bend changes into a record section with much gentler envelope slope, corresponding to the L_g -coda.

For the L_g -wave coda, the following experimental data have been obtained [Kopnischev, 1985; Kopnischev and Arakelyan, 1988; Kaazik et al., 1990]:

1. Till enough large time waves, spreading close to a ray plane, prevail in the coda.
2. With increasing travel time, the velocities of wave groups in the coda continuously rise (from 3.5 km/sec for the L_g -wave to 5-7 km/sec through 100 sec after the L_g arrival).
3. The L_g -coda is formed mainly by waves which have polarization close to the S_n -wave type.
4. The form and level of the coda envelopes depend weakly on the depth of the earthquake source (for the Hindu Kush region).

These and other data allow us to conclude that the L_g -coda is formed mainly by shear waves reflected from

multiple subhorizontal boundaries in the Earth's crust and mantle. At enough large times the waves forming the coda cross the asthenosphere and propagate spreading into deep layers of the upper and probably even lower mantle. Thus, the nature of the coda is principally different from the nature of the "channel" group L_c .

This type of wave field is observed in regions for which the average shear wave attenuation in the crust is relatively weak [Kopnichev and Arakelyan, 1988]. When the attenuation in the crust and uppermost mantle increases, the wave picture at regional distances is continuously changing.

Our investigations have shown that in many regions of Eurasia at regional distances the L_c group is absent on the records. In the first instance the largest part of the Alpine belt, young plates - Turanian and West-Siberian, Tibet, and back-arc basins are characterized by this type of wave field [Kopnichev, 1983; Kopnichev, Arakelyan, 1988]. It is worth noting, that a "critical" distance at which this wave disappears, is appreciably different for different ray paths. In such cases the envelopes of the short-period records, in the first approximation, can be divided into three types. Envelopes on which two "eroded" wave groups, comparable in intensity with the direct P-wave are distinguished, can be attributed to the first type. The first wave group usually arrives considerably earlier, and second, later than the L_c group, according to the travel-time curves. Maximum amplitudes in these wave groups, as a rule, are reached in a few tens of seconds (often in 1

minute or even more) after their arrivals. The velocities corresponding to maximum amplitudes of these groups, most often are in the ranges 3.8-4.2 and 2.9-3.4 km/sec accordingly.

Values of effective Q for the second wave group are by an order of magnitude greater, than for the L_g wave [Kopnichev and Arakelyan, 1988]. It proves, that the second group does not correspond to the crustal phase L_g . The first wave group has received the name S_n [Molnar and Oliver, 1969], for the second group a generally accepted name does not exist yet.

The envelopes, on which the S_n -wave amplitude is close to that of the P-wave, but the second wave group is considerably weaker, or it can not be picked out at all, are attributed to the second type (Fig. 5.3).

Finally, the envelopes for which the wave groups described are considerably weaker than the P-wave, or they cannot be picked out against the background of the P-coda, are attributed to the third type (Fig. 5.3, see also [Kopnichev, 1990]).

It is important to note that this classification is in a sense a conditional one, because levels of the wave groups described relative to the P-wave regularly diminish with increasing epicentral distance (Fig. 5.4); thus records of the same event in principle can be attributed to any of the types under consideration. In addition, the relative level of these groups also depends on station location (with other conditions being equal it is usually higher for stations

situated in regions of ancient platforms and shields).

It is interesting, that in contrast to the teleseismic zone, where for relatively weak events the P-wave is rather impulsive, at regional distances for the wave field types under consideration the P-wave is usually characterized by an "emergent" first arrival, a slow amplitude increase during few tens seconds and a monotonic attenuation after a maximum (Fig. 5.1).

Below, the main experimental characteristics of these wave groups are described.

Characteristics of the records for various source depths. Fig. 5.5 shows envelopes of records of two neighboring earthquakes from the Crete area, but with different depths (3 and 100 km), recorded by two temporary stations of the CSE, installed in the Ukrainian Shield and in the North Caucasus regions (Table 5.1.). In this case the second group is absent from the records for the both events, and the S_n -wave level is considerably higher for the deep-focus event than for the crustal event. This effect for the first group has been pointed out earlier by Molnar and Oliver [1969].

For deep-focus events from the Hindu Kush area recorded by station Zerenda, which is situated in the Kokchetav massif (northern Kazakhstan, Table 5.1.) a more eroded wave train in the coda is observed (Fig. 5.6.). It is possible to pick out this wave group relatively rarely in this case. The coda level relative to P-wave can vary considerably, but in any case, on average, it is not diminished with a source

depth down to 200 km [Kopnichev, 1978].

Polarization characteristics of the short-period seismograms. The records of three-component channels RVZT were used for studying the polarization (predominant periods of the seismograms 1-2 sec).

The envelopes of the vertical, the radial and the transverse components were considered. It has been shown by Kopnichev and Arakelyan [1988] that for many regions of Eurasia first and the second wave groups have polarization mainly of SH-wave type. At the same time earthquakes and explosion records from various regions have some peculiarities. In some regions the horizontal polarization is expressed more strongly, in others - weaker. For example, for some regions of Central Asia the amplitudes for the transverse component for the first and second wave groups are 2.5-3 times larger than for the radial and vertical components. It is worth noting that in some cases the coda polarization is abnormal - the isotropic or even the radial component is predominant [Arakelyan and Kopnichev, 1986]. In this report we will not consider such cases.

Spatial variations of the short-period wave field structure. For the first and second wave groups fundamental variations of the relative level are observed as a function of the epicentral distance and from azimuth to the source. Fig. 5.7 shows the character of the change of the S_n wave level relative to the P-wave, as a function of the

epicentral distance. The graph is constructed using records of two stations located in aseismic regions - in the Voronezh uplift (Tikhiy Don) and in the central Urals (Severnnyy) areas, (see Table 5.1). Earthquakes from the central part of the Alpine belt were considered. For each earthquake the envelopes of the records were measured for both stations. On the graph a straight line corresponds to each pair of envelopes, describing the change of the relative level of the first wave group with respect to the time of the P-wave arrival (t_p). These straight lines are arbitrarily shifted in parallel to the abscissa in order to obtain a better compare the various curves.

It can be seen in Fig. 5.7 that the average relative level regularly diminishes with epicentral distance. But against this background cases of an unusual change of the relative level - increasing with distance are observed.

In Fig. 5.8 examples of envelopes of records for the north-south profile in the eastern Mediterranean region are shown. The envelopes were constructed using data from station Zelenitza, located in the Ukrainian shield (Table 5.1). It can be seen that for events from the northern part of the Aegean sea the S_n -wave level is close to that of the P-wave. Moving to the south, the relative level of this wave group notably diminishes, reaching a minimum in the area between the volcanic arc and Crete (here amplitudes of the first group are by an order of magnitude smaller than the P-wave amplitudes). With further increases in distance, to

the south of Crete, the relative level significantly increases again. An analogous situation is observed for the Kuril-Kamchatka arc region, with the difference that there the first wave group disappears completely in a relatively narrow band between the trench and the arc [Kopnichev, 1988].

Thus, cases of an abnormally fast drop or, on the contrary, an abrupt growth of the relative S_n -level with distance are observed against the background of the regular decrease of this value (either for records of one event recorded by different stations, or for various events recorded by the same station).

Consider now variations in space of relative level of the second wave group. From Fig. 5.4 one can see that the intensity of this wave group (relative to the P-wave) diminishes with epicentral distance, moreover often considerably more quickly than for the first wave group.

Fig. 5.9 shows a map of spreading path of the second group in the central part of the Alpine belt. Here the paths for which the second group is correspondingly very strong, less strong or is not observed at all are indicated by different lines. It is interesting that this group does not cross the Black Sea basin, the South Caspian depression and Pre-Caspian basin. Such an effect has been noted by various authors for long-period L_g waves [Sikharulidze, 1978]. So some accordance exists between characteristics of the long-period L_g -wave and the second wave group. Nevertheless fundamental difference between these wave groups is also

observed. The map shows that the second wave group is not traced for many earthquakes from Turkey and Central Iran, and for the earthquakes from the Transcaucasian uplift area it is not recorded even at relatively small epicentral distances.

The second wave group is very clearly observed at the Ukrainian stations of the CSE from the Caucasus regions to the north (from 40° N), from western Turkey and from the northern part of the Aegean Sea. In addition, it is propagating efficiently through the western and north-western periphery of the Black Sea. In general, the zone of disappearance of the second wave group when crossing the Black Sea, like the L_g -wave, is limited approximately by the 2000 m depth contour.

From an analysis of the map two important conclusions follow. Firstly, the second wave group do not pass regions characterizing by high thickness of young sediments (Black Sea basin, South-Caspian depression and Pre-Caspian basin). Secondly, it is abruptly weakened or even completely removed for paths crossing areas of low velocity and high attenuation in the upper mantle. For the central part of the Alpine belt such areas are primarily the Aegean sea and the Transcaucasian uplift, for which a decrease of the P-wave velocities and an increase of the shear wave attenuation have been reliably established [Arakelyan et al., 1986; Arakelyan and Kopnichev, 1986; Vinnik et al., 1978].

5.1.2. Interpretation of the experimental data.

Let us consider a possible schema of generation of short-period wave fields and select from them models that reflect the reality most clearly, by comparison with the experimental data. At first we will discuss arguments, common for both wave groups.

In principle these groups can be formed by waves of various types: direct, reflected and scattered Love and Rayleigh waves, shear and longitudinal waves scattered by small-scale heterogeneities and reflected from various boundaries in the crust and upper mantle, etc. Nevertheless the experimental data obtained and some theoretical results allow to narrow considerably the circle of the possible coda generation models.

For example, the very large coda intensity for the deep-focus events allows us to confidently state that it cannot be formed by surface waves. In addition, the S_n -wave has a group velocity too large for the Love and Rayleigh waves (with periods about 1 sec), and too small for Love waves. Last, surface waves reflected from the fault zones and scattered by crustal heterogeneities, which arrive at the station from various directions, should have close to isotropic polarization. This differs from the coda polarization that is usually observed. Thus, it is possible to suppose, that short-period coda is formed mainly by body waves.

The character of the coda polarization shows that shear

waves dominate in this part of records. Here a few schemes are possible. The first possibility is the formation of the coda by S-waves multiply reflected from crustal boundaries. Simple calculations show that when angles of incidence are less than the angle of total reflection, the energy of reflected waves is strongly diminished because of losses by refractions [Kopnichiev, 1985]. Consequently, in this case only post-critical reflected waves, may make a significant contribution to the coda energy [Levshin, 1973; Kopnichiev, 1985]. But, as pointed out earlier, in the regions under consideration the L_g wave is absent at distances more than few hundred kilometers. Thus, it is impossible to explain the characteristics of the short-period coda using the model of the shear waves multiply reflected from crustal boundaries under the post-critical angles.

The other possibility is reflection of shear waves from subvertical fault zones. Fault zones have very complicated structure; for this reason the linear polarization of the coda would not be expected.

Scattering of the body waves by heterogeneities of the crust and upper mantle also could not explain the coda formation at the regional distances, because in this case it should have isotropic polarization.

Consequently, none of the models discussed can explain the nature of the short-period coda at regional distances.

Let us pass on to a more detailed analysis of nature of the first and the second wave groups.

On the nature of the S_n wave. Taking into account all

the data described, it is natural, that 25 year ago Molnar and Oliver [1969] had made the conclusion, that the first wave group is formed mainly in the upper mantle. The recently obtained data, show that their conclusion, that this wave group is formed by shear waves, spreading only in the uppermost mantle, above the asthenosphere, for continental paths must be corrected. Note first, that in the article [Molnar and Oliver, 1969] convincing arguments were given, which testify impossibility of a formation of the S_n -wave by head waves, going on the mantle roof, and also by "channel" waves, spreading in a thin layer, located directly under the M boundary. Let us now show, that the other transmission mechanisms of the energy of this wave in the continental lithosphere are almost impossible.

Firstly, S_n is often expressed well at distances even more than 30° , at the same time the refracted S-wave is rarely observed on the records of the short-period channels at distances more than 25° [Molnar, Oliver, 1969].

Secondly, as it was shown above, in many cases for the same profile S_n -group has considerably larger amplitudes at greater epicentral distances, sometimes it appears even after the absence at relatively small distances. It is impossible to explain this striking effect, if we suggest, that the relative level of the S_n -wave is characterizing an attenuation of the shear waves in the uppermost mantle at the whole trace from source to receiver, as it has been suggested by Molnar and Oliver [1969]. A stability of this effect for various earthquakes from the eastern

Mediterranean and the Kuril-Kamchatka regions testify, that radiation patterns of P- and S-waves do not play an essential role in these cases.

All of the results described above allow us to consider, that S_n -wave cannot be formed by the shear waves, spreading only in the lithosphere. Hence a natural conclusion follows, that in the continental areas the S_n -group is formed by waves penetrating into the asthenosphere and deeper horizons of the upper mantle. We suppose, that most probable mechanism of S_n wave formation, by analogy with the mechanism of Lg-coda formation [Kopnichev, 1985] - are reflections of the shear waves from numerous weak boundaries in the upper mantle.

It is essential, that singly reflected waves should play a major role here. As it will be shown below, multiply reflected waves are coming considerably later, than singly reflected waves.

It is not so complicated to be convinced, that such a model does not contradict the experimental data obtained. So, when shear waves are spreading close to the ray plane, they should have the polarization, normal to this plane, because S_v -waves lose more energy, than S_H -waves when crossing subhorizontal boundaries. An absence of the effect of the coda level decrease with the source deepening can be explained by a fact, that ray traces for shallow and deep-focus events are rather close, and consequently also amplitudes of reflected waves. The increase of the relative S_n -wave level for deeper events, often observed, probably,

is connected with a fact, that for the crustal hypocenters shear waves cross an anomal mantle - layer of very strong attenuation, located in many areas in the uppermost mantle, close to the M boundary [Artyushkov, 1979]. An absence of the refracted S-wave on the records is explained by strong scattering in the Earth's crust and upper mantle, especially at the great depth for angles of incidence, close to the angle of total reflection. It leads to "immersion" of S-wave into coda [Kopnichev, 1985].

Large variations of the relative S_n -wave level, observed for unessential changes of the epicentral distances, most likely are conditioned by the strong heterogeneity of the shear waves attenuation field in the lithosphere and asthenosphere. It is worth to emphasize, that heterogeneities in the relatively close environments of a source and a station basically influence on the level of the first wave group. For this reason the relative level of this wave group can grow abruptly with an increase of the epicentral distance.

Note, that results of numerical modelling confirm the conclusions made above [Kaazik and Kopnichev, 1990].

On the nature of the second wave group. By kinematic characteristics this group can correspond to the shear waves, multiply refracted in the Earth's crust and multiply reflected from the M boundary. But, as it was shown earlier [Kopnichev, Arakelyan, 1988], this suggestion contradicts the dynamic characteristics of the second wave group - the effective Q values, corresponding to this group, are a few

times higher, than really observed for the paths of this group spreading. In addition, for multiply refracted waves, quite a different form of the record is observed - very slow amplitude increase and abrupt decrease after the maximum is reached [Ocean Acoustics, 1974]. Multiple waves, reflected under steep angles, are strongly attenuate because of the large losses when reflecting from the M boundary [Kopnichev, 1985].

It is impossible also to explain a formation of the second group by a conversion of types $S \rightarrow L_g$ or $L_g \rightarrow S_n$, as it has been suggested for traces, crossing Atlantics and North America [Isacks, Stephens, 1975]. Firstly, velocities for the second group are less, than for both of these phases; secondly, in many cases, it is spreading completely trough the regions with the continental type of the crust (Fig.5.9).

A totality of the data received allows us to suggest, that the second group is formed by shear waves, in contrast to the S_n -wave, multiply reflected from various boundaries in the Earth's crust and upper mantle, including the Earth's surface. Relatively strong attenuation in the crust and uppermost mantle leads to such an effect, that only multiply reflected waves, crossing the lithosphere and astenosphere more steeply, than singly reflected waves, may have enough high intensity. In this case not only the Earth's crust and uppermost mantle, but also layers, located much deeper, than the asthenosphere, characterized by very low attenuation [Teng, 1968], essentially influence their formation. It is

obvious, that these waves will arrive at relatively large times, considerably later, than singly reflected waves.

It is easy to be convinced that the formation of the second group does not contradict the experimental data, described above. Our opinion is that this scheme most naturally explains, why the second wave group does not pass through the regions of the strong attenuation in the crust (thick sedimentary layers) and in the upper mantle.

So, the data obtained testify, that the wave groups under consideration are formed by reflected from numerous boundaries in the crust and mantle shear waves and differ only by the reflections number.

The absence of the short-period L_g -wave on the records of the considered types is connected with the increased mean attenuation in the Earth's crust [Kopnischev, Arakelyan, 1988; Kopnischev, 1992]. Both direct estimations of the Q values [Kopnischev, Arakelyan, 1988] and data on the other geological and geophysical fields witness this conclusion. In such areas of Eurasia, where the short-period L_g -group is absent, high heat flow is usually observed, they are characterized either by development of thick sedimentary layers or by young volcanism [Heat flow of Europe, 1982]. It is essential, that in many cases L_g waves with frequencies about 1 Hz don't pass through regions with a well expressed "granitic" layer in the Earth's crust (for example, many areas of the Alpine belt of Eurasia). Possibly, this circumstance will allow to specify also the reasons of the disappearance of this group at oceanic paths.

The data decreased above testify greatly to the variability of the short-period wave fields in various Eurasia regions. Taking into account these results, it is possible to suppose that a universal criteria for the discrimination between earthquakes, nuclear explosions and chemical explosions in all areas do not exist. Hence it is necessary to use a different approach for analysis of the experimental data for various regions under consideration.

5.2. Analysis of records of underground nuclear explosions from the Semipalatinsk test site, close chemical explosions and earthquakes.

Material used. We processed more than 60 seismograms of various events. The data have been obtained by the Talgar station, situated in the northern Tien Shan region, and also by temporary stations, installed in the Kokchetav massif area, in environs of the famous station Borovoye (mainly by the Zerenda station, see Fig. 5.10, Tables 5.1, 8.A).

The records of the narrow-band vertical channel CSE, centered at 1 Hz, were used. As it is known, analysis of the narrow-band seismograms allows us to divide much more effectively, factors of the source and media, because of the exclusion of the effect of variation in source spectra. A magnification of the channels was about 200 thousand at the Talgar station and from 400 thousand to 1 million at the stations of the Kokchetav array.

We analyzed records of 16 nuclear explosions, produced

in tunnels at the Degelen area and one explosion in a borehole at the Balapan area. In addition, we processed seismograms of a few chemical explosions (one from the Degelen area), and industrial explosions from quarries in Bayanaul and Sayak, located in eastern Kazakhstan (Fig. 5.10). We picked out mainly the explosions of intermediate power - (up to 20 kT), because the analysis was limited by the dynamic range of the channels. The minimum power corresponds to explosions produced at the Bayanaul quarry (18.0 and 19.5 T).

We also processed records of 18 crustal earthquakes from the Altai region, close to the Semipalatinsk test site. Earthquakes were picked from regional catalogs, published during several tens of years in the collected volume "Earthquakes in the USSR". Earthquakes and chemical explosions were relatively weak; their energy class K vary from 9.0 to 12.0, which corresponds to magnitudes M approximately from 2.8 to 4.5. For this reason most of these events were not published in international bulletins.

Epicentral distances for the explosions from the STS were approximately equal for the Talgar and Kokchetav stations (700-800 km). For quarry blasts, only records of the stations around Borovoye were analyzed. Their epicentral distances were about 450 km (Bayanaul) and 800 km (Sayak). Epicentral distances for the earthquakes varied to a greater extent: from 500 to 800 km for the Talgar station and from 750 to 1150 km for the Kokchetav stations.

Note that azimuths to the stations differ considerably:

by about 90° for the explosions from the Semipalatinsk test site and slightly less - for the earthquake epicenters.

Methods of data processing. For each explosion or earthquake the envelopes of seismograms were measured from the P-wave until the L_g -coda. Figures 5.11 and 5.12 show that for the records considered the S_n -wave usually does not have a clear arrival. Amplitudes, as a rule, monotonously increase from the P-coda until the crustal L_g -wave arrival. As has been shown earlier [Kopnichev, 1985; 1992], such a trend is connected with very weak attenuation of the short-period shear waves in the Earth's crust and upper mantle. This conclusion coincides with an inference made by joint Soviet - American works on the control of nuclear explosions [Soviet-American..., 1991]. An analogous form of the record's envelopes is observed as well in other regions of central Asia, for example, in the Altai-Sayan area.

Our investigations have shown that in various Eurasian regions the maximum of the first wave group is, on average reached at a time $t \approx 2t_p$ [Kopnichev, Arakelyan, 1988]. Taking this into account, we measured the amplitude of the first wave group at this time for the area under investigation. We denote this wave as S_g to distinguish it from the "pure" S_n -wave.

The data obtained earlier permit us to infer, that this wave group is formed by the interference of shear waves, reflected from numerous boundaries in the upper mantle. At large enough distances these waves pass through the asthenosphere.

In addition, we measured the maximum amplitudes for P_n -, P_g - and L_g -waves. Note that, especially on the records of the Talgar station, the maximum amplitude for the P_n -group in this region is reached significantly later (sometimes by as much as tens seconds), than the P_n -wave arrived. From these data we may infer that this wave is formed by longitudinal waves, which have a nature close to the S_g -wave and which are spreading by similar paths. The results of investigations of the nature of the P-coda at regional distances support such a conclusion [Kopnichev, 1989].

After this we determined values of $\lg(A_{Sg}/A_{pn})$, $\lg(A_c/A_{pn})$ and $\lg(A_{Lg}/A_{pm})$. Here A_c is the level of the L_g -coda which was estimated from the envelope at time $t=300$ sec (by its comparison with common envelope, constructed using records of many events from the region considered (Fig. 5.13)). P_m is the maximum amplitude of P-waves, which for the records of the Talgar station usually corresponds to the P_g -wave, and for the Kokchetav stations to the P_n - wave. In the following we will denote these parameters simply as S_g/P_n , C/P_n and L_g/P_m .

When determining the parameter S_g/P_n , we included a correction for the epicentral distance in accordance with results obtained earlier [Kopnichev and Arakelyan, 1988] (Fig. 5.14).

5.2.1. Analysis of experimental data.

In Fig. 5.15 results of an analysis of the parameters considered for the stations Talgar and Zerenda are shown. As a whole, the values of the all parameters are significantly larger for the earthquakes than for the nuclear explosions and chemical explosions. An exception is the parameter L_0/P_N for the station Talgar, for which earthquakes and nuclear explosions are practically the same. For both stations the best discrimination of nuclear explosions and earthquakes is observed when using the parameter S_0/P_N . The number of false alarms in this case reaches 21% and 5% for the stations Talgar and Zerenda, respectively (when all explosions are found). The efficiency of the discrimination using the other parameters is much worse.

It is interesting that values of the all parameters for an explosion in a borehole at the Balapan area are found to be smaller than those for explosions in tunnels at the Degelen area. At the same time values of the parameters for the given explosion for the station Zerenda are close to the maximum values obtained for the Degelen area.

For the station Zerenda, the values of the parameters described for the chemical explosions and earthquakes are similar. Only for chemical explosions are they in the range of nuclear explosions.

Fig. 5.16 shows the results of an analysis for all events recorded by both stations, Talgar and Zerenda. One can see that use of the data from both stations, situated at

different azimuths from the epicentral zones, increases considerably the efficiency of the discrimination between earthquakes and explosions. The best separation is observed for the parameter S_g/P_n , for which data for the nuclear explosions and earthquakes do not intersect. The discrimination between nuclear explosions and earthquakes also is significantly improved when using the other parameters.

Of course, it is necessary to take into account that in Fig. 5.16 a smaller amount of the data is represented, than was considered separately for the stations Talgar and Zerenda. Nevertheless, it follows from this figure that in such cases, if the values considered are close for the explosions and earthquakes for one station, then for the other station they will, as a rule, be significantly different.

For the data for the only chemical explosion recorded by the both stations, all of the parameters are close to the boundaries between the data areas for the nuclear explosions and earthquakes.

Note that for the explosion in the borehole at the Balapan area the values of all parameters are essentially lower than for the explosions at the Degelen area and for earthquakes.

It is interesting that in the left chart a positive correlation is observed between values of the parameter S_g/P_n for two stations for earthquake records, but for the explosion records the correlation is negative. At the same

time, such a correlation is absent for the other parameters.

5.3. Analysis of records of the underground nuclear explosions from the Pre-Caspian depression.

As part of our investigation we analysed the possibility of discriminating earthquakes and underground nuclear explosions produced in salt. For this purpose we chose records of underground nuclear explosions, conducted in the region of the Pre-Caspian depression (mainly from the Astrakhan area, and also from Azgir and Elista areas, see Table 9.A). We processed 32 seismograms of explosions, obtained by the same stations Talgar and Zerenda. Magnitudes of the events were 4.7-6.0. Epicentral distances varied from 2280 to 2520 km for the station Talgar and from 1580 to 1850 km for the station Zerenda.

For comparison we picked out earthquakes from the closest seismoactive regions - the northern Caucasus and the central part of the Caspian sea. We processed 29 seismograms of earthquakes recorded by the stations Talgar and Zerenda (Table 9.A). Magnitudes of the earthquakes were from 3.9-5.4, and epicentral distances were 2300-2500 km for the Talgar station and 1950-2230 km for the Zerenda station.

Note that in this case the azimuths to the stations for both explosions and earthquakes differ less than in the previous case, but all the same by about 30° , which is enough.

We analyzed mainly records of the narrow-band channel

of CSE. Excluded are records of the explosions for the station Zerenda, for which because of limited dynamic range and relatively large power of the explosions it was necessary to process the records of the broad-band channel RVZT (analog of the SKM channel).

Methods of data processing. As in the previous case, we measured seismogram envelopes from the P-wave arrival until the noise level.

In Fig. 5.17 one can see that the form of the envelopes of the records of earthquakes and explosions is essentially different from the case considered above.

For the Zerenda station a relatively steep amplitude slump in P-coda, an abrupt amplitude increase in S_n -wave and rapid attenuation after the maximum in this wave group are observed. For the earthquake records a little eroded S_n -wave is sometimes observed; the maximum amplitude of this wave group may shift relative the travel-time curve by more than 50 sec. Usually for earthquakes the amplitude level of the S_n -wave relative to the P-wave is higher than for the explosions (even when the differences in the epicentral distances are not taken into account).

For the Talgar station the wave picture is quite different. In spite of the epicentral distances for earthquakes and explosions being almost the same, the form of the records differs significantly. For the explosion records a very rapid amplitude attenuation in P-coda takes place, and it is often impossible to see even a small amplitude increase of the S_n -wave against the background of

P-coda. For the earthquakes from the Caucasus region one can see usually a slow amplitude increase in P-waves (sometimes during about 30 sec), then relatively weak attenuation, monotonous amplitude growth after S_N -wave arrival (for some events during 2 min) and later a gradual attenuation in S_N -coda. It follows from a comparison of Fig. 5.17 (a,b,c,d), that a difference in form of earthquake and explosion records are much more significant for the Talgar station than for the Zerenda station. Hence, here is a situation quite contrary to the previous case observed. (It was shown earlier that for the Semipalatinsk test site and for the Altai earthquakes the maximum differences correspond to the records of the station Zerenda).

In the case above the two parameters S_S/P_N (which already was analyzed above) and S_N/P_N were used. The second parameter represents a ratio of the maximum amplitudes of S_N - and P_N -waves (with a corresponding correction for the epicentral distance). In addition, a correction for the instruments was included for the records of explosions at the Zerenda station, because the mean values of the parameters considered for the narrow-band CSE channel are higher by 0.2 log. unit, than for the broad-band RVZT channel. In Fig. 5.18 one can see that the discrimination between nuclear explosions and earthquakes is much more effective for the Talgar station than for the station Zerenda. (Although, of course, it is necessary to take into account, that in the first case a smaller number of the earthquake records were processed than in the second case).

For the Talgar station the data distribution do not overlap at all, and for the parameter S_g/P_n the difference between closest values for the explosions and earthquakes reaches 0.7. For the station Zerenda the quantity of the false alarms (when all explosions are found) equals 14 and 9% (respectively for the parameters S_n/P_n and S_g/P_n).

In this case, two-dimensional analysis was not conducted because we have not enough events recorded simultaneously by both stations.

5.4. Discussion.

From the analysis above it follows that use of data of two or more stations situated at significantly different azimuths from the area under consideration improves the discrimination between underground nuclear explosions and earthquakes. We suppose that this is due to the following circumstances. It is well known, that, for explosions, the greater part of seismic energy is generated in the form of longitudinal waves (in comparison with earthquakes). Consequently, for earthquakes, all parameters based on amplitude ratios for phases formed by shear and longitudinal waves as a whole should be larger than for explosions (for definiteness we use the parameter S_g/P_n). This conclusion agrees well with experimental data (for example [Gupta and Burnett, 1981]). At the same time, in some cases radiation patterns of P- and S-waves can be oriented relative to some station in such a way, that it may lead to an abrupt

decrease of values of the parameter S_g/P_n for some earthquake epicenters and result in their similarity to explosions for a given station. But it is obvious that for some other station situated at a significantly different azimuth, the probability of a second accordance in an area of the minimum value of the parameter S_g/P_n is rather small. For this reason the use of data of two stations gives a much more reliable guarantee of no overlap of this parameter with the distributions of data, corresponding to the explosions.

The positive correlation between the values of the parameters S_g/P_n observed for the Altay earthquakes, recorded by the stations Talgar and Zerenda, can in our opinion, be explained as follows. It has been shown earlier [Kopnichev and Arakelyan, 1988; Kopnichev and Pavlova, 1988; Kopnichev; 1990; 1992] that for other equal conditions this parameter is a measure of the total attenuation of shear waves in the lithosphere and asthenosphere in an area of the earthquake or explosion source. For this reason, low values of the parameter S_g/P_n for the both stations correspond to higher attenuation in the areas of epicenters of these earthquakes, and high values to the lower attenuation in these areas.

It is significant that such the correlation also is a source of an uncertainty in the discrimination of earthquakes and explosions. Indeed, for high attenuation in the region of the earthquake epicenter values of the parameter S_g/P_n may correspond to the same area as the explosions (by relatively low attenuation in a test site

area).

It is more difficult to explain the possible negative correlation between the values of parameter S_g/P_n , which is outlined for nuclear explosions. One of possible reasons for this effect may be directivity of shear wave radiation, which probably is observed for the nuclear explosions in tunnels. (Though, generally speaking, it is hard to expect that this directivity may be expressed more strongly, than for earthquakes). But in favour of such a suggestion we note, that data for the chemical explosion, for nuclear explosion in borehole, and for some explosions in tunnels correspond to a continuation of the dependence obtained for earthquakes.

From Fig. 5.15 it follows that data for the chemical explosions for the station Zerenda are similar to data for the earthquakes. The best division is observed for the parameter S_g/P_n , for which distributions of data for the chemical explosions and nuclear explosions practically do not overlap. But for Talgar station, as in the case of comparison of records of earthquakes and nuclear explosions, the division of chemical explosions and nuclear explosions is practically impossible. This result again testifies to a necessity to use the records of few stations, situated at various azimuths from a region under consideration to discriminate nuclear explosions and earthquakes.

The division of the explosions and earthquakes by the parameters C/P_n and L_g/P_m is found to be less effective, than by the parameter S_g/P_n . We suppose that a reason for

this effect is the following. As we already mentioned, for a given hypocenter-station pair, P_n - and S_n -waves are spreading by similar paths and the heterogeneity of media between the source and receiver has a much smaller influence on the ratio of their amplitudes. But coda waves travel much more steeply than P_n -waves. In addition to this, the maximum phase in a group of P-waves may correspond in various cases either to a P_n -wave or a P_g -wave, which are spreading by quite different paths. All this, naturally, leads to a greater data dispersion when using the parameters C/P_n and L_g/P_m .

A specific form of the records for nuclear explosions from the Pre-Caspian depression and for earthquakes from the Caucasus region is connected with a relatively high attenuation of shear waves in the lithosphere and asthenosphere of the regions considered [Kopnichev and Arakelyan, 1988]. For these regions the discrimination results are less convincing than for the Semipalatinsk test site and Altay earthquakes due to greater distances between epicenters of these events. For this reason a very good division of distributions for the explosions and earthquakes by records of the station Talgar may be partly connected with the stronger shear wave attenuation in the Earth's crust and uppermost mantle in the Pre-Caspian depression in comparison with the northern Caucasus region.

Gupta and Burnett [1981] concluded that a parameter characterizing the ratio of a maximum amplitude before the S_n -wave to a maximum amplitude after this wave is a useful

discriminant for recognizing explosions and earthquakes on the territory of the former Soviet Union. In our opinion, this empirical parameter cannot ensure the best discrimination, because the wave picture in this vast region is highly variable. This follows even from Fig. 5.12 and 5.17, in which the maximum amplitudes before and after the Sn-group may correspond to different seismic phases.

Our data show that in the regions under consideration the best recognition of the explosions and earthquakes is reached by using the parameter S_g/P_n , and by analysing data obtained by at least two stations which are situated at significantly different azimuths from the area under consideration.

CONCLUSIONS.

The study carried out. We constructed magnitude calibration functions in the range from 200 to 2600 km for stations of the northern Tien Shan and for waves P_n , P_g , S_n , L_g and LR.

We estimated azimuthal variations of amplitudes of P_n , P_g , S_n , L_g -waves for 12 stations of the CSE in the northern Tien Shan.

Peak amplitudes and corresponding visible periods of different seismic phases recorded by the SK and the SKM seismographs were considered as discrimination criteria of explosions and earthquakes.

We compared amplitude ratios of P_g/P_n , $2P/1P$, S_H/S_V , S_H/P_V , L_g/P , L_{gH}/L_{gV} . An amplitude ratio here is marked by symbols corresponding to the wave types; vertical and horizontal components are marked by symbols V and H respectively. We estimated the dependence of these ratios on magnitude and distance.

We considered visible periods of waves dominating at regional distances, T_p and T_{Lg} . We estimated the variation of these values as a function of distance and magnitude.

We analyzed the well-known m-M criterion, which uses both amplitudes and visible periods of P- and L-waves, and which includes a distance correction. Factors which influence this criterion but which have not been considered by other researchers were analyzed in detail. We obtained

regional m-M relationships for explosions and earthquakes. We propose new criterion of explosions/earthquakes discrimination from the rise time, T_r , of amplitudes of longitudinal waves from the first arrival to the maximum. This criterion works at distances greater than 1000 km.

We considered spectral-temporal characteristics of seismic signals from earthquakes and explosions recorded at CHISS (a multiple band pass station). We propose from an analysis of the records two modifications of the spectral-temporal discrimination criterion. This criterion uses complex differences of the characteristics of all the seismic phases.

We studied the nature of some regional phases, especially the coda of S_n - and L_g -waves by detailed analysis of spatial and time characteristics of short-period seismic wave fields.

We used parameters describing ratios of maximum amplitudes of different wave groups, among them the usual (S_n/P_n , L_g/P_m) as well as those related to an analysis of irregular waves (S_g/P_n , C/P_n) for discrimination of records of underground explosions, chemical explosions and earthquakes.

We analyzed more than 60 records of UNEs conducted at the STS, chemical explosions at a nearby sites, and Altay earthquakes. More than 60 records of UNEs conducted in salt in the region of the Pre-Caspian depression as well as nearby earthquakes inside the northern Caucasus and central part of the Caspian Sea were also analyzed.

Results obtained. We showed that azimuthal variations of P_n , P_g , S_n and L_g -waves are comparable with differences of amplitude ratio of various wave types from explosions and earthquakes. On one hand, these variations may allow us to discriminate seismic sources wherever they are and independently of their type. On the other hand, if the differences in the amplitude ratios are due to different source types, the variations related to medium structure will complicate the determination of source type.

We established that the criteria P_g/P_n and S_H/S_V are not effective for discrimination. The criteria S/P and L_g/P do not work at distances less than 900 km, but are relatively effective at larger distances. The criterion $2P/1P$ also can be used at distances greater than 1000 km. The criteria L_{gH}/L_{gV} , T_p , T_{Lg} , and $m-M$ are effective in the whole range of distances studied. The criterion T_r works only at distances greater than 1000 km.

No one of the criteria allows for 100-percent discrimination of explosions and earthquakes. But joint application of independent criteria (for example, L_g/P_m , L_{gH}/L_{gV} and T_r) allows us to improve substantially the efficiency of discrimination of underground explosions and earthquakes. Note that the criteria mentioned above are based on the characteristics of the dominate regional phases. Thus, the criteria S/P , $2P/1P$, T_{Lg} , $m-M$ were not used. It is hard to estimate the efficiency of all the criteria applied together by calculation (simulation) since some of them have the same genesis (like T_p and T_{Lg}). In

this case, an experimental comparison of complex criterion is needed.

A study of irregular waves recorded at regional distances allowed us to conclude that S_n - and L_g -waves are formed in general by shear waves reflected from numerous interfaces in the upper mantle. At later arrival times, these waves cross the asthenospheric layer beneath the source and receiver. These conclusions permit us to use the characteristics of various wave groups more purposefully to solve discrimination problems.

We showed that simultaneous use of two stations at different azimuths from the region under investigation provides for more efficient discrimination of underground explosions and earthquakes. For the Semipalatinsk explosions, explosions in salt inside the Pre-Caspian depression, as well as for nearby earthquakes, the best discrimination is from S_g/P_n parameter related to the analysis of irregular waves arriving between S_n and L_g . In the spaces of different parameters, chemical explosions are usually between underground explosions and earthquakes.

Naturally, spectral-temporal criteria of discrimination have greater resolution and allow us to discriminate explosions and earthquakes more reliably. Note, that the modifications elaborated here do not use absolute amplitude but rather the steepness of spectral slope.

Many of the conclusions obtained from the analog seismograms, may be used in constructing some algorithms for digital records. Each part of a record, from the first

arrival to the coda mixing with seismic noise, is informative about the seismic source. Short-period components of the initial part are the most informative at the distances less than 1000 km, while low-frequency components are more informative at larger distances.

The optimal recording frequency band is determined not only by discrimination requirements, but also by the problem of detection of weak signals. If discrimination requires the broadest band, detection should be done in the band where the signal/noise ratio is appropriate. A choice of optimal band can be helped by available estimates of T_p and T_{Le} separating earthquakes and explosions. As surface wave records from the northern Tien Shan stations (the SK records) at distances greater than 2500 km have on average periods of 8 sec, it is helpful to filter shorter periods where the most intensive seismic noise has a periods of 5 to 6 sec.

We recommend determining the optimal frequency band by digital equipment taking into account all the requirements of seismic monitoring of nuclear explosions.

We emphasize that we have used only a small part of the data available from the CSE. It is possible to carry out additional analysis of the data from the mentioned test sites, as well as from different regions of the Eurasia. In particular, there are some unique possibilities for a statistically representative comparison of characteristics of records of underground nuclear explosions and of many chemical explosions conducted at the STS. It is also helpful

to study a possibility to discriminate nuclear explosions from the Lop Nor test site and nearby earthquakes. The relatively high seismicity of the Xinjiang region favours this study. Novaya Zemlya explosions as well as industrial explosions conducted over the territory of the former USSR including tectonically active regions also can be studied.

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APPENDIX.

Table 1.A

Basic information on the seismic stations

N	Station name	Coordinates	
		Lat., °N	Long., °E
1	Talgar*	43.2	77.2
2	Shohel'Dal'nyaya*	43.2	77.4
3	Alma-Ata*	43.2	77.0
4	Rybach'ye*	42.5	76.2
5	Przheval'sk*	42.5	78.4
6	Kadzhisay*	42.1	77.2
7	Frunze*	42.8	74.6
8	Naryn*	41.4	76.0
9	Boomskoye	42.5	75.9
10	Fabrichnaya	43.1	76.4
11	Ili	43.9	77.1
12	Chilik	43.6	78.4
13	Kurmenty	43.0	78.3
14	Orto-Merke	42.9	78.8
15	Charyn	43.5	79.2
16	Kyzyl-Agach	45.4	78.7
17	Zerenda	52.9	69.1
18	Borovoye	53.0	70.0
19	Bayanaul	50.8	75.5
20	Karkaralinsk	49.4	75.4
21	Verkhotur'ye	58.9	60.8
22	Garm	39.0	70.3

* Stations equipped with middle-period instruments (SK), together with short-period ones (SKM).

Table 2.A

List of explosions at the Semipalatinsk
test site

Date	Origin time			Magnitude m b	Area
	h	m	s		
03/15/64	07	59	58.2	5.6	D*
05/16/64	06	00	58.7	5.6	D
07/19/64	05	59	58.6	5.5	D
01/15/65	05	59	58.5	6.3	B
03/03/65	06	14	57.0	5.6	D
05/11/65	06	39	57.8	5.2	D
06/17/65	03	44	58.2	5.4	D
09/17/65	03	59	57.5	5.6	D
10/08/65	05	59	58.6	5.7	D
12/24/65	04	59	58.3	5.1	D
02/13/66	04	57	57.9	6.2	D
05/07/66	03	57	58.0	4.8	D
03/20/66	05	49	57.7	6.2	D
06/29/66	06	57	58.0	5.6	D
07/21/66	03	57	57.6	5.4	D
10/19/66	03	57	57.7	5.7	D
01/30/67	04	01	57.6	4.8	D
02/26/67	03	57	57.7	6.0	D
04/20/67	04	07	57.6	5.7	D
07/15/67	03	26	57.4	5.4	D
08/04/67	06	57	58.0	5.3	D
09/16/67	04	03	58.2	5.3	M*
09/22/67	05	03	57.1	5.3	M
10/17/67	05	03	58.0	5.6	D
10/30/67	06	03	57.9	5.5	D
11/22/67	04	03	57.5	4.8	M
12/08/67	06	03	57.7	5.4	D
01/07/68	03	46	57.6	5.3	D
04/24/68	10	35	51.3	5.0	D
06/11/68	03	05	58.0	5.2	D
06/19/68	05	05	57.4	5.5	D
07/12/68	12	07	57.6	5.3	D
08/20/68	04	05	58.1	4.8	D
09/05/68	04	05	57.5	5.4	D
11/09/68	02	53	57.7	4.9	D
12/18/68	05	01	57.1	5.0	D
03/07/69	08	26	57.6	5.6	D
05/16/69	04	02	57.3	5.2	D
05/31/69	05	01	56.9	5.3	D
07/04/69	02	46	57.3	5.2	D
07/23/69	02	46	58.0	5.4	D
09/11/69	04	01	57.5	5.0	D
10/01/69	04	02	57.7	5.2	D
12/28/69	03	46	57.8	5.7	M
01/29/70	07	02	57.7	5.6	D
03/27/70	07	02	57.0	5.0	D
06/28/70	01	57	57.7	5.7	D
07/21/70	03	02	57.0	5.4	M

Date	Origin time			Magnitude m _b	Area
	h	m	s		
07/24/70	03	56	57.6	5.3	D
09/08/70	04	02	57.6	5.4	D
05/25/71	04	02	57.9	5.1	D
06/19/71	04	03	57.7	5.4	M
06/30/71	03	57	02.1	5.2	B*
10/09/71	06	02	57.3	5.3	M
12/15/71	07	52	59.1	4.9	D
02/10/72	05	02	57.6	5.4	B
06/07/72	01	27	57.1	5.5	D
08/16/72	03	16	57.5	5.0	D
09/02/72	08	56	57.6	4.9	D
12/28/72	04	27	00.0	4.8	D
04/19/73	04	32	57.6	5.4	M
07/10/73	01	26	58.0	5.2	D
07/23/73	01	22	57.7	6.1	B
10/26/73	04	26	57.8	5.2	D
12/14/73	07	46	57.1	5.8	B
04/16/74	05	52	56.9	4.9	B
06/25/74	03	56	57.4	4.7	D
07/10/74	02	56	57.6	5.2	D
12/07/74	05	59	56.5	4.7	M
12/16/74	06	23	02.4	5.0	D
12/16/74	06	41	02.4	4.8	D
03/11/75	05	42	57.6	5.4	D
08/07/75	03	56	57.6	5.2	D
12/13/75	04	56	57.3	5.1	D
01/05/76	04	46	57.6	5.2	D
03/20/76	04	03	39.6	5.1	M
04/21/76	04	57	57.0	5.1	D
05/19/76	02	56	57.7	5.0	D
06/09/76	03	02	57.6	5.3	B
07/23/76	02	32	57.9	5.1	D
12/30/76	03	56	57.1	5.2	D
04/25/77	04	06	57.8	5.1	D
06/29/77	03	06	57.8	5.3	B
07/30/77	01	56	58.0	5.1	D
08/17/77	04	26	57.7	5.1	D
12/26/77	04	02	57.7	4.9	D
03/19/78	03	46	57.4	5.2	B
05/29/78	04	56	57.4	4.7	D
10/15/78	05	26	57.5	5.2	D
10/31/78	04	16	57.8	5.2	D
02/16/79	04	03	58.2	5.4	M
05/06/79	03	16	57.6	5.2	D
05/31/79	05	54	57.6	5.3	D
06/23/79	02	56	59.0	6.2	B
07/07/79	03	46	57.5	5.8	B
07/18/79	03	17	02.6	5.2	M
09/27/79	04	12	57.5	4.5	D
10/28/79	03	16	57.0	6.0	B
11/30/79	04	52	57.8	4.5	D
12/21/79	04	41	56.8	4.7	D
04/04/80	05	32	57.3	4.9	M

Date	Origin time			Magnitude	Area
	h	m	s	m b	
04/25/80	03	56	57.4	5.5	B
09/25/80	06	21	10.5	4.7	D
05/27/81	03	59	13.3	5.5	B
07/17/81	02	37	15.7	5.2	D
08/14/81	02	27	12.9	5.0	D
11/20/81	04	57	02.5	5.1	D
11/29/81	03	35	08.8	5.7	B
12/29/81	04	31	02.6	5.1	D
02/19/82	03	56	11.1	5.4	D
06/25/82	02	03	04.4	4.8	B
08/23/82	02	43	04.3	4.7	M
08/31/82	01	31	00.7	5.3	B
09/21/82	02	57	01.0	5.2	D
04/12/83	03	41	05.6	4.9	D
05/30/83	03	33	44.0	5.5	D
06/24/83	02	56	11.2	4.7	D
09/11/83	06	33	10.5	4.9	D
11/20/83	03	27	04.6	5.5	B
09/09/84	02	59	06.5	5.0	D
10/18/84	04	57	06.0	4.5	D
10/26/84	01	55	05.0	6.1	B
02/10/85	03	27	07.7	5.9	B
04/25/85	00	57	06.5	5.9	B
06/15/85	00	57	00.9	6.0	B
06/30/85	02	39	02.9	6.0	B
07/20/85	00	53	14.8	5.9	B
07/25/85	03	11	06.9	5.0	D
02/26/87	04	58	22.1	5.4	D
03/12/87	01	57	17.3	5.6	B
05/06/87	04	02	58.0	5.6	D
06/06/87	02	37	07.1	5.3	D
06/20/87	00	53	05.0	6.1	B
07/17/87	01	17	07.1	5.8	D
12/13/87	03	21	04.7	6.1	B
12/27/87	03	55	04.9	6.1	B
04/31/88	01	33	05.9	6.1	B
05/04/88	00	57	06.8	6.1	B
12/17/88	04	18	07.7	5.9	B
10/19/89	09	49	57.3	5.9	B

* D - Degelen area (STS)
M - Murzhik area
B - Balapan area

Table 3.A

Industrial explosions

Date	Origin time		Coordinates	
	h	m	Lat., °N	Long., °E
04/22/66*	02	58	47.9	47.7
09/30/68	05	59	38.8	64.5
10/06/67	07	00	52.7	65.3
07/01/68*	04	02	47.9	47.9
05/21/68	03	59	38.9	65.1
11/02/69	04	59	57.3	54.8
09/08/69	04	59	57.4	55.0
09/26/69	06	59	45.9	42.5
12/06/69	07	02	43.8	54.8
02/21/70	07	09	59.4	60.0
06/25/70	04	09	52.2	55.7
12/23/70	07	00	43.8	54.8
07/02/71	17	00	67.8	62.0
07/10/71	16	59	64.2	54.8
09/19/71	11	00	57.8	41.4
10/04/71	10	00	61.6	47.2
10/22/71	05	00	51.6	54.4
04/11/72	06	00	37.4	62.1
08/20/72	02	59	49.4	48.1
10/03/72	08	59	46.9	44.9
11/24/72	09	59	51.8	64.2
08/15/73	01	59	42.7	67.4
08/28/73	02	59	50.6	68.4
09/19/73	02	59	45.7	67.8
10/26/73	05	59	53.6	55.3
08/14/74	14	59	68.9	75.8
08/29/74	14	59	67.2	62.1
02/08/75	06	59	41.9	73.2
08/10/77	22	00	50.9	110.8
08/20/77	21	59	64.1	99.6
09/10/77	16	00	57.3	106.2
09/21/78			66.4	85.8
10/17/78	13	59	63.2	63.2
07/14/79	04	59	47.8	48.2
11/06/79	17	59	65.0	99.6
19/06/79	15	59	60.7	71.5
11/01/80	12	59	60.8	97.5
12/10/80	06	59	61.7	67.0
10/22/81	13	59	63.7	97.6
09/04/82	17	59	69.2	81.6
09/25/82	17	59	64.3	91.8
08/11/84	18	59	65.1	55.1

* Probably, it is explosion in salt.

Table 4.A

Underground nuclear explosions in salt

Date	Origin time			Coordinates	
	h	m	s	Lat., °N	Long., °E
09/21/72	09	00	00	52.1	52.0
11/24/72	09	00	00	52.1	51.8
09/29/75	11	00	00	69.6	90.4
07/29/76	05	00	00	47.8	48.1
07/26/77	17	00	00	69.5	90.6
09/30/77	07	00	00	48.1	47.8
09/17/79	08	00	00	48.0	48.2
10/08/80	06	00	00	46.7	48.2
11/26/81	05	00	00	46.8	48.2
		04	00	46.8	48.3
10/16/82	06	00	00	46.7	48.2
		05	00	46.7	48.2
		10	00	46.7	48.3
		15	00	46.7	48.2
07/10/83	04	00	00	51.3	53.3
		05	00	51.3	53.3
		10	00	51.3	53.3
09/24/83	05	00	00	46.8	48.3
		05	00	46.8	48.3
		10	00	46.9	48.3
		15	00	46.8	48.3
		20	00	46.8	48.3
		25	00	46.8	48.2
07/21/84	03	00	00	51.3	53.2
		05	00	51.4	53.2
		10	00	51.3	53.3
10/27/84	06	00	00	46.8	48.1
		05	00	46.8	48.1
10/03/87	15	15	00	47.6	56.2

Table 5.A

Earthquakes, used for study of regional differences of various wave types.

Date	Origin time			Coordinates	
	h	m	s	Lat., °N	Long., °E
N-E:					
07/02/63	00	15	24	44.4	85.0
07/31/63	21	53	00	42.5	88.5
07/14/64	19	41	44	44.7	88.2
04/03/65	03	02	01.7	44.1	82.4
05/01/65	12	33	38.6	43.5	82.9
05/20/65	11	37	52	43.9	83.3
10/21/65	15	56	35	44.1	86.8
11/20/65	08	56	02	43.9	87.7
06/08/66	17	51	23	44.4	83.0
06/15/66	17	20	18	44.2	83.7
07/07/66	16	18	22	44.6	83.2
08/20/67	02	02	05.0	45.2	80.0
E-NE:					
03/23/62	02	48	33	47.3	79.1
04/13/62	18	36	00	49.4	87.2
02/24/63	14	33	23.8	48.4	83.9
S:					
01/09/66	16	17	02	40.3	75.9
03/12/66	12	33	12	40.5	76.9
03/21/66	05	39	06	39.6	78.1
05/12/66	11	42	48	40.3	78.1
05/19/66	05	58	42	40.1	77.8
06/13/66	15	52	27	40.5	78.0
SW:					
01/26/66	08	18	16.2	40.4	73.0
01/28/66	08	52	05	39.4	73.0
04/11/66	16	42	51	39.0	70.6
04/14/66	21	06	13	38.9	70.5
04/25/66	23	22	50	41.3	69.3
05/15/66	02	13	03	39.9	74.3
05/20/66	20	09	02.6	40.7	73.3
06/23/66	07	12	18	41.6	72.7
11/25/66	20	31	35.1	41.7	72.7

Table 6.A.

Calibration functions for various waves for northern Tien Shan stations (source depth is less than 60 km).

Epicentral distances, KM	Waves type				
	P _n	P _g	S _n (S)	L _g	LRV*
			S _n		
200	5.65	4.85	4.60	4.34	4.10
300	5.80	5.14	5.20	4.57	4.28
400	5.94	5.36	5.40	4.78	4.39
500	6.06	5.54	5.58	4.98	4.50
600	6.18	5.70	5.73	5.15	4.61
700	6.32	5.87	5.86	5.30	4.72
800	6.44	6.00	6.00	5.42	4.82
900	6.45	6.10	6.14	5.50	4.91
1000	6.22	6.22	6.23	5.55	4.99
1100	6.32		6.26	5.55	5.06
1200	6.42		6.30	5.56	5.12
1300	6.46		6.31	5.60	5.17
1400	6.50		6.34	5.67	5.22
1500	6.53		6.40	5.73	5.27
			S		
1600	6.55		6.54	5.80	5.32
1700	6.59		6.62	5.86	5.36
1800	6.63		6.62	5.90	5.40
1900	6.63		6.60	5.94	5.44
2000	6.40		6.48	6.00	5.48
2100	6.36		6.30	6.05	5.52
2200	6.39		6.29	6.12	5.56
2300	6.40		6.38	6.20	5.59
2400	6.41		6.44	6.28	5.62
2500	6.42		6.48	6.38	5.65

Comment:

*We included a correction into the calibration function to transfer data, obtained for the vertical component, to a usual calibration system for the horizontal component.

Criterion	Explosion type	Distance range, km	Parameter value	% earthquakes found	% explosions skipped
1	2	3	4	5	6
lg Trise(SKM)	industrial, include those in salt	1000-3100	0.6	72	28
spectrum-temporal					
"Maina-Vira"	STS	735		~100	~0
"Tatsukava"	STS	1100		~100	~0
	STS	735		~100	~0
	STS	1100		~100	~0

Content:

- * Ratio of maximum amplitudes of corresponding type waves.
- ** Criterion is not efficient.
- *** Underground nuclear explosion.
- **** Longitudinal waves having velocities less and more than those of Pg waves.

Table 8.A

Underground nuclear explosions at the Semipalatinsk test site, nearby earthquakes and chemical explosions.

N	Date	t ₀	φ°, N	λ°, E	K*	m _b	Source type	Stations
1	08/15/70	09-41-38	47.6	82.1	11.0	4.9	Earthquake	Kr. Cordon, Talgar
2	12/15/71	07-52-59.1	50.0	77.9		4.4	UNE, Degelen	Zerenda, Talgar
3	07/06/72	01-02-57.7	49.7	78.0		4.8	"-	Talgar
4	12/28/72	04-27-00	49.73	78.10			"-	Chkalovo, Talgar
5	08/23/73	17-23-27	46.6	83.3	11		Earthquake	Zerenda
6	12/31/73	04-02-57.7				4.7	UNE, Degelen	Chkalovo, Talgar
7	04/16/74	05-52-56.9	49.98	78.88		4.9	UNE, Balapan	Zerenda, Talgar
8	06/25/74	03-56-58.1	49.8	78.1		4.7	UNE, Degelen	Zerenda, Talgar
9	10/05/75	04-26	49.38	78.98		4.7	"-	Zerenda
10	06/24/76	02-04-17	46.7	80.6	11.0		Earthquake	Zerenda, Talgar
11	03/17/77	22-41-39.0	46.3	80.1	12.0		"-	Zerenda, Talgar
12	04/27/77	05-29-28	47.8	82.4	11		"-	Vostochnyy
13	05/11/78	00-28-23	47.8	80.4	10		"-	Borovoye, Talgar
14	05/29/78	04-56-58	49.9	78.2		4.7	UNE, Degelen	Chkalovo
15	09/16/78	11-16-32	50.2	80.0	10		UNE, Degelen	Borovoye, Talgar
16	09/13/79	08-14-50	47.1	82.2	12		Earthquake	Zerenda
17	02/18/79	11-49-32	49.2	82.0	11.0		Earthquake	Borovoye, Talgar
18	02/20/79	19-37-47	50.1	80.3	11		"-	Chkalovo, Talgar
19	09/30/80	11-03-05	Sayak				Chemical explosion	Zerenda
20	10/17/80	10-11-48	"-		10		"-	Vostochnyy
21	02/20/81	11-13-13	"-				"-	Zerenda
22	03/31/81	07-51-35	48.0	81.4	11.7		Earthquake	Chkalovo, Talgar
23	12/25/82	04-23-05.6	49.9	78.1		4.8	UNE, Degelen	Zerenda
24	02/05/84	08-07-15.2	47.7	81.6	9.3		Earthquake	Talgar
25	03/15/84	06-15-9.9	49.99	78.91			Chemical explosion	Zerenda, Talgar
26	10/18/84	01-11-46.0	47.3	81.7	10.7		Earthquake	Zerenda, Talgar
27	10/18/84	04-57-05.4	49.80	78.16		4.5	UNE, Degelen	Zerenda, Talgar
28	07/20/85	08-30-26.0	47.3	83.6	11.2		Earthquake	Zerenda, Talgar
29	09/16/86	10-36-27	47.4	82.6	9.8		"-	Zerenda, Talgar
30	09/17/86	16-04-59	47.4	81.5	10.2		Earthquake	Zerenda, Talgar

N	Date	t ₀	φ°, N	λ°, E	K*	m _b	Source type	Stations
31	11/19/86	12-50-06.0	47.81	80.85	11.3		Earthquake	Zerenda, Talgar
32	12/22/86	10-21-25.5	Bayanaul				Chemical explosion	Zerenda
33	11/29/86	08-17-33.2	Bayanaul				"	"
34	05/29/87	02-29-56	Bayanaul				"	"
35	06/28/87	05-00-49	47.4	81.5	10.1		Earthquake	Zerenda, Talgar
36	06/28/87	09-25-02	47.4	81.1	8.9		Earthquake	Talgar
37	10/16/87	06-06-08.6	49.78	78.24		4.6	UNE, Degelen	Zerenda, Talgar
38	09/18/87	02-32-09.1	50.18	78.02		4.3	UNE, Degelen	Zerenda, Talgar
39	12/20/87	02-55-06.3	49.75	78.0		4.8	UNE, Degelen	Zerenda, Talgar
40	02/06/88	04-19-11.8	49.87	77.97		4.7	UNE, Degelen	Zerenda, Talgar
41	04/22/88	09-30-06.7	49.8	78.1		4.9	UNE, Degelen	Zerenda, Talgar
42	10/18/88	03-40-06.7	49.9	78.10		4.9	UNE, Degelen	Zerenda, Talgar
43	10/04/89	11-29-57.9	49.83	78.09		4.7	UNE, Degelen	Chkalovo, Talgar

* Energy class

Table 9.A

Underground nuclear explosions in region of the Pre-Caspian depression
and earthquakes in the Caucasus region

N	Date	t ₀	φ° , N	λ° , E	K	m _b	Source type	Stations
1	07/01/68	04-02-00.9	47.85	47.72		5.5	UNE	Talgar
2	12/22/71	06-59-56.5	47.9	48.57		6.0	"	"
3	10/03/72	08-59-57.8	46.86	44.87		5.6	"	Zerenda
4	01/09/75	23-40-03.0	42.9	47.1	12.0		Earthquake	Talgar
5	01/10/75	01-09-18.7	42.9	47.1	12.0		"	"
6	01/10/75	04-35-33.3	42.9	47.1	11.0		"	Zependa
7	01/10/75	11-50-10.5	43.0	47.0	11.0		"	"
8	01/12/75	13-51-51.0	43.0	47.0	11.0		"	"
9	01/13/75	07-58-31.3	43.0	47.0	12.0		"	"
10	06/20/75	13-53-26.0	42.73	48.10		4.7	"	Talgar
11	10/20/75	02-54-05.7	43.4	44.4	11.0		"	Zerenda
12	03/29/76	07-00-00.0	47.87	48.22		4.7	UNE	"
13	07/29/76	04-59-58.0	47.78	48.12		5.9	"	Zerenda, Talgar
14	07/29/76	06-30-22.3	43.0	45.1	11.0		Earthquake	Zerenda
15	07/29/76	08-14-07.0	43.0	45.1	11.0		"	"
16	07/31/76	17-11-05.6	43.0	45.3	11.0		"	"
17	09/30/77	06-59-58.0	47.8	48.15			UNE	"
18	03/16/78	21-51-41.7	43.0	47.50		4.3	Earthquake	"
19	03/21/78	08-33-19.0	43.08	47.17			"	"
20	07/12/78	11-52-15.0	43.2	45.0		4.4	"	"
21	10/17/78	04-59-56.6	47.81	48.09		5.8	UNE	Talgar
22	11/16/78	05-46-15.0	43.6	47.0	11.0		Earthquake	Zerenda
23	01/17/79	07-58-56.9	47.98	48.21		6.0	UNE	Talgar
24	02/09/79	11-20-44.0	43.3	45.8	11.0		Earthquake	Zerenda
25	03/05/79	16-54-03.0	42.31	48.25			"	Talgar
26	07/14/79	04-59-56.0	47.83	48.29		4.7	UNE	Talgar
27	10/08/80	05-59-57.3	46.79	48.24		5.2	"	Zerenda, Talgar
28	09/26/81	04-59-57.5	46.78	48.24		5.3	UNE	"
29	09/26/81	05-03-57.0	46.71	48.24		5.4	"	"
30	10/18/81	05-22-28.1	43.26	45.38			Earthquake	Talgar
31	03/08/82	09-42-20.0	42.06	48.42		4.7	"	"

N	Date	t ₀	φ°, N	λ°, E	K	m _b	Source type	Stations
32	10/16/82	06-14-57.5	46.75	48.20		5.4	UNE	Zerenda
33	09/24/83	04-59-57.0	46.81	48.29		5.2	"	Zerenda, Talgar
34	09/24/83	05-04-57.0	46.81	48.27		5.1	"	"
35	09/24/83	05-09-57.0	46.84	48.33		5.0	"	"
36	09/24/83	05-14-57.9	46.84	48.29		5.2	"	"
37	09/24/83	05-19-57.4	46.88	48.30		5.4	"	"
38	09/24/83	05-24-57.0	46.80	48.29		5.3	"	"
39	06/30/83	21-39-58.5	43.3	45.7		4.6	Earthquake	Zerenda
40	10/27/84	05-59-57.3	46.9	48.15		5.0	UNE	"
41	10/27/84	06-04-57.2	46.94	48.12		5.0	"	"
42	05/05/87	10-40-48.4	42.35	46.68		5.2	Earthquake	"
43	05/21/91	17-37-39.1	42.87	47.91		5.2	"	"
44	02/15/92	12-52-51.1	42.91	46.57		4.9	"	"
45	02/16/92	14-33-52.9	42.79	46.55		4.1	"	"
46	03/19/92	19-16-38.8	43.18	45.82		4.7	"	"
47	03/27/92	19-21-00.0	42.43	43.77		5.1	"	"
48	11/05/92	15-42-22.2	42.48	45.28		4.8	"	"
49	09/25/92	15-53-49.4	42.63	45.78		4.0	"	"

FIGURE CAPTIONS.

Figure 1.1. The frequency responses of short-period channels employed at seismic stations of the CSE:

- 1- the SKM type seismometer normalized at period $T_0=2.0$ sec;
- 2- the same normalized at 1.5 sec;
- 3- the same normalized at 1.25 sec;
- 4- the narrow-band channel CSE-1;
- 5- the narrow-band channel CSE-2;
- 6- the narrow-band channel CSE-3.

Figure 1.2. The frequency responses of intermediate-period and long-period channels employed at seismic stations of the CSE:

- 1- the SK type seismometer;
- 2- the SKD-0 type seismometer;
- 3- some experimental seismometers.

Figure 1.3. The frequency responses of the channels of the frequency selective seismic station (ChISS) used in this work.

Figure 1.4. Map showing locations of seismic stations, test sites, quarries, epicenters of industrial explosions and epicenters of earthquakes:

- 1- Semipalatinsk test site (STS);
- 2- sites of mass nuclear explosions in salt;

- 3- epicenters of nuclear explosions in salt;
- 4- quarries;
- 5- epicenters of industrial explosions;
- 6- epicenters of earthquakes;
- 7- seismic stations.

Figure 2.1. Graphs of amplitude attenuation of P_N -type waves as function of distance from the SKM records of the northern Tien Shan stations for different azimuths (the level of the amplitudes corresponds to magnitude $m_B=4.4$):

- 1- the northern direction, explosions;
- 2- the east-northeastern direction, earthquakes;
- 3- the southern direction, earthquakes;
- 4- the southwestern direction, earthquakes.

Figure 2.2. Graphs of amplitude attenuation of P_e -waves as function of distance from the SKM records of the northern Tien Shan stations for different azimuths (the level of the amplitudes corresponds to magnitude $m_B=4.4$). Symbols are the same as in Figure 2.1.

Figure 2.3. Graphs of amplitude attenuation of S_N -type waves as function of distance from the SKM records of the northern Tien Shan stations for different azimuths (the level of the amplitudes corresponds to magnitude $m_B=4.4$). Symbols are the same as in Figure 2.1.

Figure 2.4. Graphs of amplitude attenuation of L_g -waves as

function of distance from the SKM records of the northern Tien Shan stations for different azimuths (the level of the amplitudes corresponds to magnitude $m_E=4.4$). Symbols are the same as in Figure 2.1.

Figure 2.5. Diagrams illustrating the dependence of mean amplitude level of P_n - and L_E -waves on direction of wave arrival for several stations of the North Tien Shan.

Figure 3.1. Distribution of $\lg(A_S/A_P)$ values for earthquakes and quarry blasts. Here and in later figures the experimental estimations (the light and the dark circles) are approximated by Laplace functions.

Figure 3.2. Distribution of $\lg(A_S/A_P)$ values for earthquakes and underground nuclear explosions at the STS.

Figure 3.3. Distribution of $\lg(A_S/A_P)$ values for earthquakes and underground nuclear explosions in salt at distances of 1200-3100 km.

Figure 3.4. Distribution of $\lg(A_{2P}/A_{1P})$ values for earthquakes and underground nuclear explosions in salt. The symbol A_{2P} designates the maximum amplitude of P-waves with apparent velocities less than for P_E -waves. The symbol A_{1P} designates the maximum amplitude of P waves with apparent velocities larger than that for P_E -waves.

Figure 3.5. Distribution of $\lg(A_{Lg}/A_p)$ values for earthquakes and underground nuclear explosions at the STS.

Figure 3.6a. Distribution of $\lg(A_{Lg}/A_p)$ values for earthquakes and underground nuclear explosions in salt at distances of 1200-3100 km.

Figure 3.6b. Distribution of $\lg(A_{LgH}/A_{LgV})$ values for all types of explosions and for earthquakes at distances of 290-3100 km. The symbols A_{LgH} and A_{LgV} designate the maximum amplitudes of L_g waves on horizontal and vertical components, respectively.

Figure 3.7. The relation between magnitudes M and $m_{(SKM)}$ for earthquakes with focal depths less than 70 km at epicentral distances less than 2500 km from the North Tien Shan seismic stations:

- 1- separate events;
- 2- figures designate number of data with respective values of M and m ;
- 3- the best-fit straight line drawn by the method of orthogonal regression with the relation of the errors for axes $\delta M/\delta m=2.5$;
- 4- the line of medians for rows;
- 5- the line of medians for columns;
- 6- the border of the field of insignificant data (the data under this line were not used in calculations).

Figure 3.8. An example of insignificant data for variables M and m . Data taken from the Seismological bulletin of the ESSN for earthquakes from Japan region:

- 1- the medians for rows;
- 2- the medians for columns;
- 3- the border of the field of insignificant data (the data under this line were not used in calculations).

Figure 3.9. The relations between magnitudes M and $m(\text{SKM})$ for underground nuclear explosions at epicentral distances less than 3500 km from the northern Tien Shan seismic stations:

- 1- STS;
- 2- NZTS;
- 3- industrial explosions in the former USSR;
- 4- the Lop Nor test site;
- 5- the maximum possible estimates are too low for measurements;
- 6- the best-fit straight line determined by the method of orthogonal regression with the relation of the errors for axes $\delta m/M\delta=2.5$;
- 7- the line of medians for columns;
- 8- the line of medians for rows;

Figure 3.10. The distribution of deviation ΔM from best-fit straight lines $M=M(m)$ for earthquakes and for explosions. The equation of discriminating straight line $M=1.6m$ (SKM) is accepted for zero line.

Figure 3.11. The distribution of values of rise times (T_r) of P-waves amplitudes from the first arrival to the maximum from SKM-records of the CSE stations.

Epicentral distances:

3500 km - for the NZTS;

1200-3100 km - for industrial nuclear explosions (including explosions in salt);

1700-3100 km - for earthquakes.

Figure 4.1. The distribution of $\lg T_p$ values for quarry blasts and for earthquakes recorded by stations in the North Tien Shan. Epicentral distances are 290-430 km.

Figure 4.2. The distribution of $\lg T_p$ values for industrial explosions (including ones in salt) at distances of 1000-3100 km from SKM - records for the North Tien Shan stations. Corrections for distance were not introduced. No influence of the instrument was noticed.

Figure 4.3 a. The distribution of $\lg T_p$ values for underground nuclear explosions at different areas of the STS, for chemical explosions and earthquakes from records of the CSE stations. Epicentral distances are 590-890 km. The data for earthquakes are obtained from the SKM- and SK-records. No instrumental influence was noticed for the explosions.

Figure 4.3 b. The distribution of $\lg(T_{Le})$ values for underground nuclear explosions (including industrial explosions) and earthquakes recorded by the Talgar station. Epicentral distances are 700-2300 km.

Figure 4.4. The scheme of measurement of spectral ratios $\text{tg}\phi$ for different pairs of adjacent ChISS-channels obtained by the method of selected parameters. The numbers of the channels are shown in the bottom of the figure.

Figure 4.5. Graphical representation of the table of spectral ratios $\text{tg}\phi$ for all pairs of adjacent ChISS channels obtained by the method of selected parameters.

Figure 4.6 A plot of peak amplitudes for the initial data and the envelopes of A and $(A+\delta)$ values smoothed by the 10 sec rectangular window from the record of the underground nuclear explosion of 6/20/1967 in the Degelen area of the STS by the fourth ChISS-channel (2.2-3.4 Hz) at the Talgar station.

Figure 4.7. Map showing to location of the STS, the Talgar and Garm stations and epicenters of 11 earthquakes, seismograms of which were compared with seismograms of explosions by the method of modulus envelopes.

Figure 4.8(a,b). The smoothed amplitude envelopes from records of ChISS of Talgar. The results of the analogous

processing for microseismic noise are shown at the bottom of each figure. Explanation at symbols of the envelopes for corresponding channels are shown in the top right panel of Figure 4.8a.

- a. Left - the explosion of 07/21/66 in the Degelen area of the STS;
Right - the earthquake of 07/21/61 (Table 4.1, Fig.4.7).
- b. Left - the explosion of 06/30/71 in the Balapan area of the STS;
Right - the earthquake of 11/23/64 (Table 4.1, Fig.4.7).

Figure 4.9. The sums of the envelopes normalized to the envelope of the first channel (S1, solid line) and to the envelope of the fifth channel (S5, dashed line).

- Left - the earthquake of 11/23/64 (Table 4.1, Fig.4.7);
- Right - the explosion of 06/30/71 in the Balapan area of the STS.

Figure 4.10(a,b). The time history of the $tg\varphi$ value. Numbers of the corresponding channels are shown near the lines.

- a. Upper panel- the explosion of 06/19/68 in the Balapan area of the STS.
Lower panel- the explosion of 08/04/67 at the Degelen area of the STS.
- b. Upper panel- the earthquake of 04/18/71 (Table 4.1, Fig. 4.7);

Lower panel- the earthquake of 11/22/64 (Table 4.1, Fig. 4.7).

Figure 4.11(a,b). The mean values of the spectral ratios $\text{tg}\varphi$ for different pairs of adjacent ChISS-channels obtained by the method of selected parameters.

a. From data of ChISS of the Talgar station (epicentral distances less than 1000 km):

Upper panel- the explosion at the STS;

Middle panel - earthquakes from the eastern direction;

Lower panel - earthquakes from the southern and the Southwestern directions;

b. From data of ChISS of the Garm station (epicentral distances more than 1000 km):

Upper panel- the explosion at the STS.

Lower panel - earthquakes (without division on directions).

Figure 4.12(a-j). Comparison of the time histories of summary slopes of the seismogram spectra for explosions (Table 2.A) and for earthquakes (Table 4.1, Fig. 4.7) obtained by the method of modulus envelopes: the summary of positive slopes $A(t) = \sum_i \text{tg}(\varphi_i(t)), (\varphi_i > 0)$; the summary of negative slopes $B(t) = \sum_i \text{tg}(\varphi_i(t)), (\varphi_i < 0)$; the summary of absolute steepness of the spectrum $C(t) = \sum_i |\text{tg}(\varphi_i(t))|$.

a. Left - the explosion of 11/24/61 in the Degelen area of the STS;

Right - the earthquake of 10/01/61.

- b. Left - the explosion of 06/29/66 in the Degelen area of the STS;
Right - the earthquake of 06/11/61.
- c. Left - the explosion of 04/20/67 in the Degelen area of the STS;
Right - the earthquake of 11/21/61.
- d. Left - the explosion of 08/04/67 in the Degelen area of the STS;
Right - the earthquake of 06/26/68.
- e. Left - the explosion of 09/16/67 in the Murzhik area of the STS;
Right - the earthquake of 11/23/64.
- f. Left - the explosion of 09/22/67 in the Murzhik area of the STS;
Right - the earthquake of 10/22/65.
- g. Left - the explosion of 10/30/67 in the Degelen area of the STS;
Right - the earthquake of 11/17/65.
- h. Left - the explosion of 04/24/68 in the Degelen area of the STS;
Right - the earthquake of 08/28/67.
- i. Left - the explosion of 03/27/70 in the Degelen area of the STS;
Right - the earthquake of 04/18/71.
- j. Left - the explosion of 06/09/70 in the Degelen area of the STS;
Right - the explosion of 06/30/71 in the Balapan area of the STS.

Figure 4.13. The comparison of different functions of spectrum steepness:

$$A(t) = \sum_i \operatorname{tg}(\varphi_i(t)), \varphi_i > 0;$$

$$C(t) = \sum_i |\operatorname{tg}(\varphi_i(t))|.$$

Explanation of symbols:

- 1- explosions at the STS;
- 2- earthquakes from the southwestern direction.
- 3- earthquakes from the eastern direction.

Epicentral distances are less than 1000 km. The data are obtained from ChISS-records of the Talgar station.

Figure 4.14. The comparison of different functions of spectrum steepness:

$$A(t) = \sum_i \operatorname{tg}(\varphi_i(t)), \varphi_i > 0;$$

$$C(t) = \sum_i |\operatorname{tg}(\varphi_i(t))|.$$

Explanation of symbols:

- 1- explosions at the STS;
- 2- earthquakes.

Epicentral distances are more than 1000 km. The data are obtained from ChISS-records of the Garm station.

Figure 5.1. Examples of records of earthquakes at regional distances: 1 - Tien Shan, 2 - North China, 3 - Laptev Sea, 4 - Yugoslaviya, 5 - Kamchatka, 6 - Kopetdag, 7 - Tibet, 8 - Pakistan, 9 - Kuril Islands. The records of permanent and temporary stations of the CSE.

Figure 5.2. Examples of envelopes of records of earthquakes with very intensive L_g -phase. Arrows here and below mark arrival times of L_g from the time/distance curve. Time, t , is the lapse time.

Figure 5.3. Examples of envelopes with two (a) and one (b) wave groups. Records from permanent and temporary stations of the CSE.

Figure 5.4. Decrease of relative amplitude of wave groups with distance. Records from station Zelenitza (Ukrainian Shield).

Figure 5.5. Envelopes of earthquake records with different source depths. 1 - from station Zelenitza, 2 - from station Uchkeken (North Caucasus).

Figure 5.6. Envelopes of deep earthquakes from the Hindu Kush area. Records from station Zerenda (North Kazakhstan).

Figure 5.7. Decrease in amplitude of the first wave with distance from data of two stations. 1 - single earthquake, 2 - averaging curve.

Figure 5.8. Variation of envelope shapes with distance in the eastern part of the Mediterranean Sea. Records from station Zelenitza.

Figure 5.9. Traces of propagation of the second wave group in the central part of the Alpine belt: 1 - very intensive second group, 2 - less intensive, 3 - is not observed, 4 - seismic stations.

Figure 5.10. Map of the region.

Figure 5.11a. Examples of records of explosions at the STS.

Figure 5.11b. Examples of the Altay earthquakes records.

Figure 5.12(a,b). Envelopes of records of Altay earthquakes. Arrows here and below mark S_n arrivals from time/distance curves.

Figure 5.12(c,d). Envelopes of records of nuclear explosions at the STS.

Figure 5.12e. Envelopes of records of chemical explosions at the quarry of Sayak (near lake Balkhash).

Figure 5.13. Procedure of C/P_n parameter determination (relative to a reference event). The coda envelope is combined with a common envelope.

Figure 5.14. Procedure of S_g/P_n parameter determination (corrected for epicentral distance). The value of S_g/P_n is determined from envelope level at the time $t=2t_p$ relative to

the calibration curve.

Figure 5.15. Results of discrimination of underground nuclear and chemical explosions and earthquakes separately by the Talgar and Zerenda stations.

Figure 5.16. Discrimination results using the two stations jointly.

Figure 5.17(a,b). Envelopes of records of earthquakes from the Caucasus region.

Figure 5.17(c,d). Envelopes of records of explosions in the Pre-Caspian depression region.

Figure 5.18. Discrimination results of underground explosions and earthquakes from the data of the Talgar and Zerenda stations.

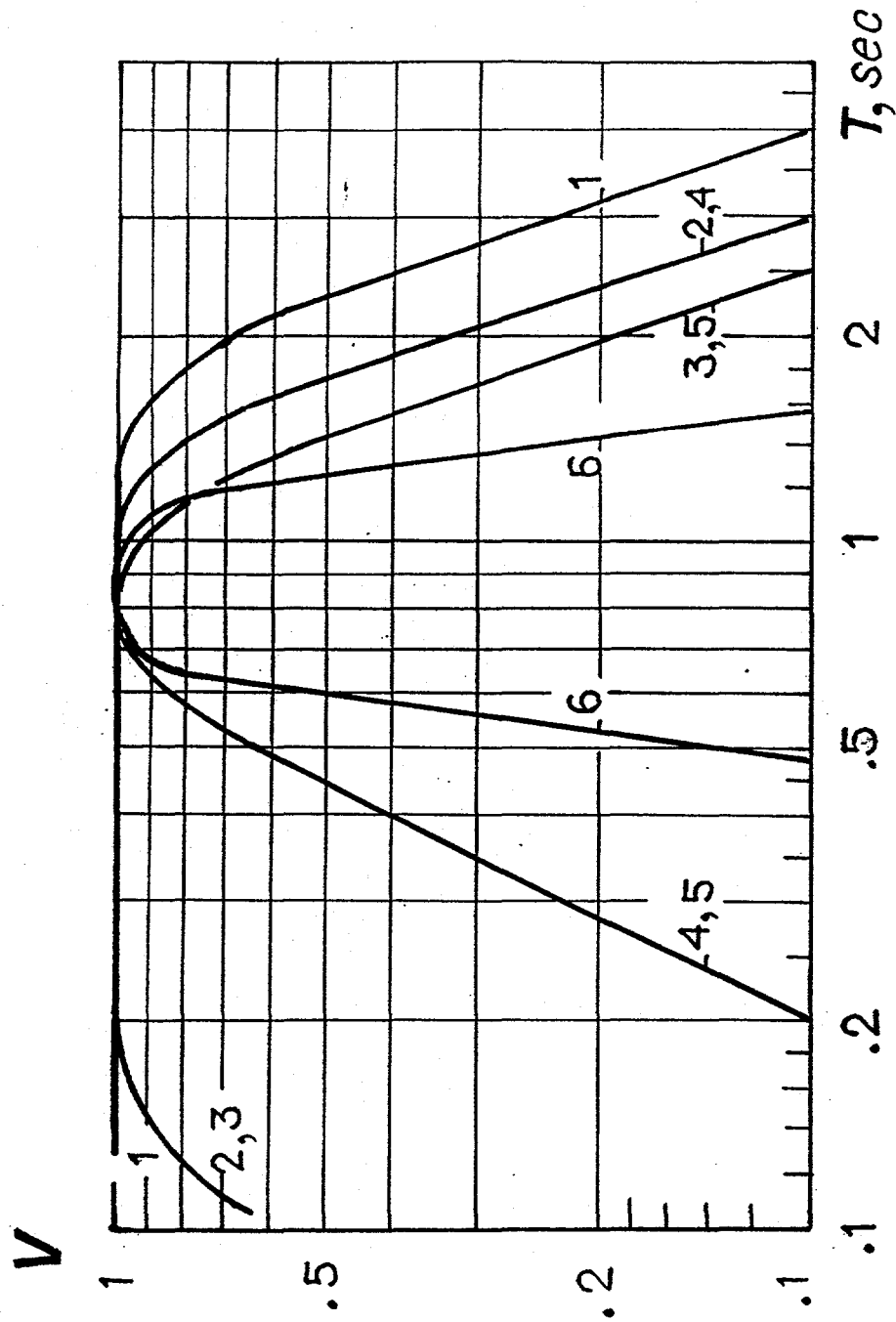


Fig. 1.1

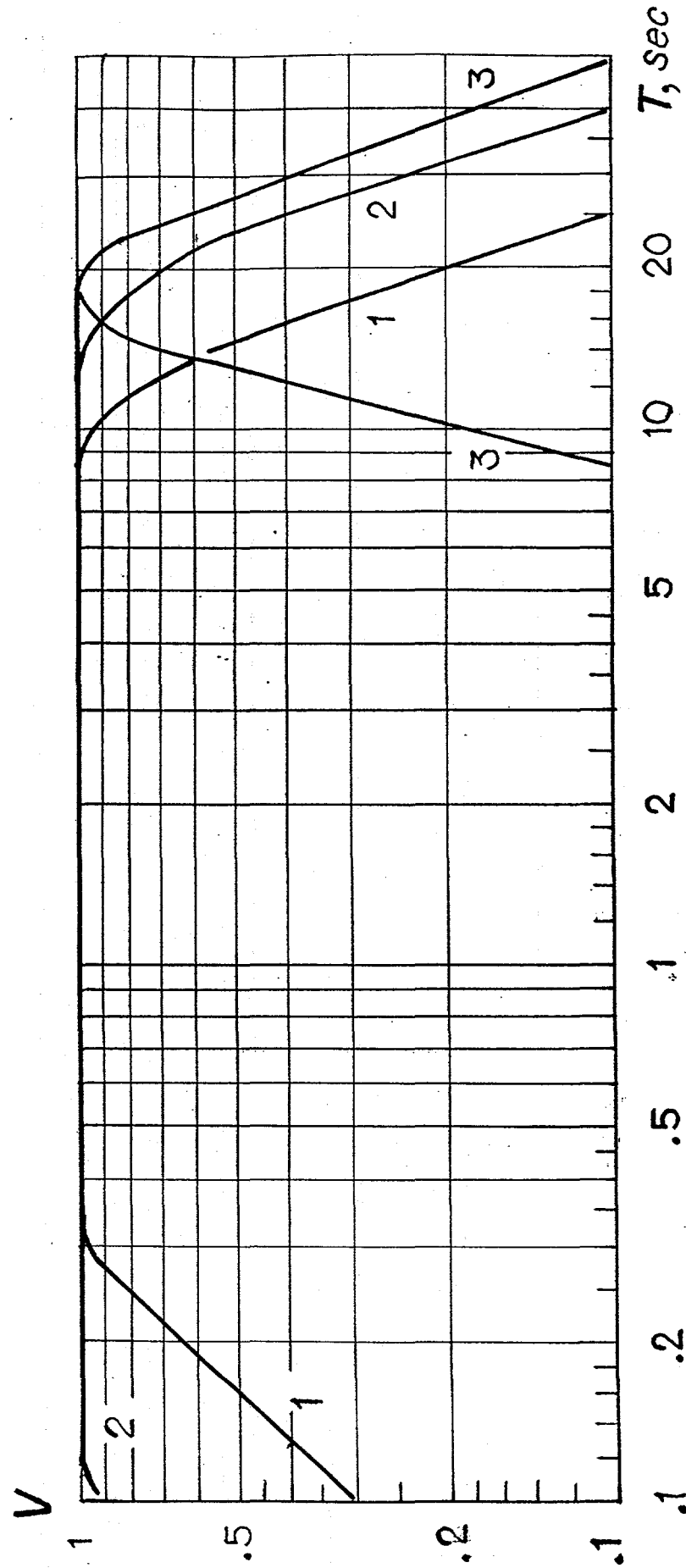


Fig. 1.2

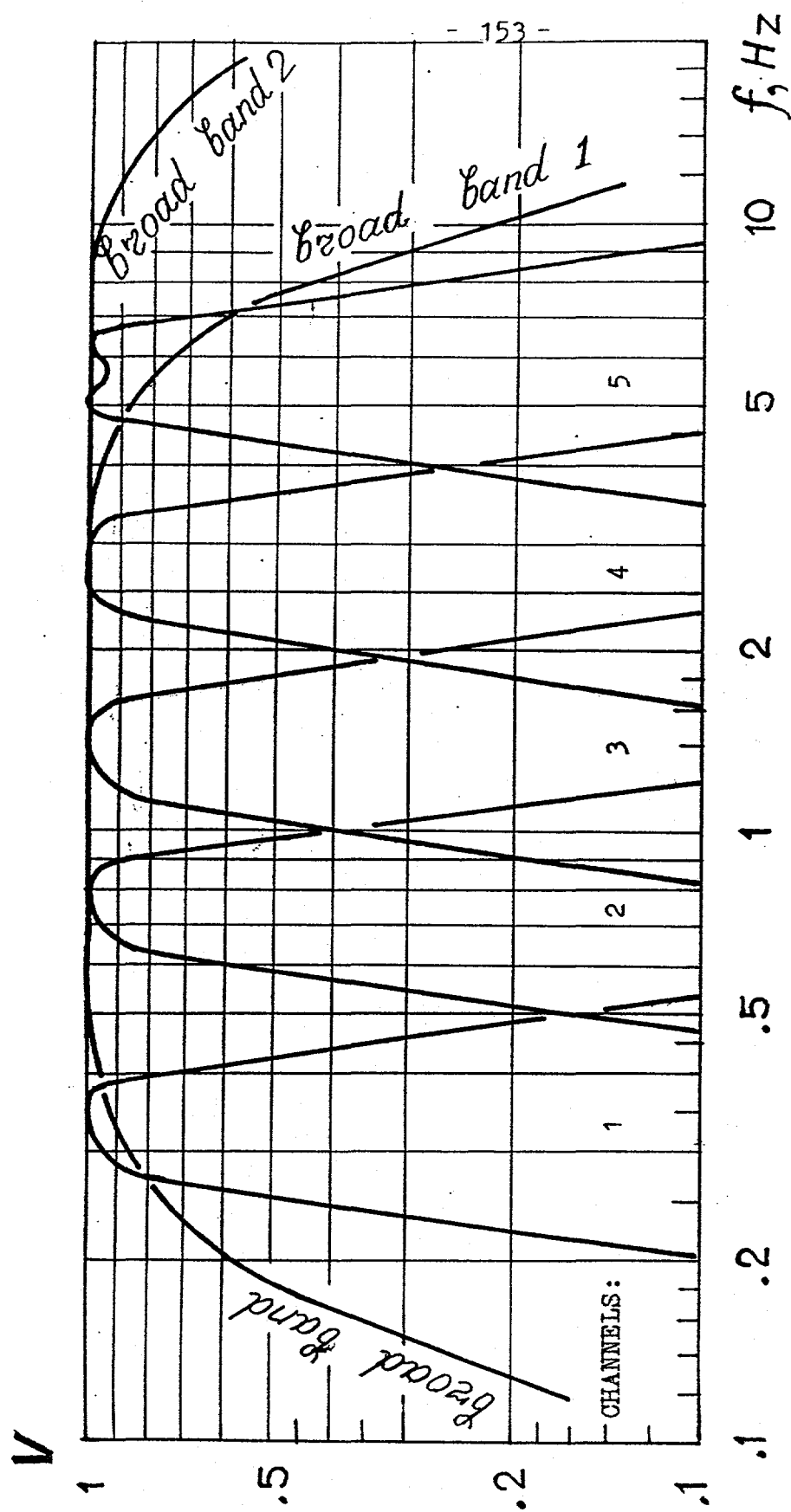


Fig. 1.3

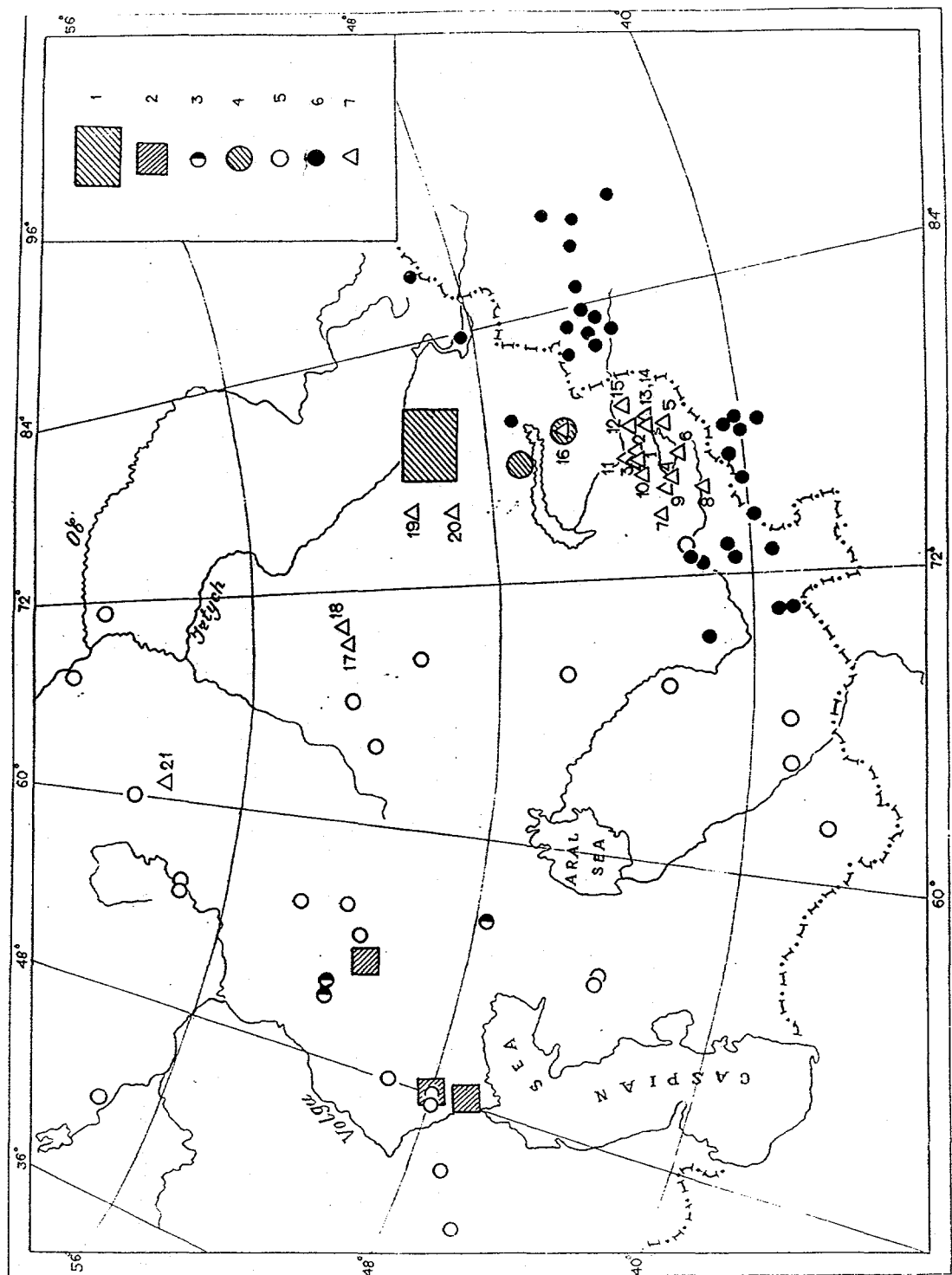


Fig. 1.4

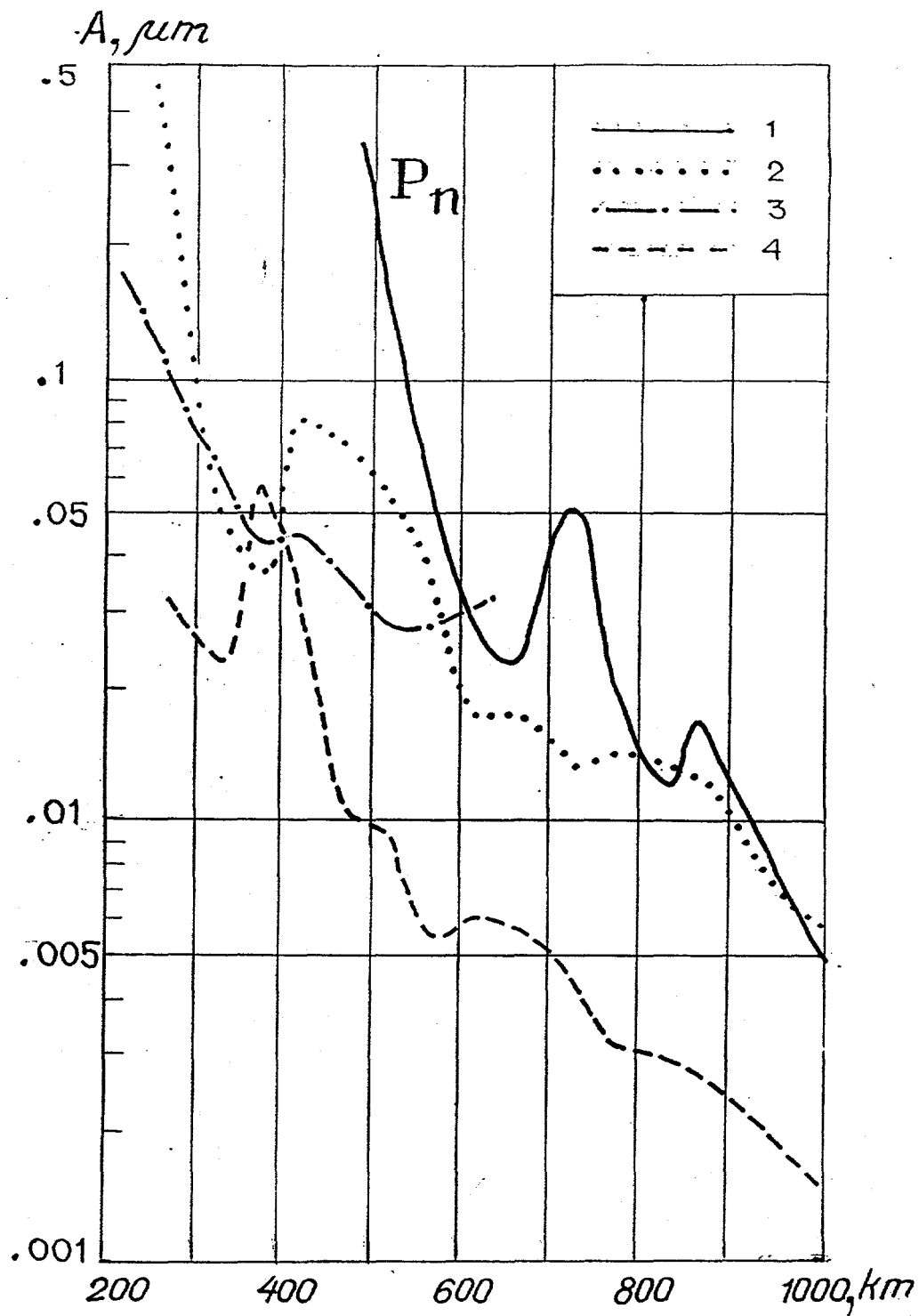


Fig. 2.1

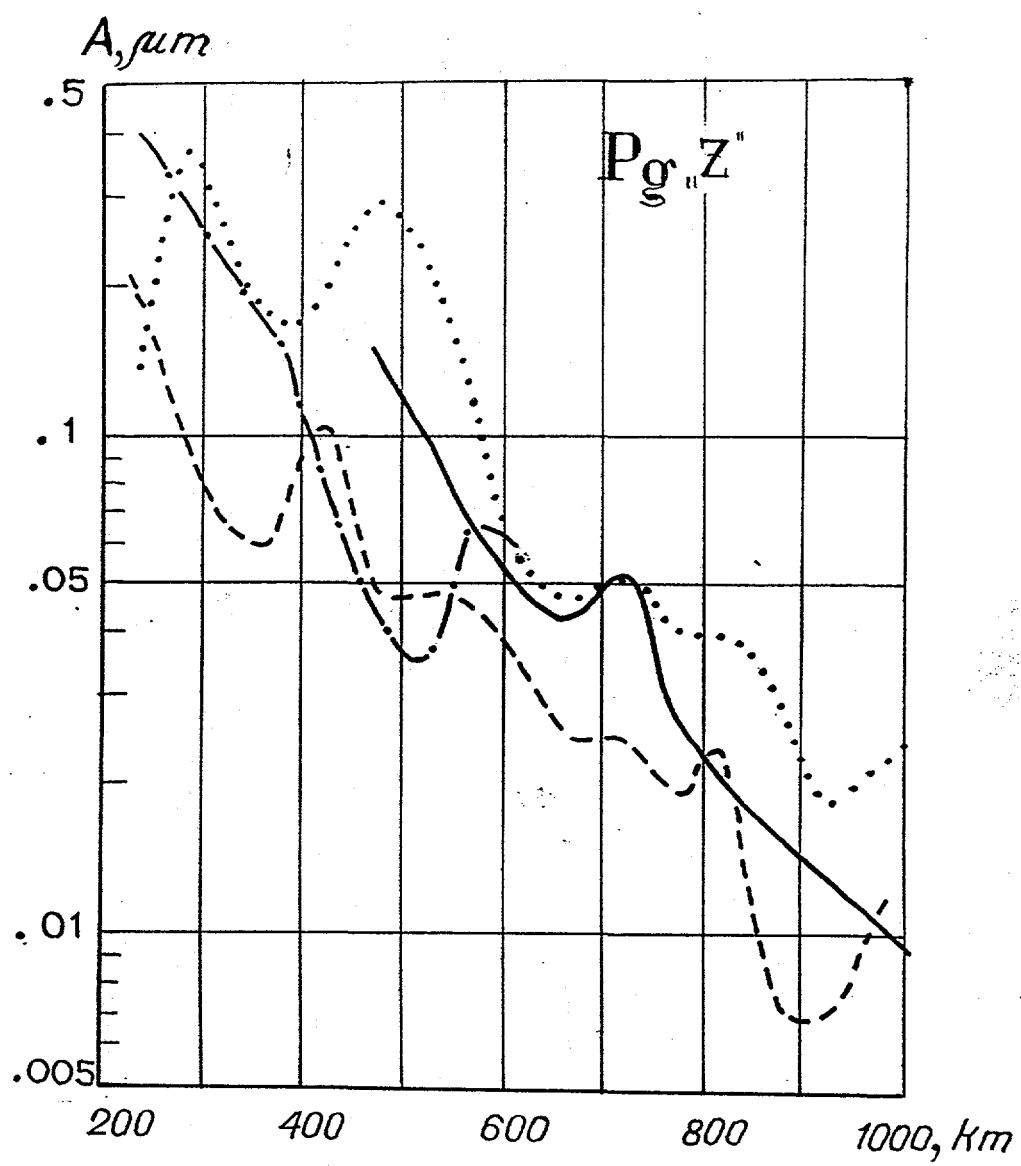


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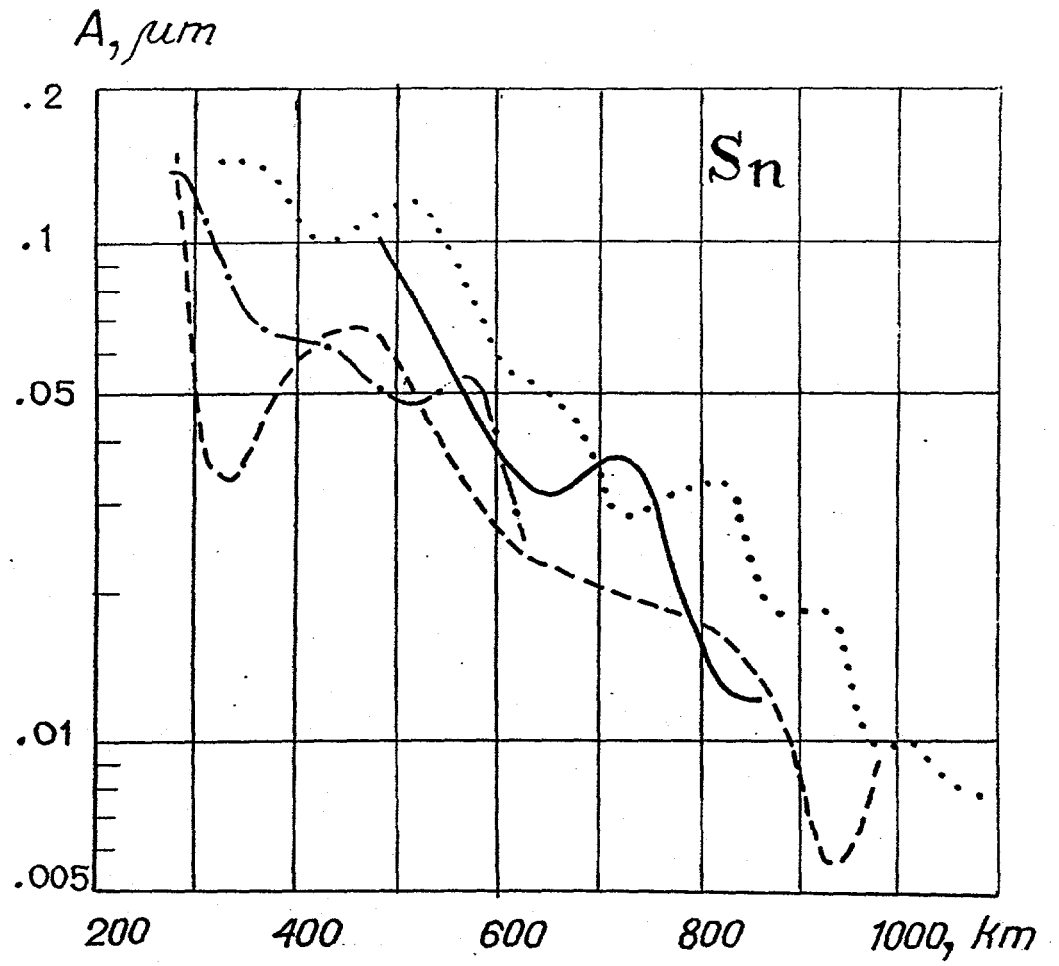


Fig. 2.3

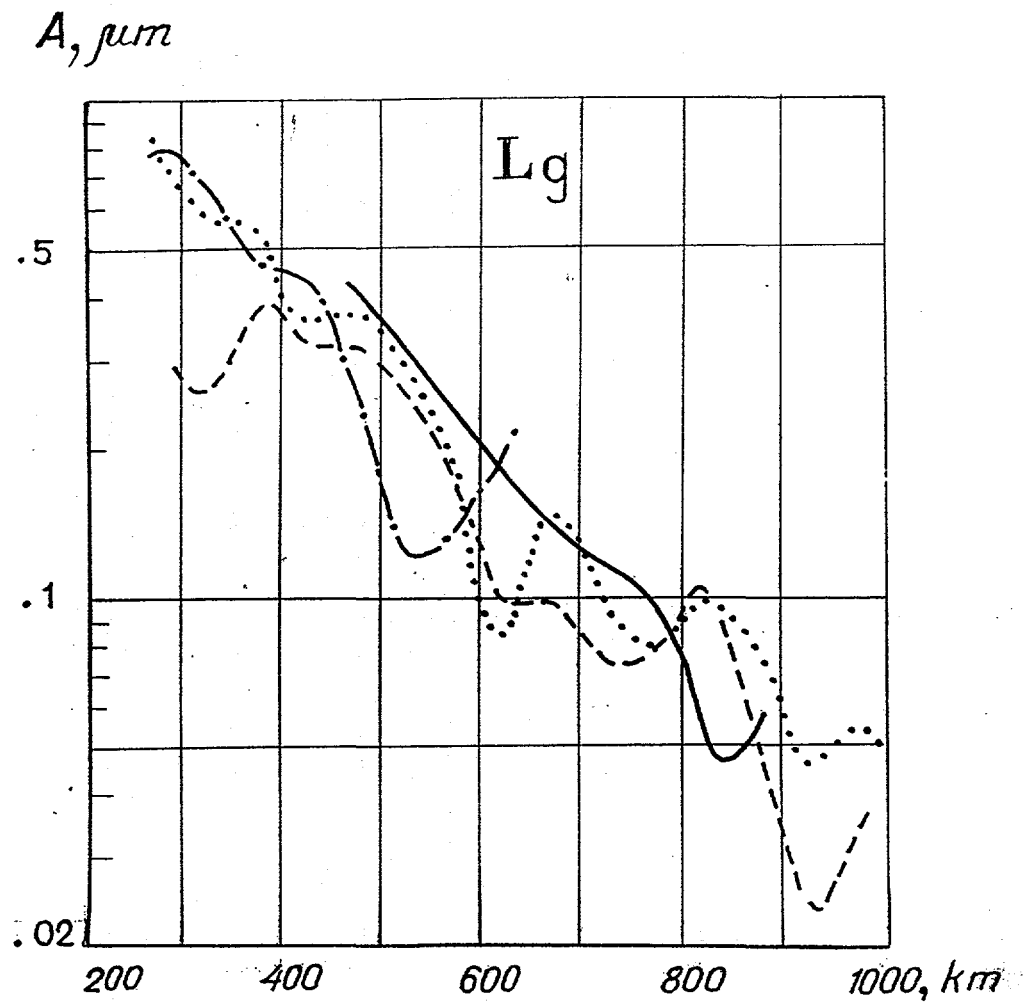


Fig. 2.4

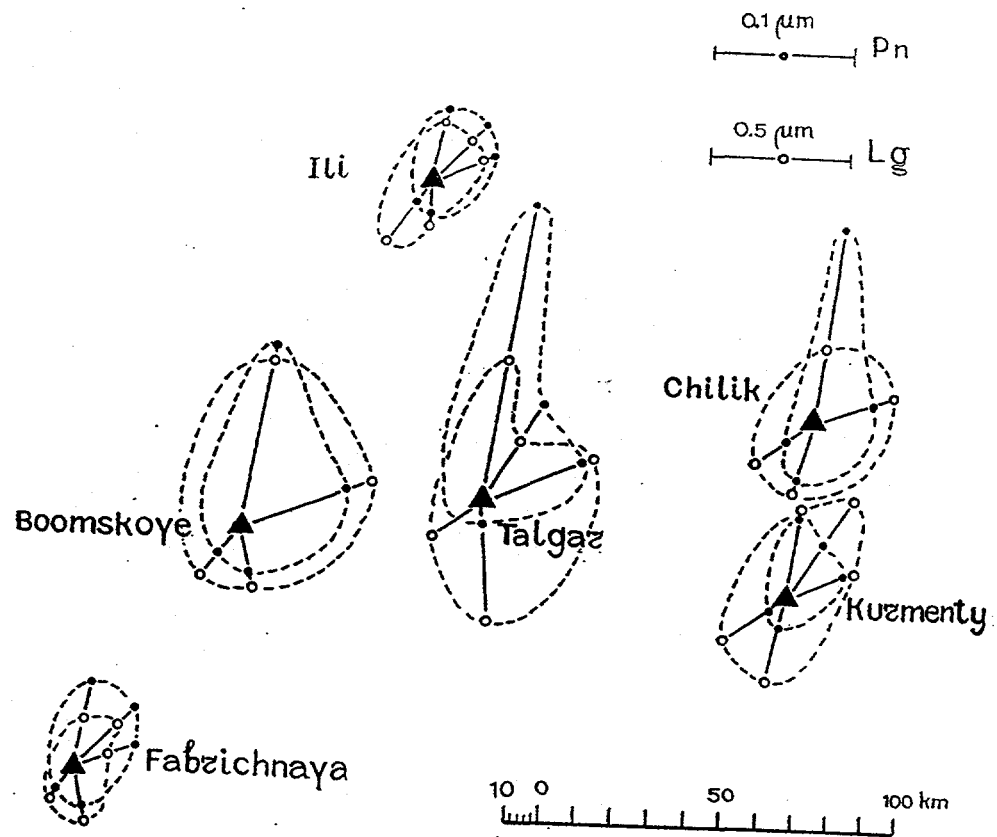


Fig. 2.5

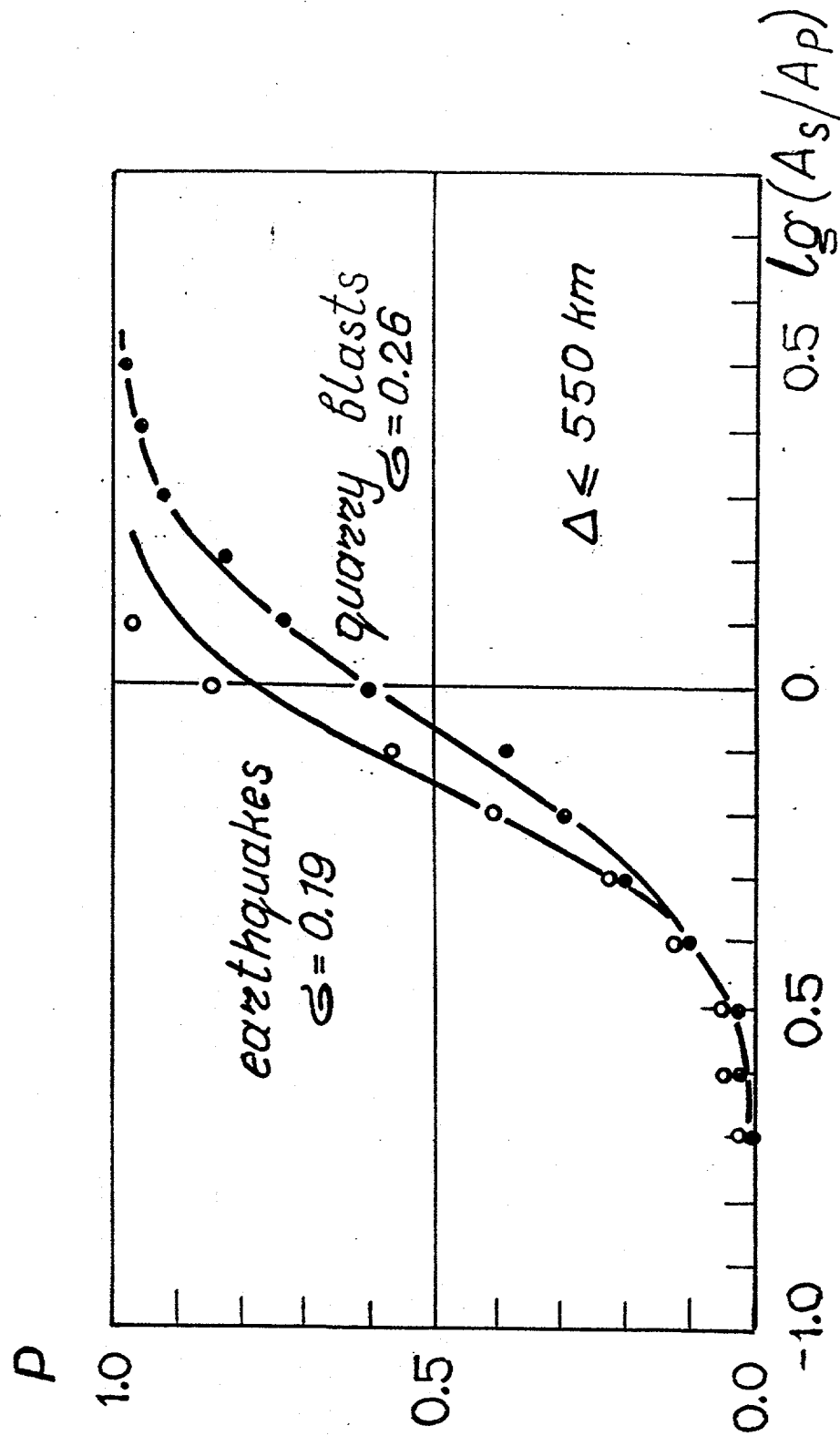


Fig. 3.1

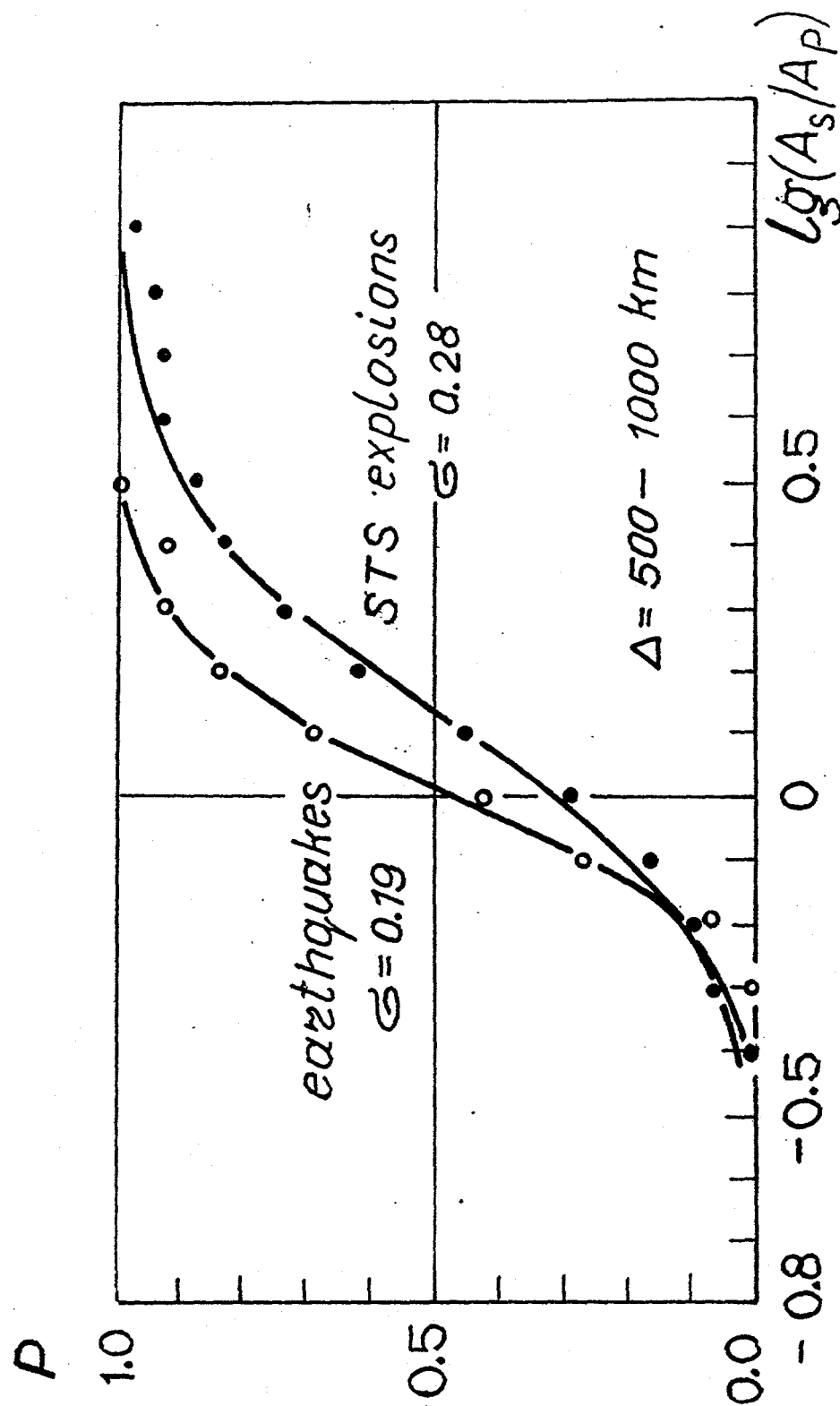


Fig. 3.2

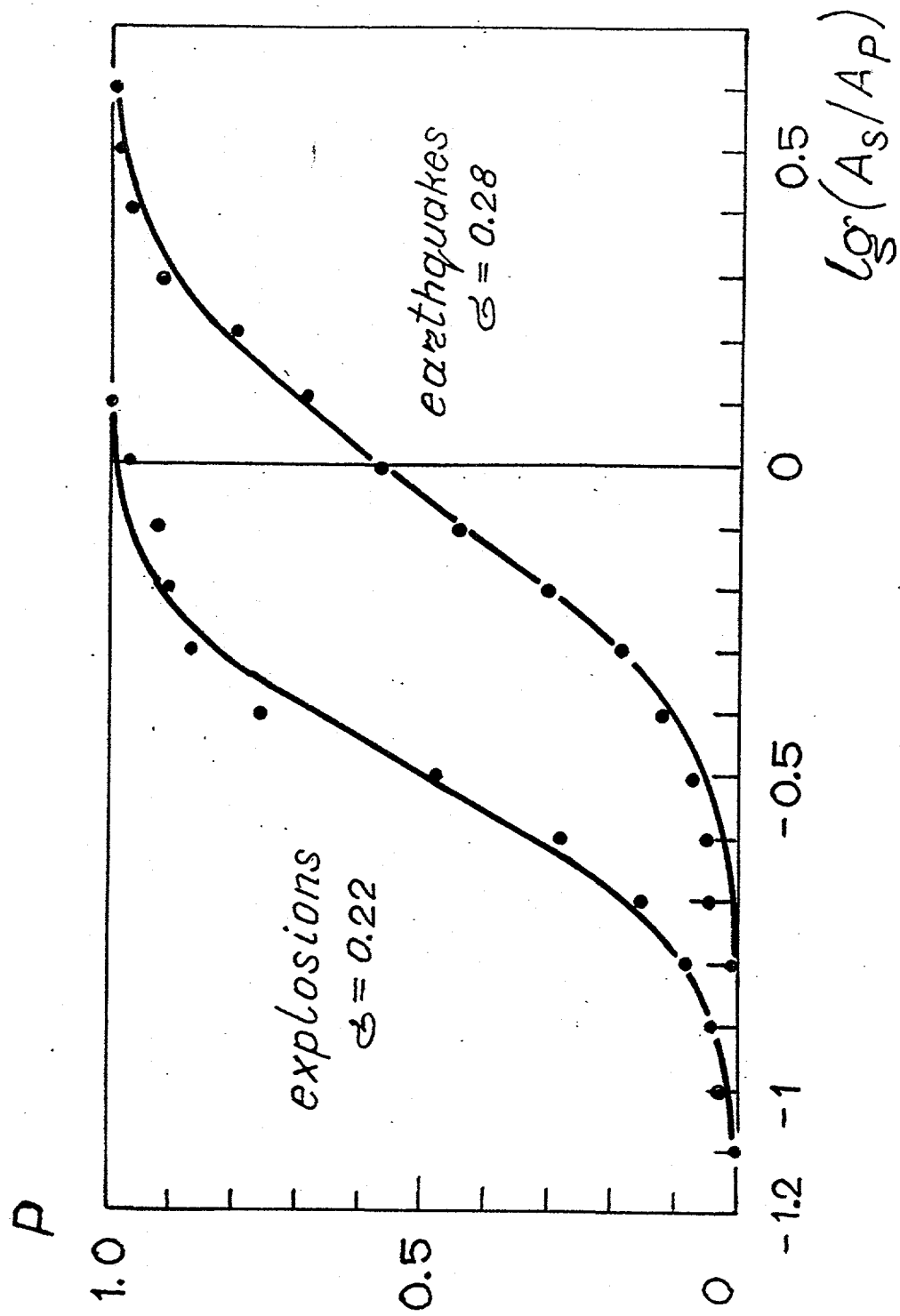


Fig. 3.3

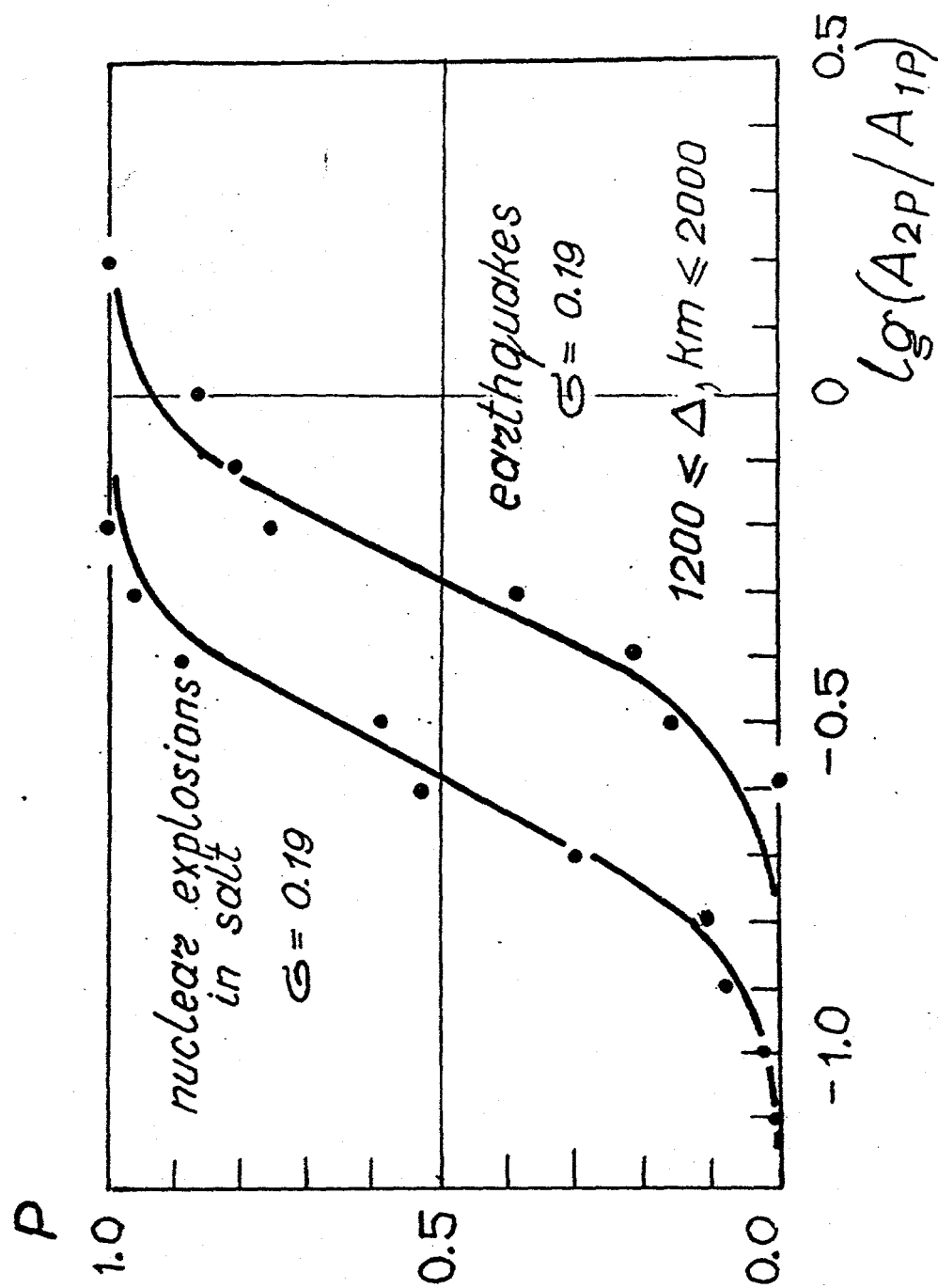


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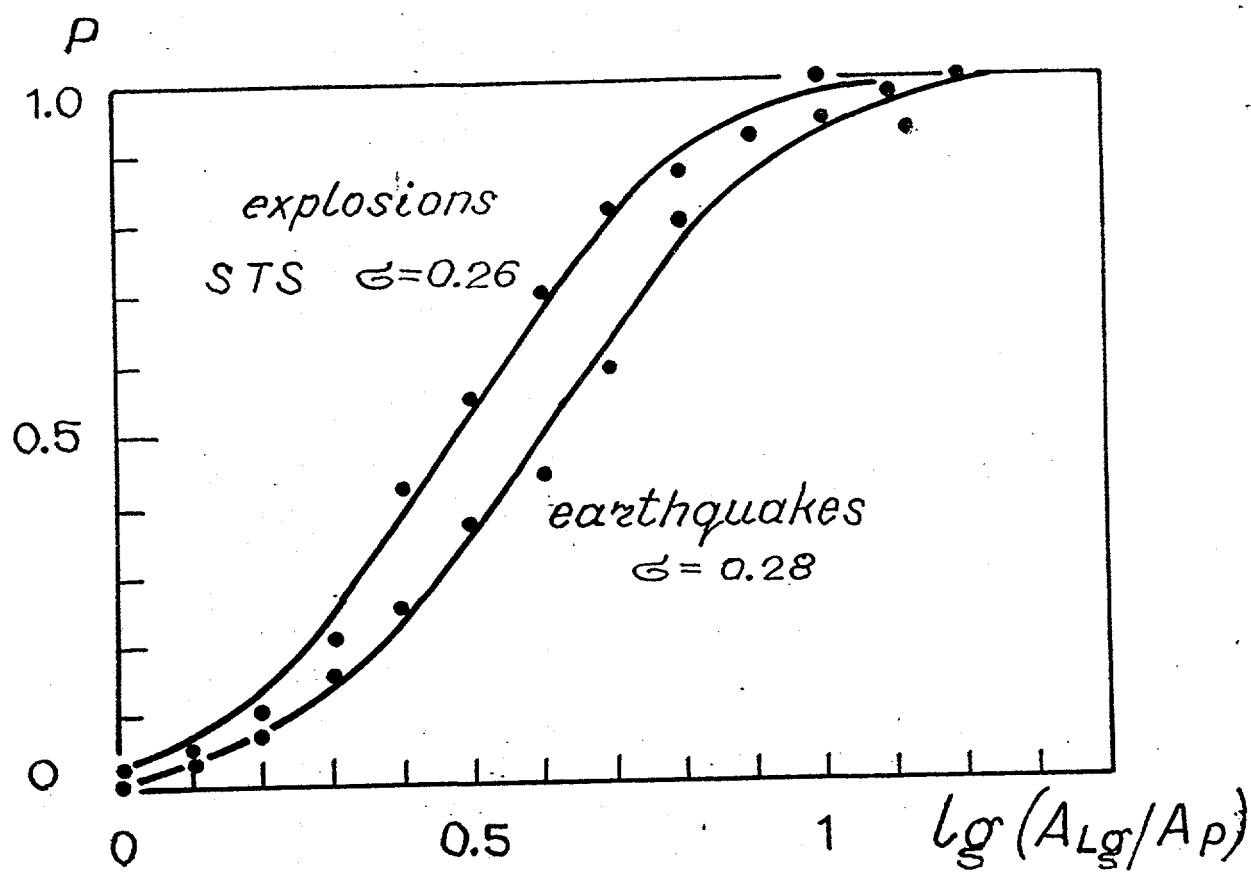


Fig. 3.5

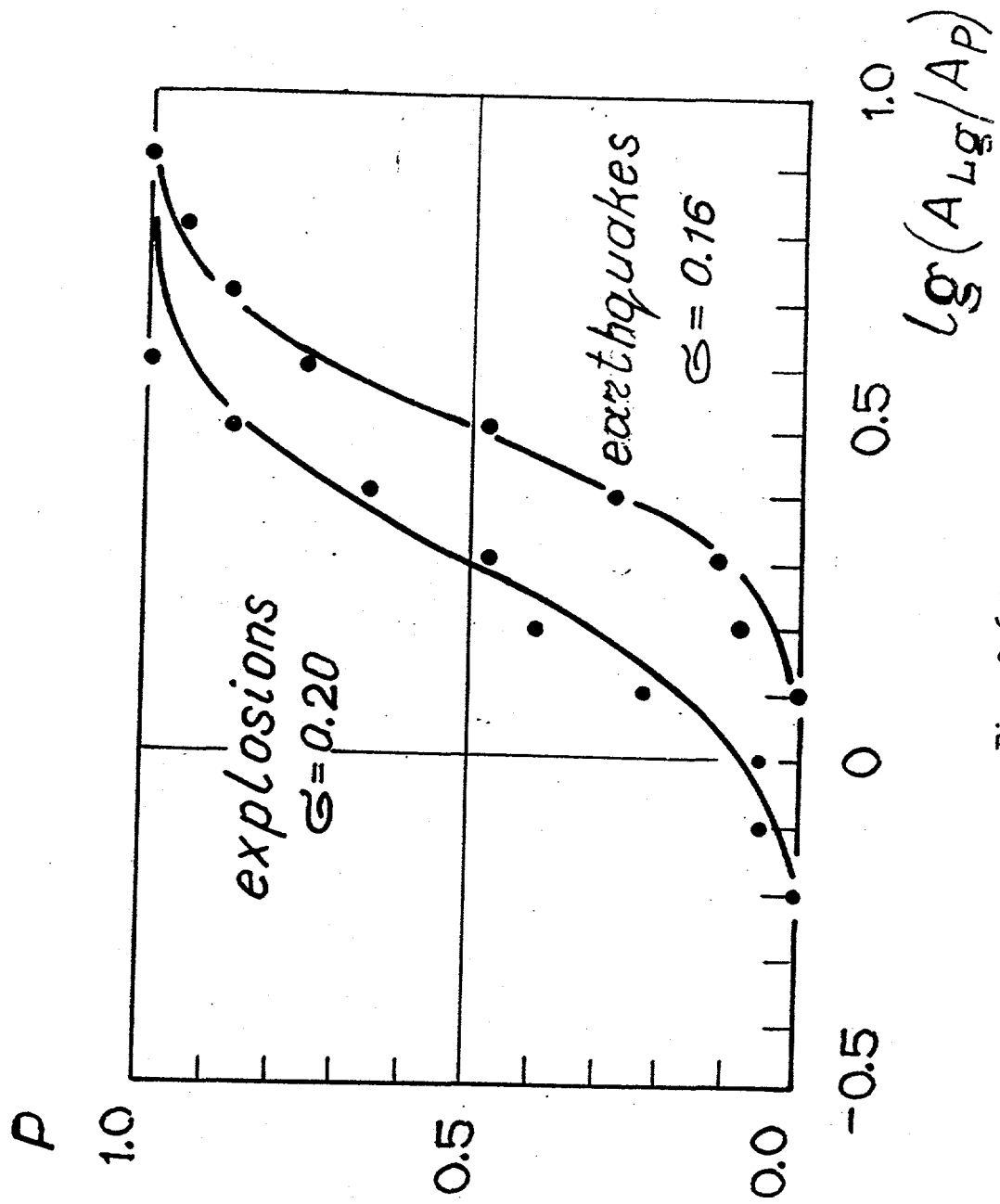


Fig. 3.6a

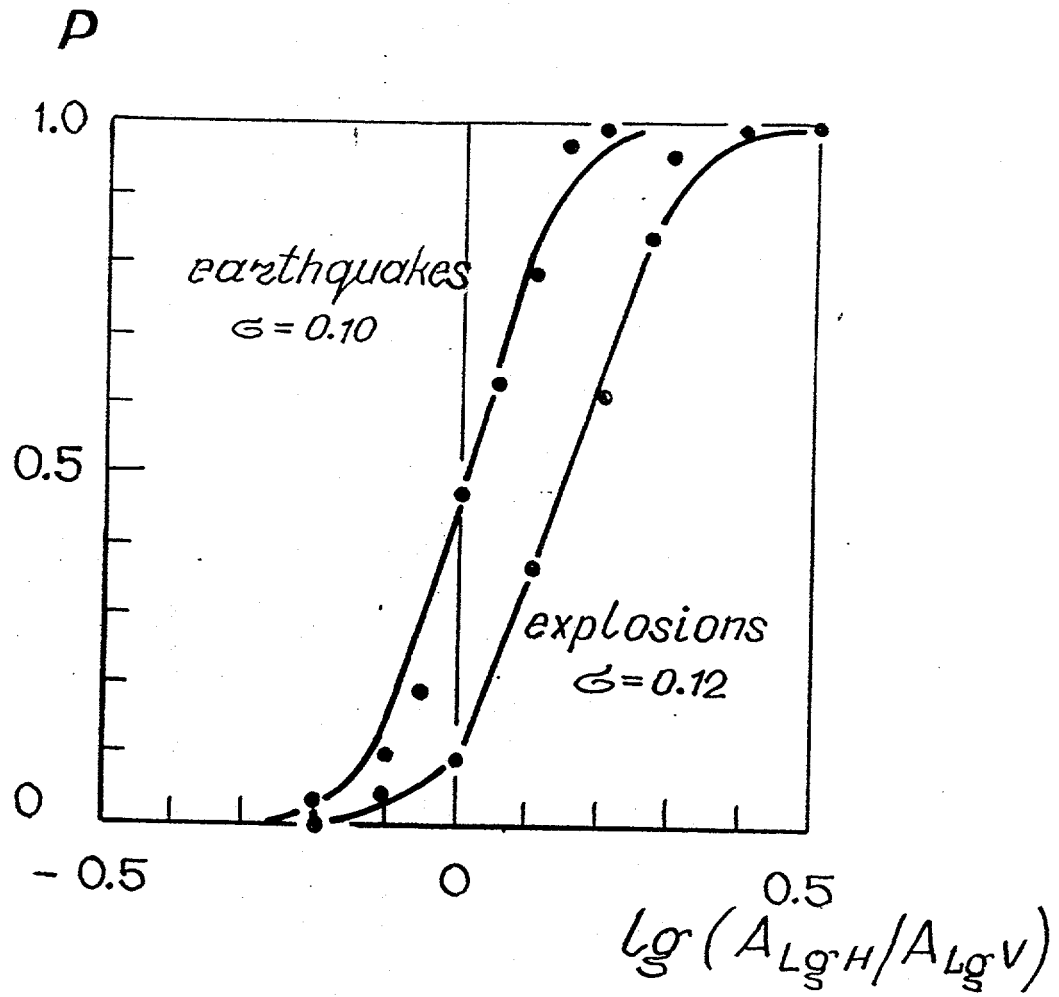


Fig. 3.66

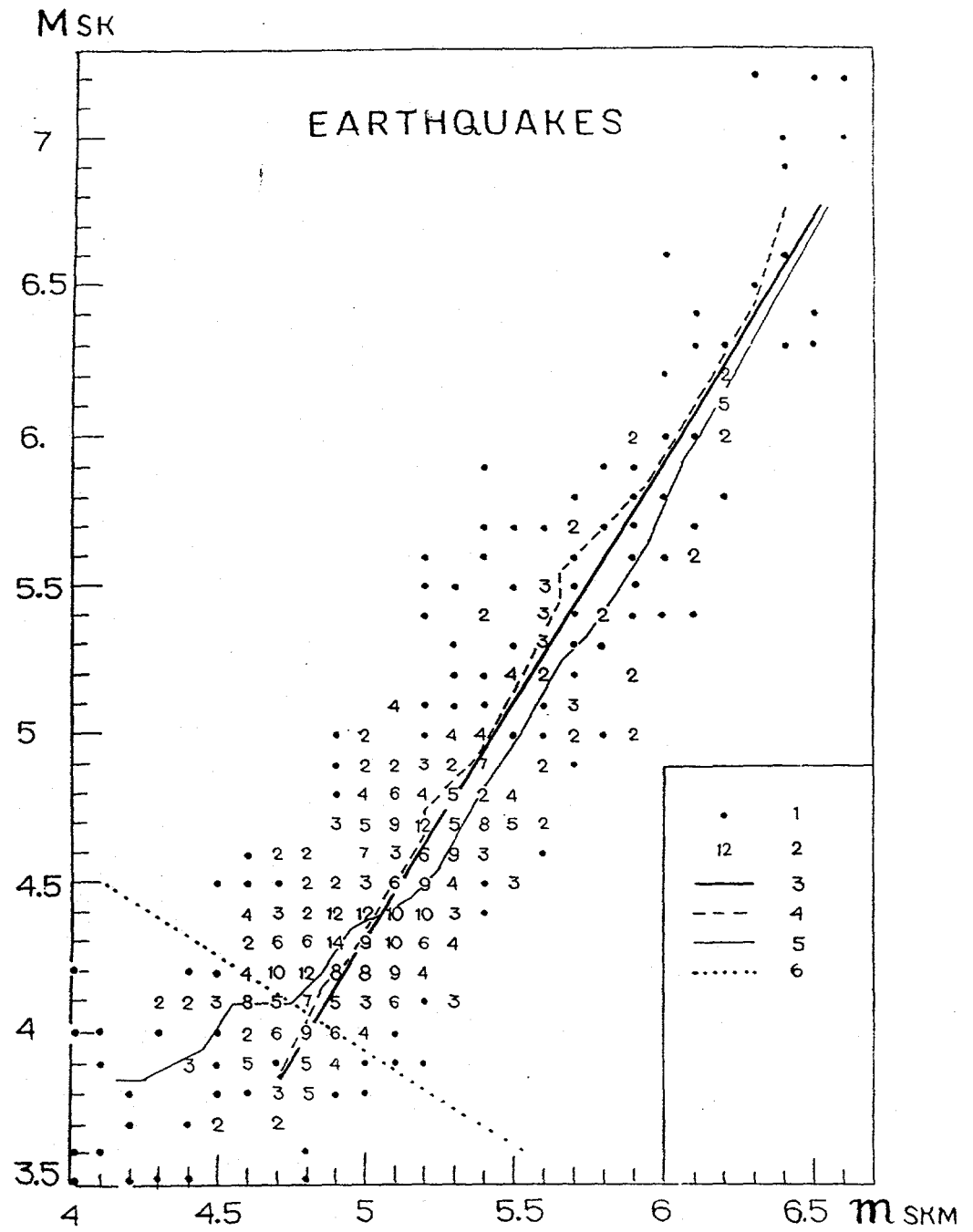


Fig. 3.7

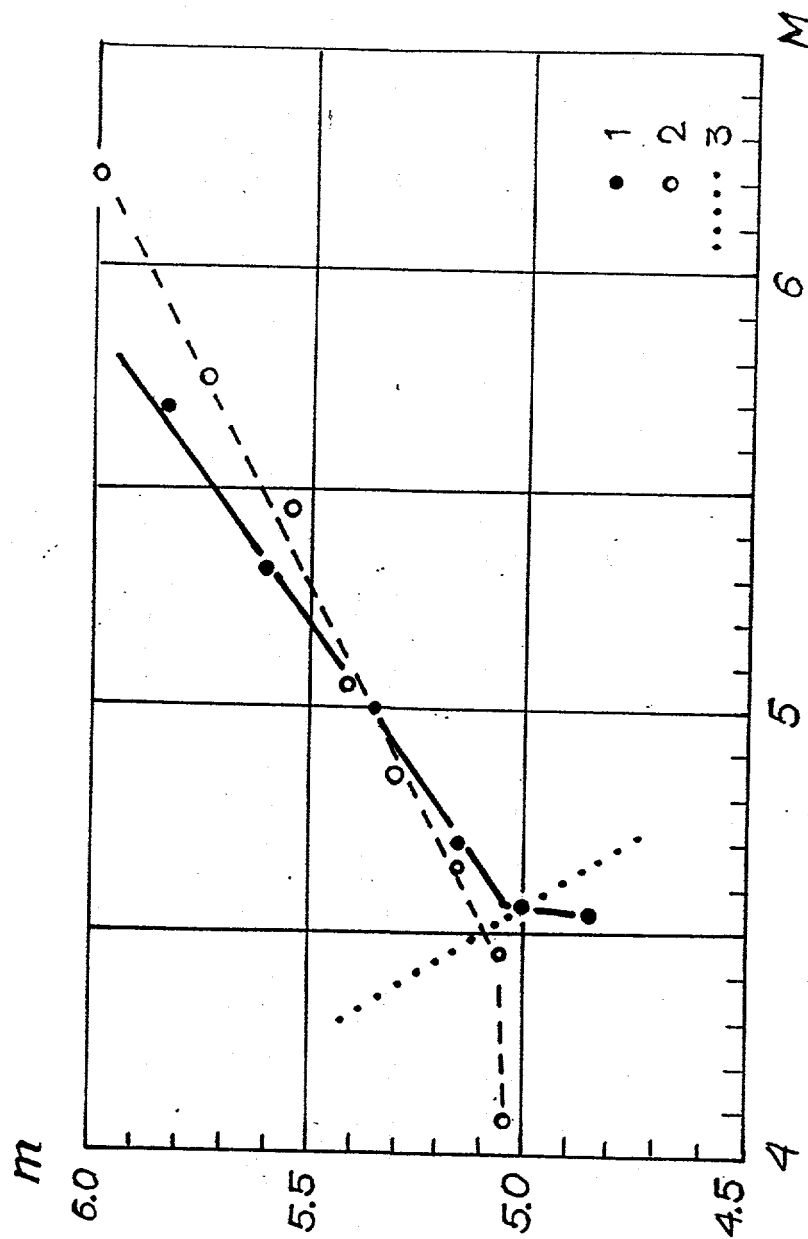


Fig. 3.8

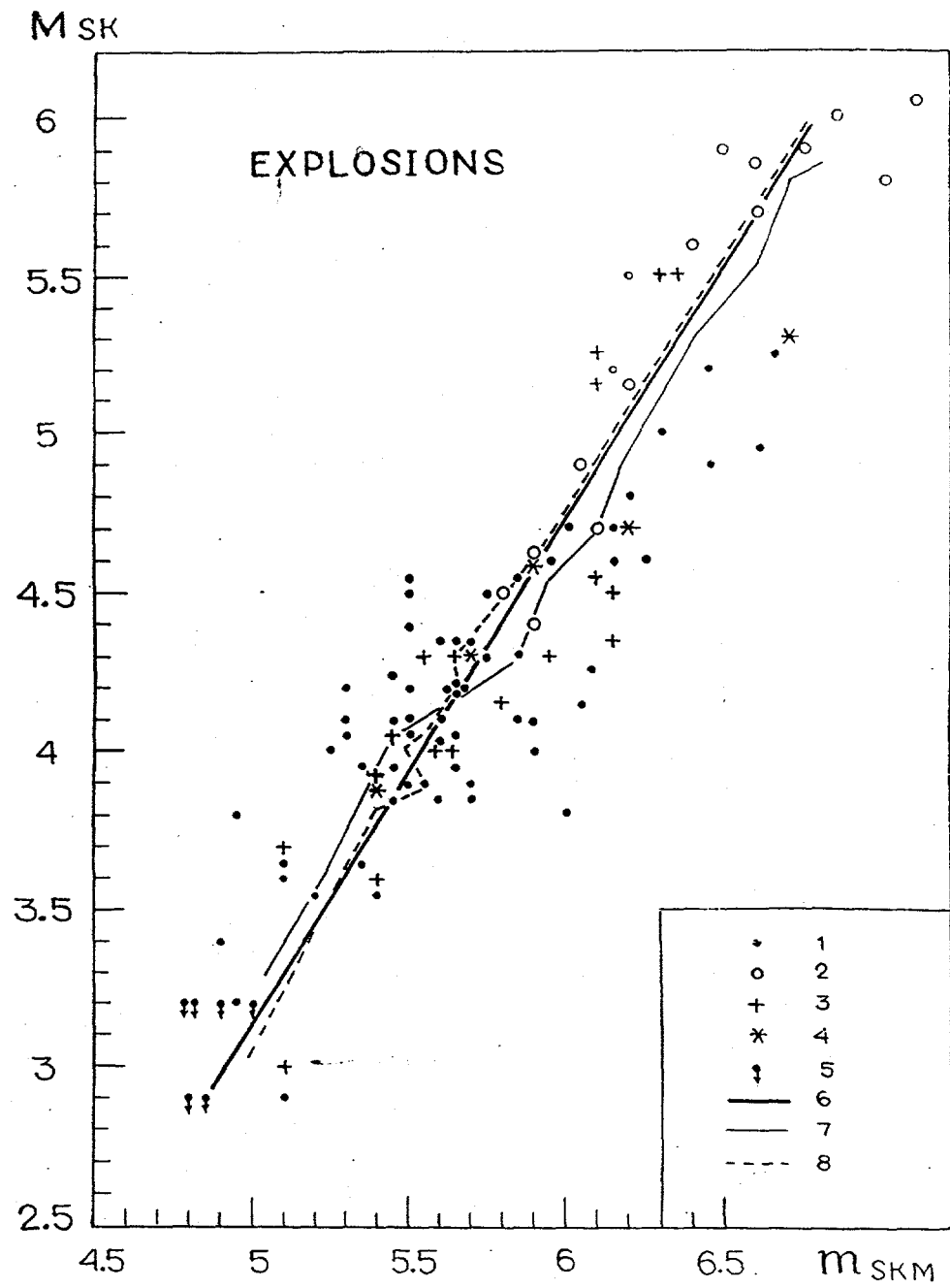


Fig. 3.9

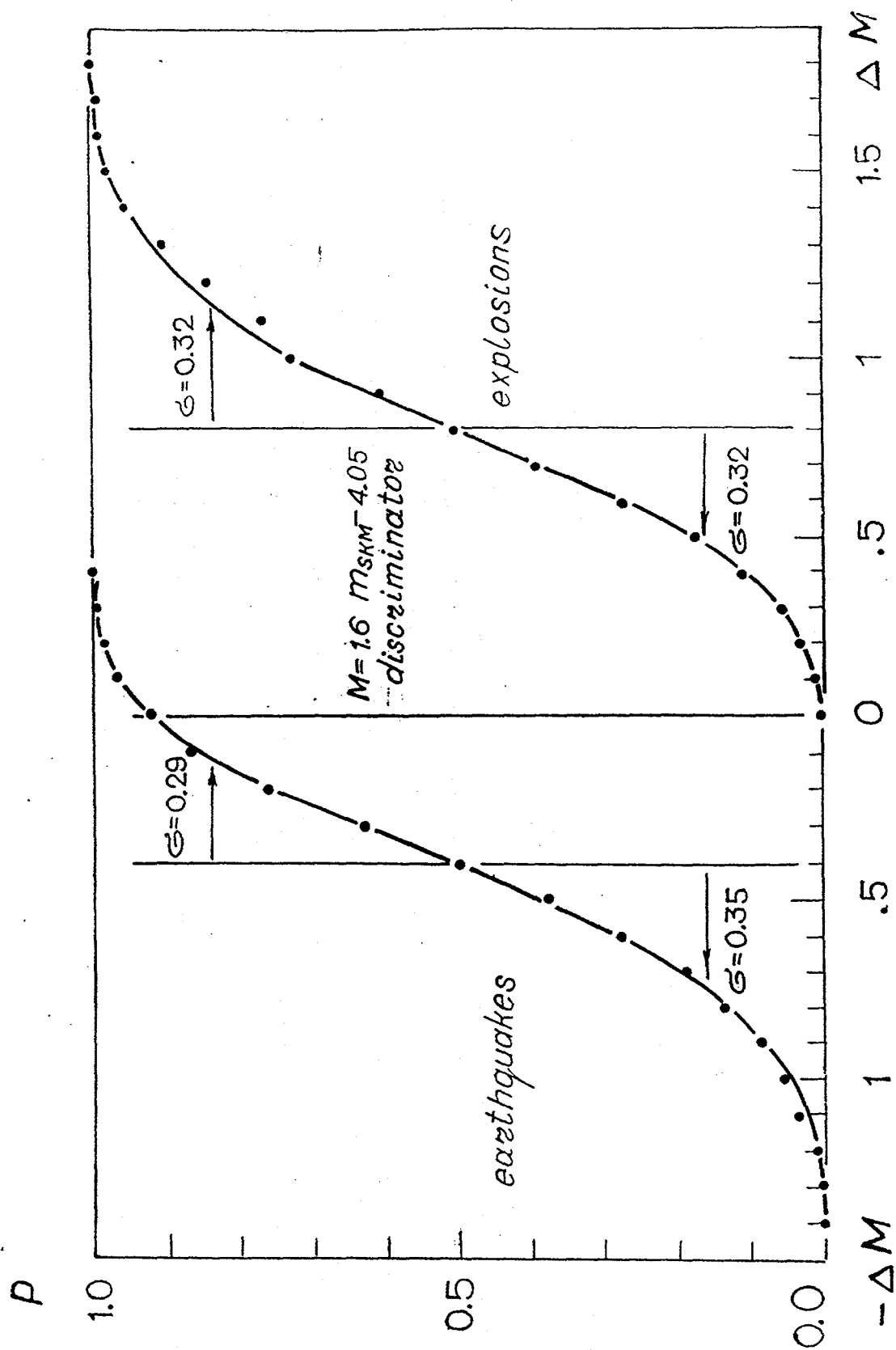


Fig. 3.10

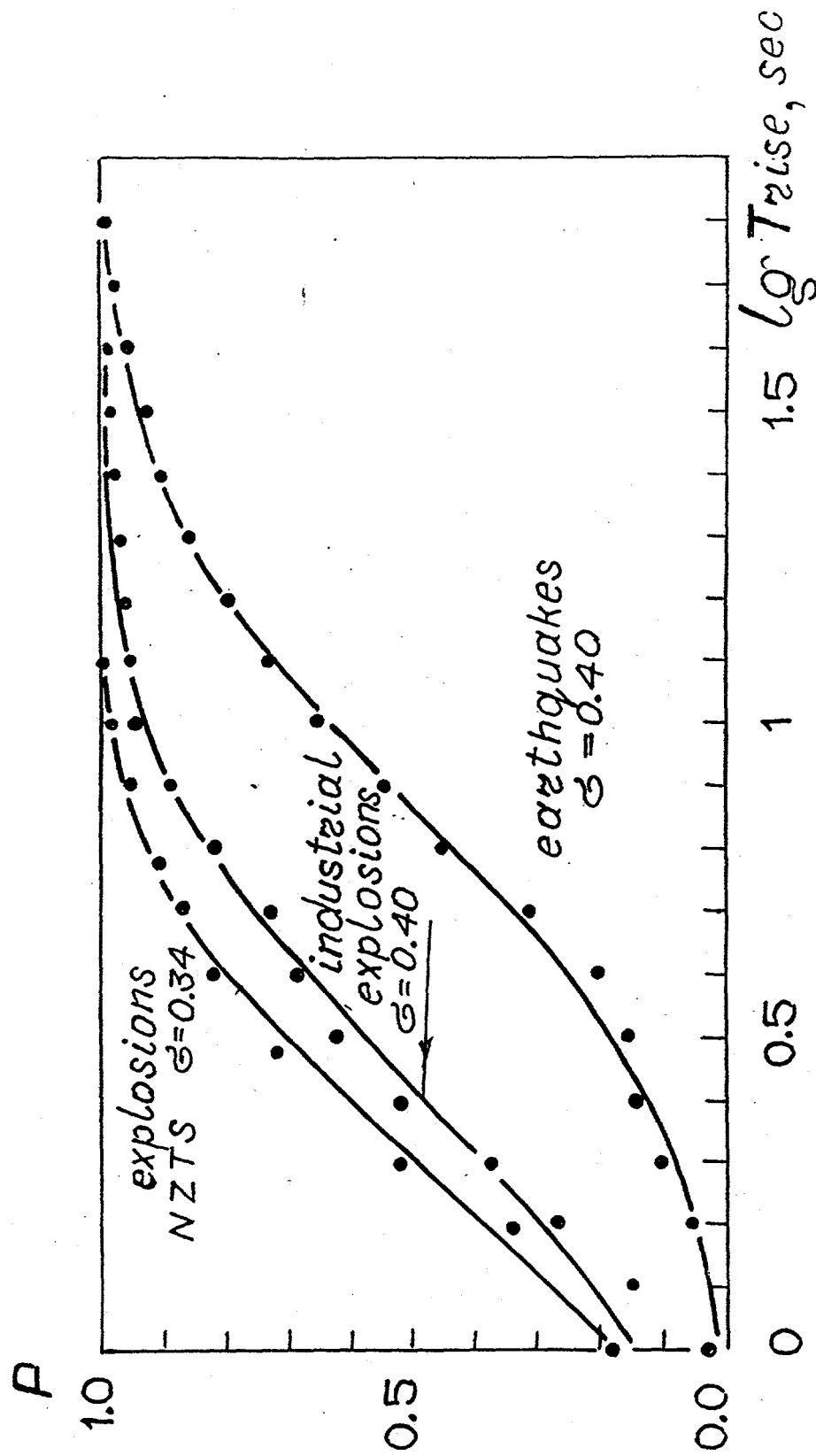


Fig. 3.11

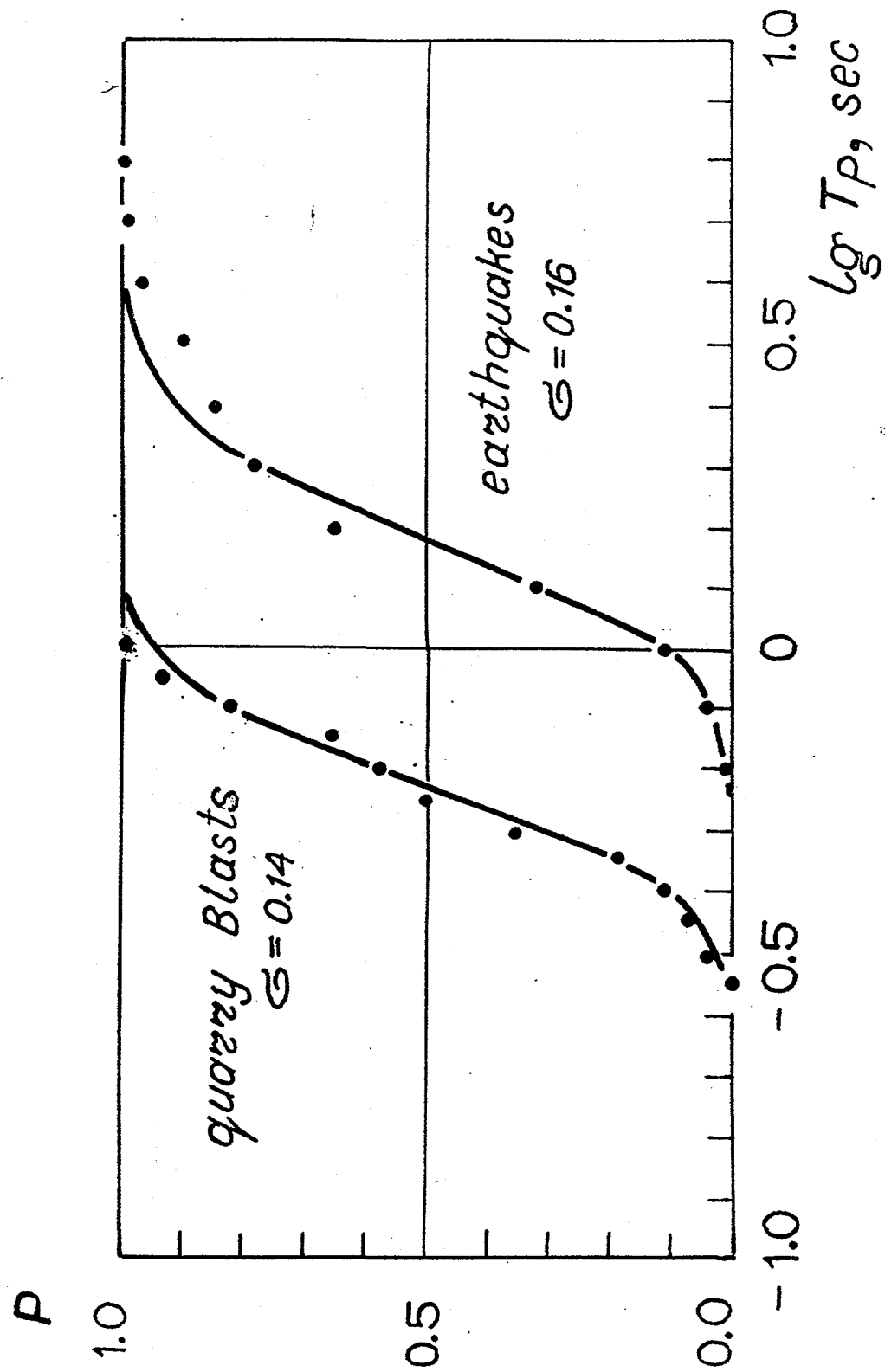


Fig. 4.1

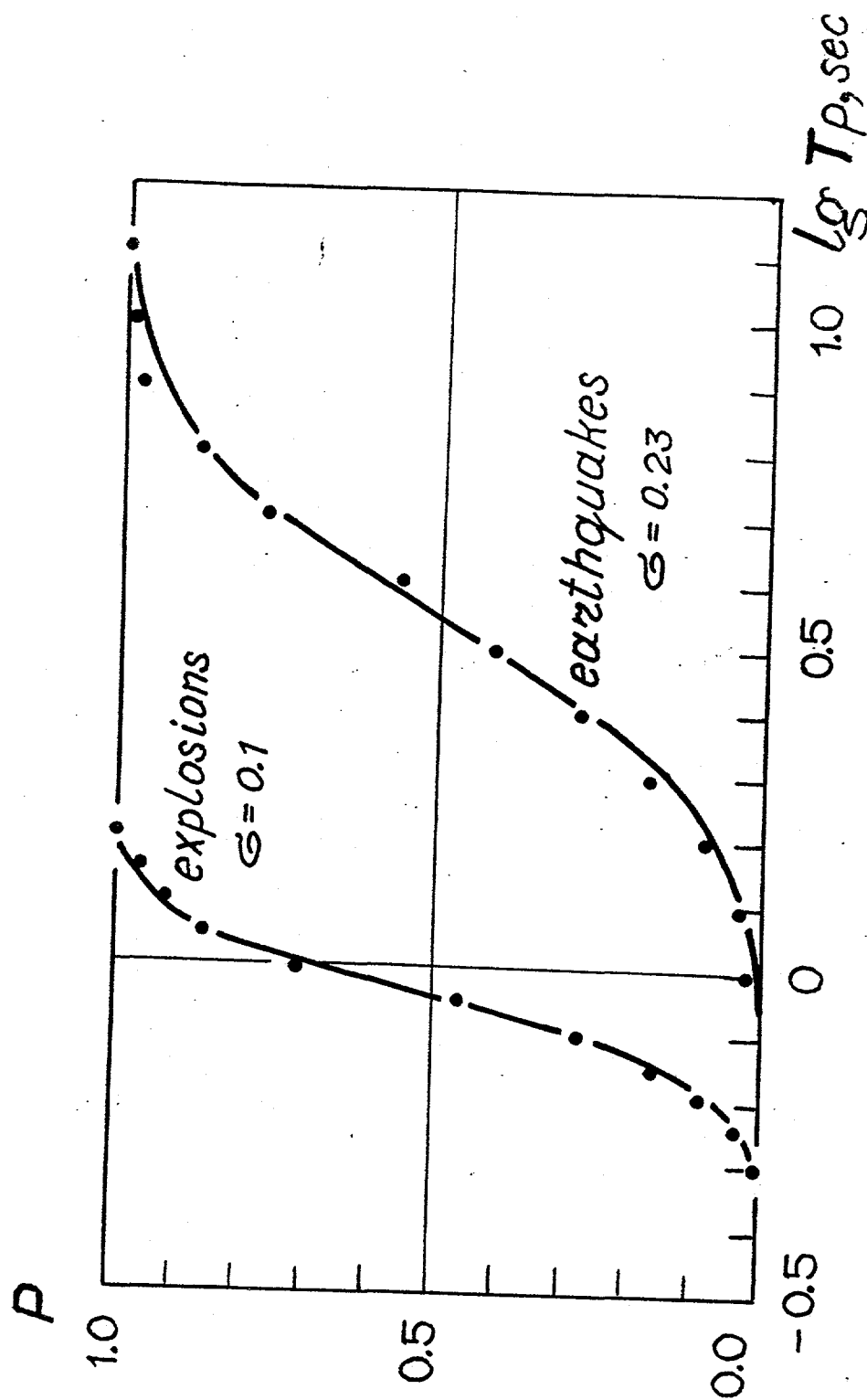


Fig. 4.2

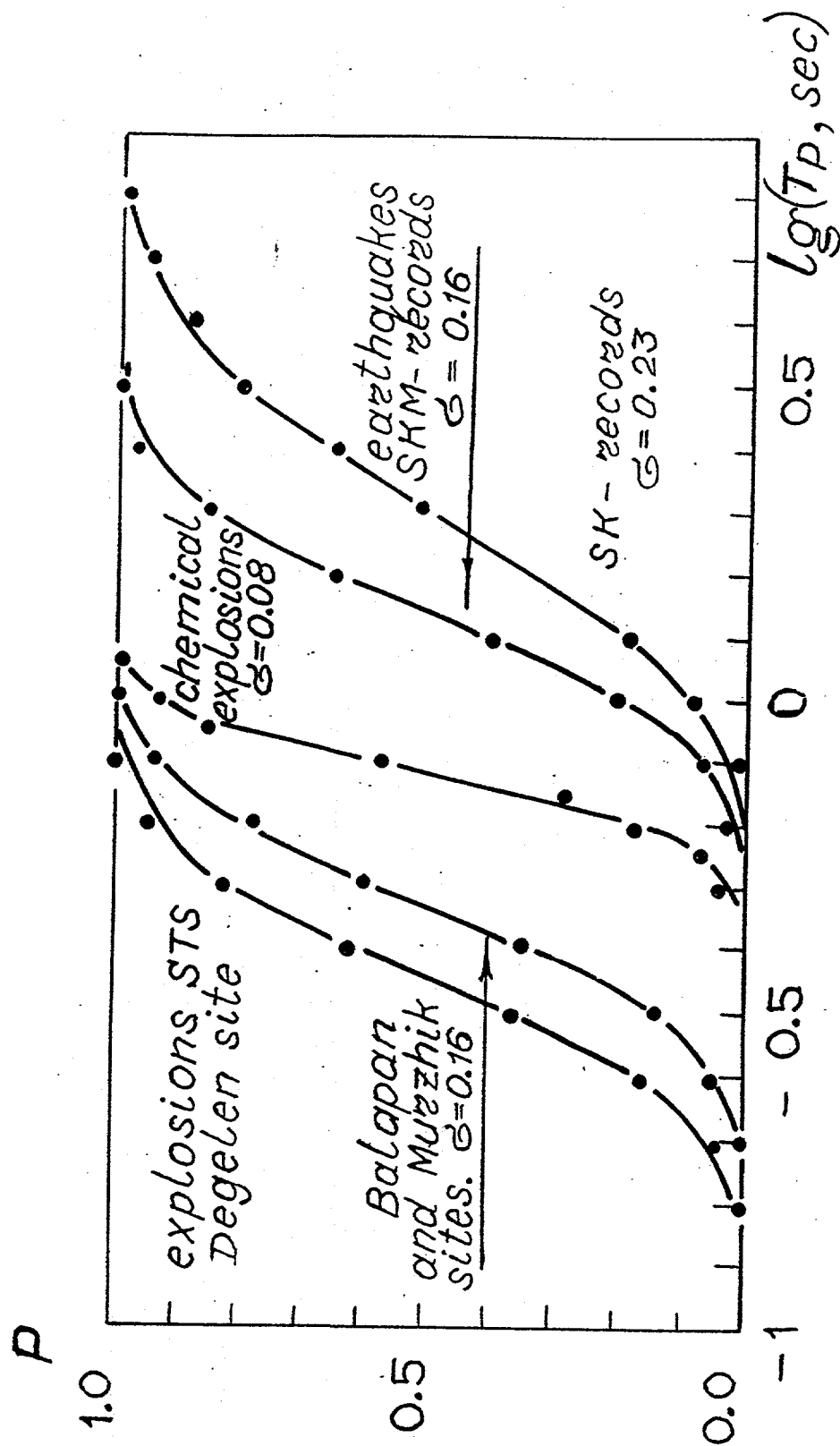


Fig. 4.3a

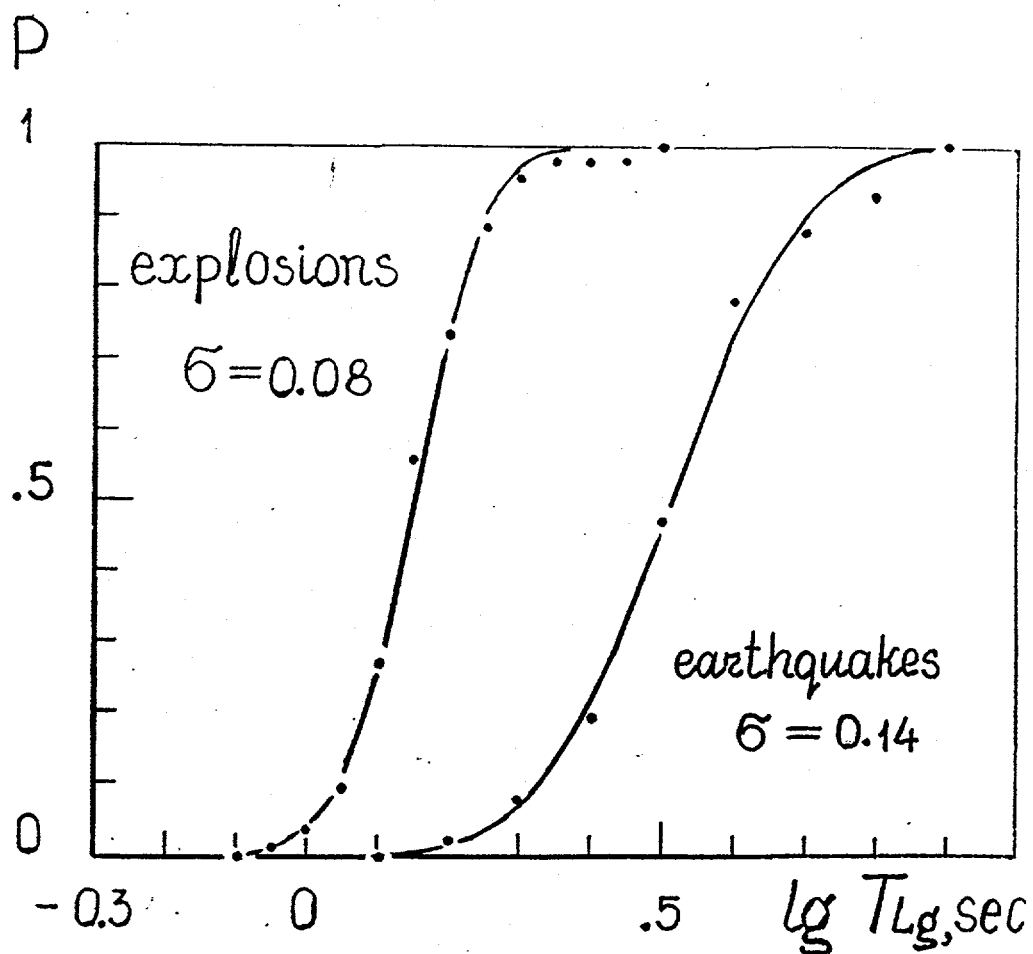


Fig. 4.36

$$\lg y = c(\lg A_{i+1} - \lg A_i)$$

$$c = 1/(\lg f_{i+1} - \lg f_i) = \text{const}$$

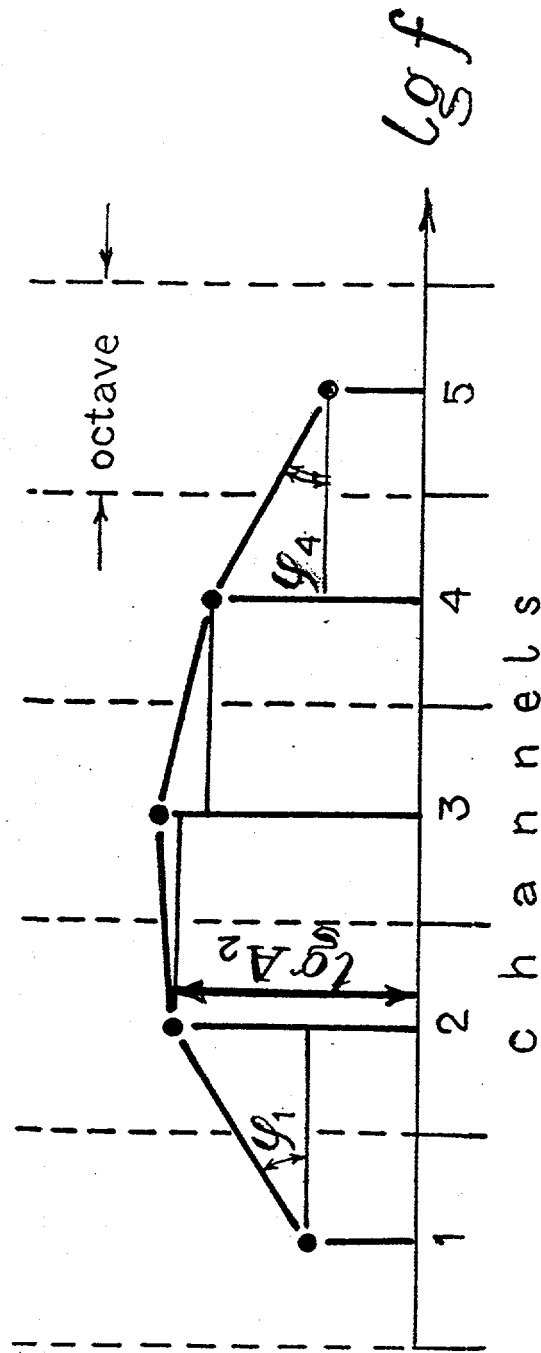


Fig. 4.4

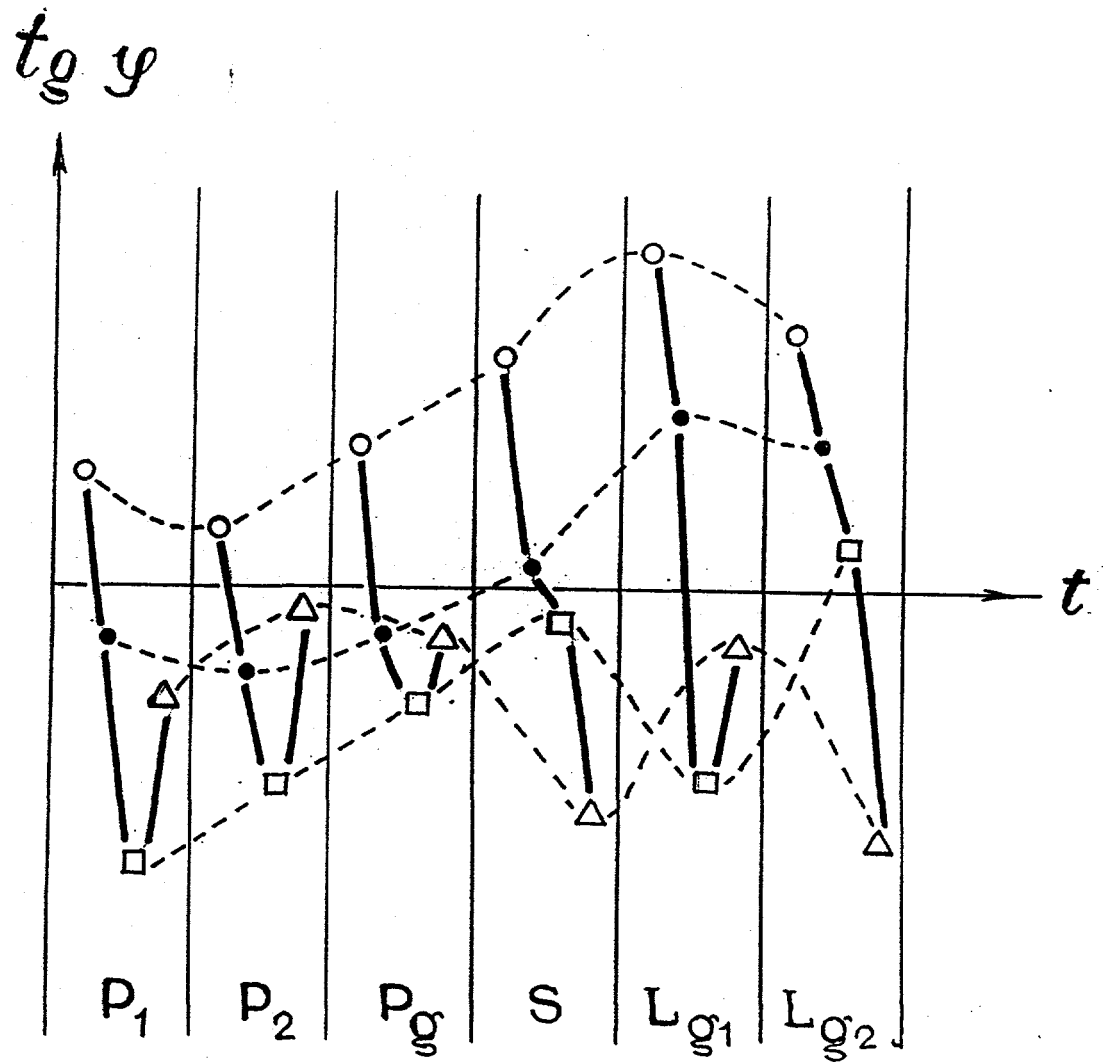


Fig. 4.5

$\lg A, nm/sec$

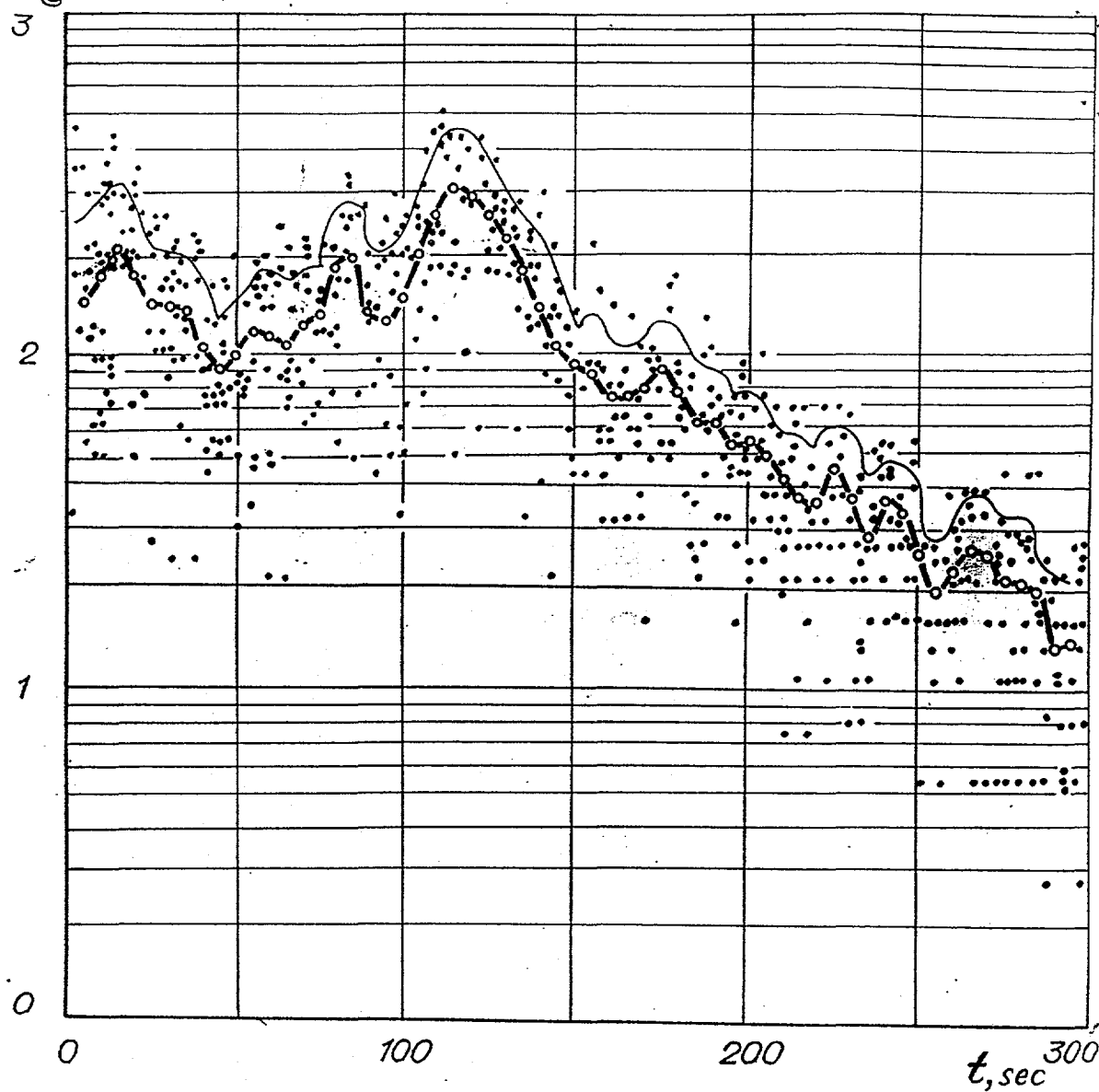


Fig. 4.6

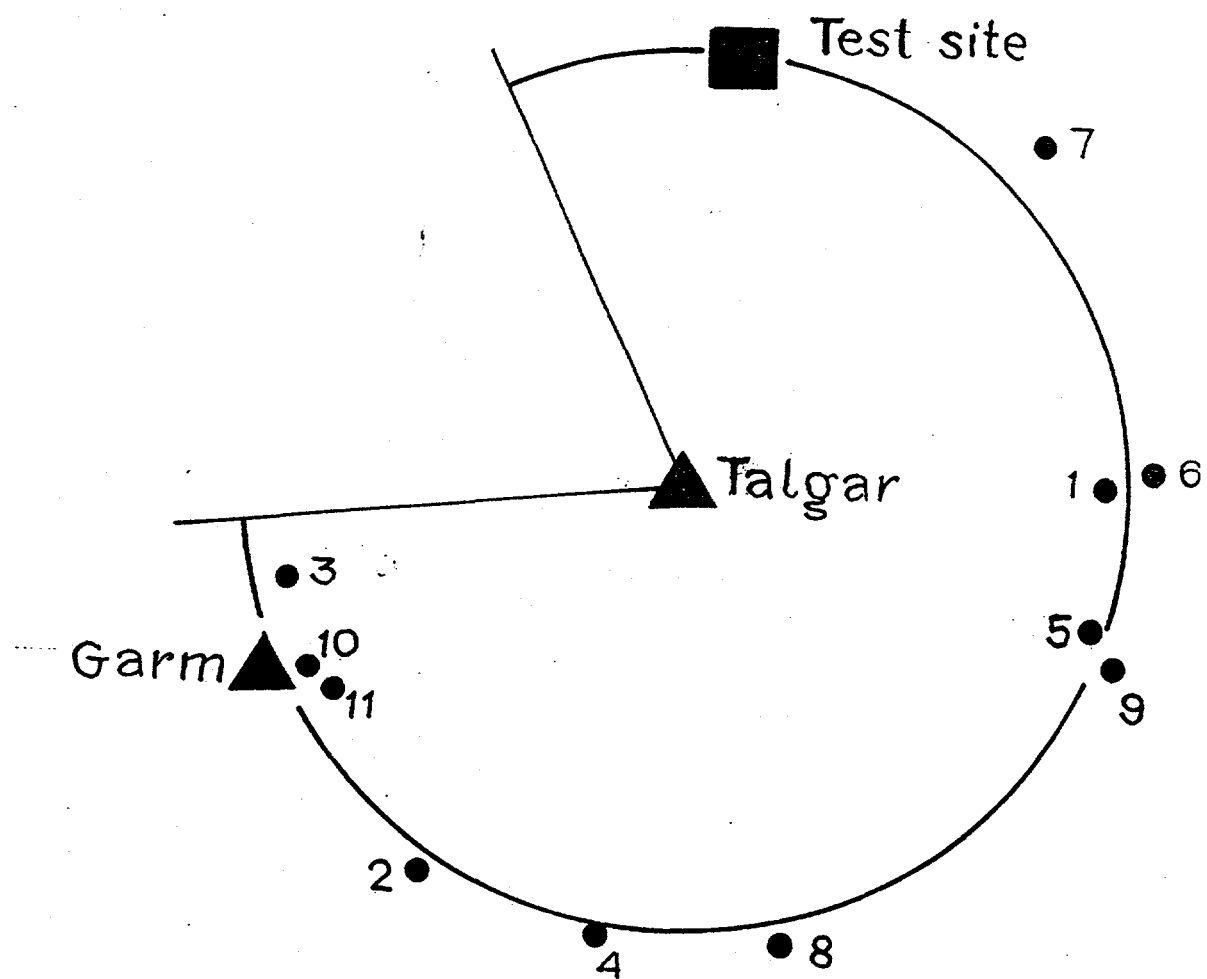


Fig. 4.7

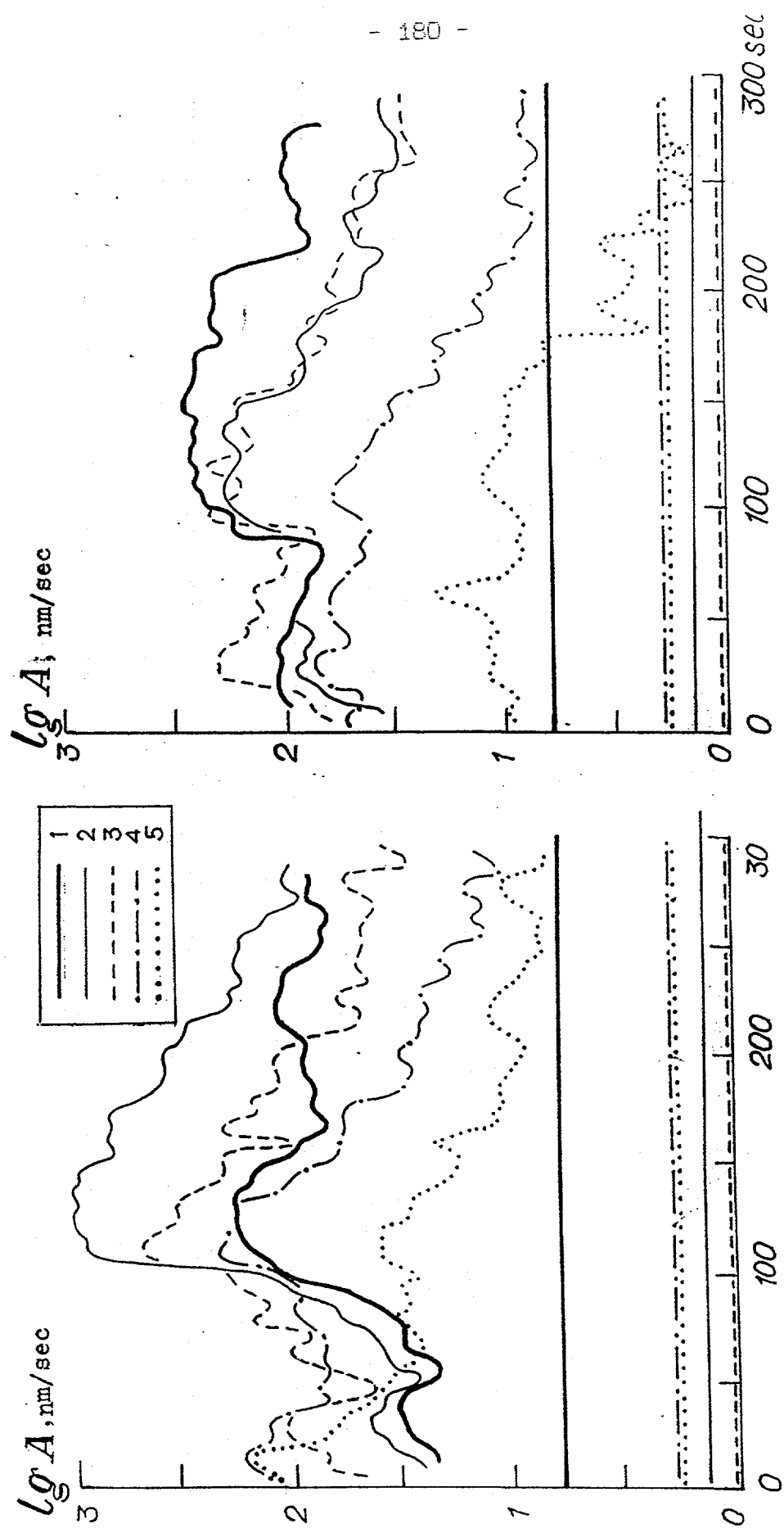


Fig. 4.8 a

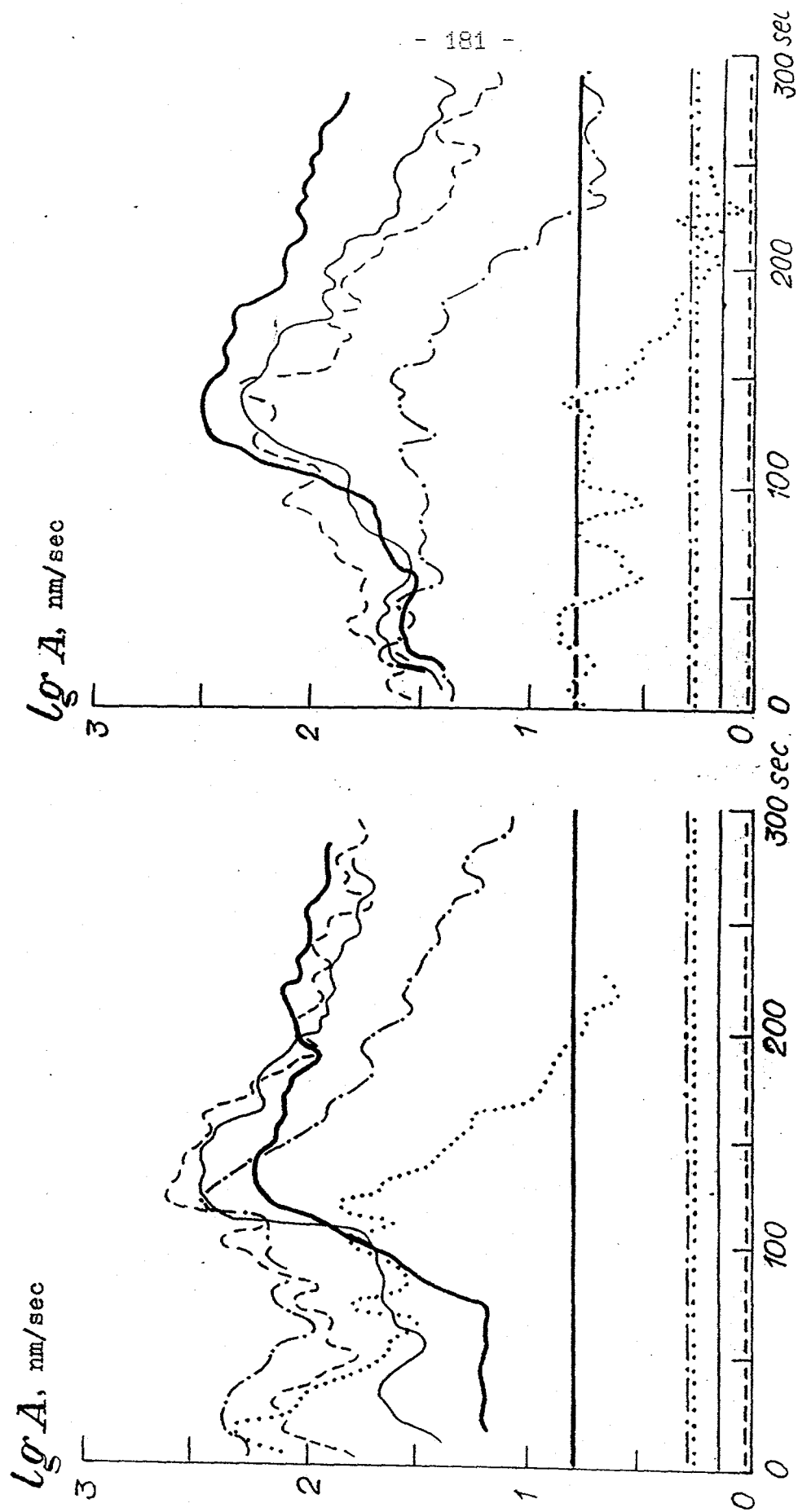


Fig. 4.8 b

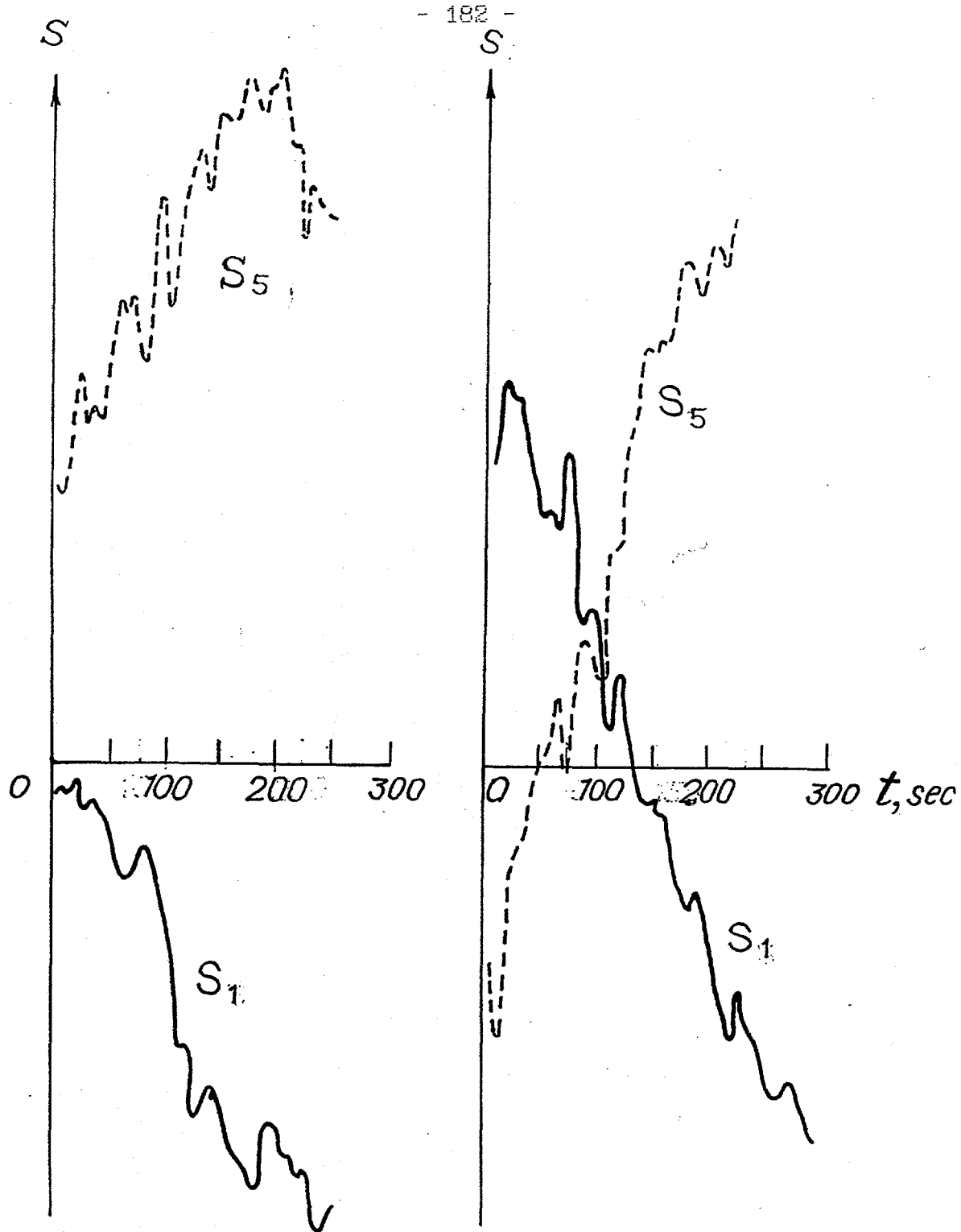


Fig. 4.9

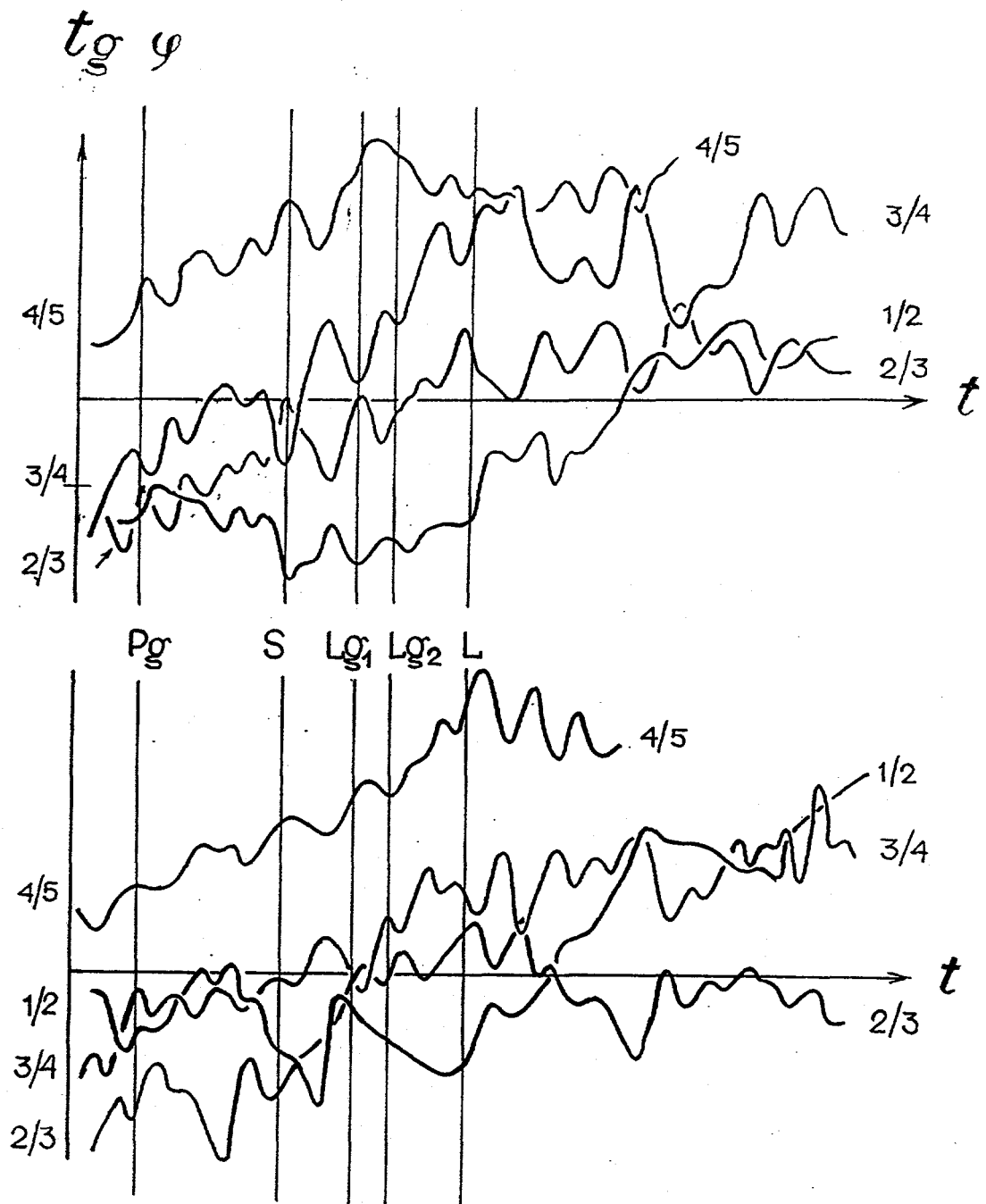


Fig. 4.10 a

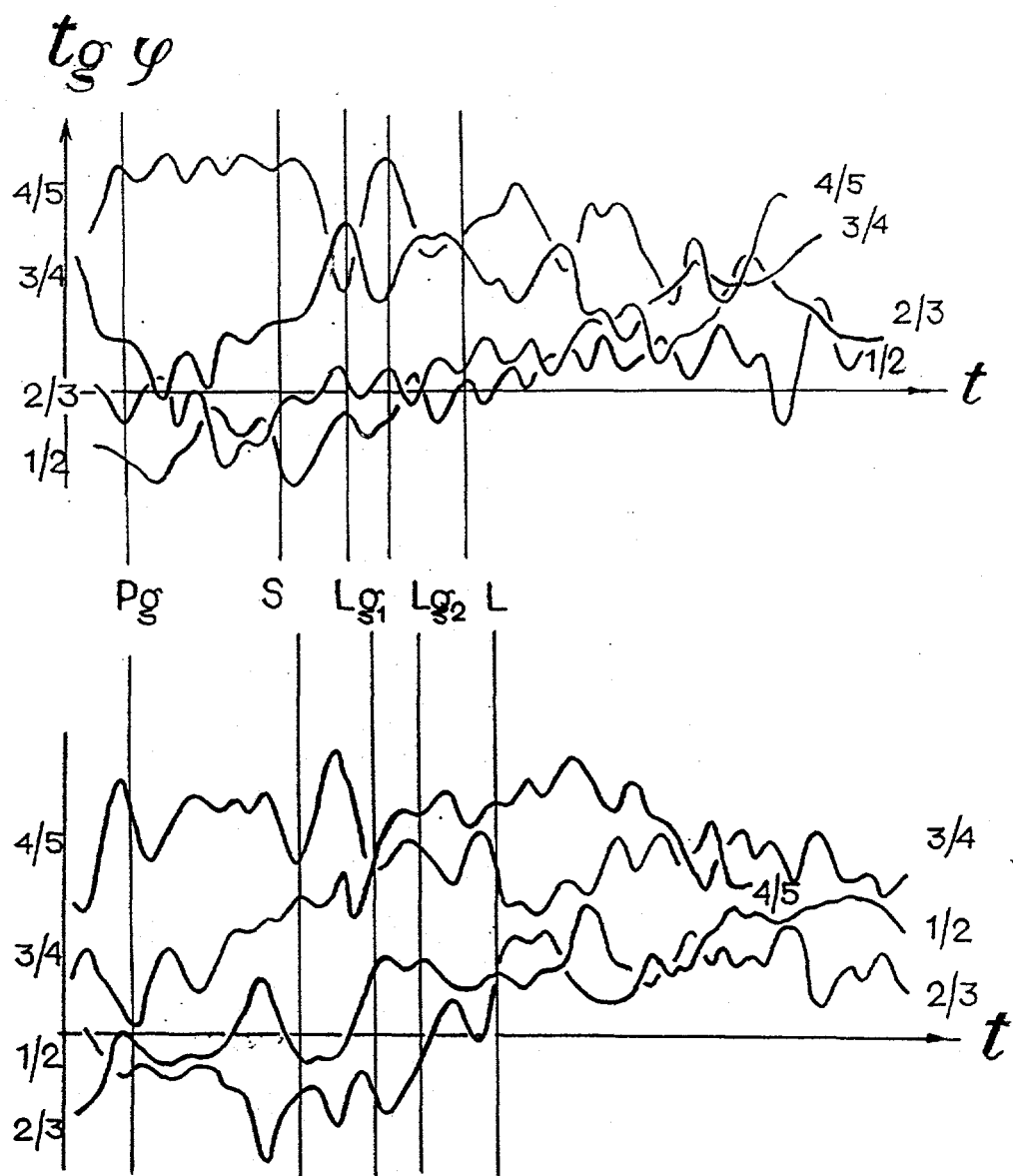


Fig. 4.10 b

$\operatorname{tg} \varphi$

- 185 -

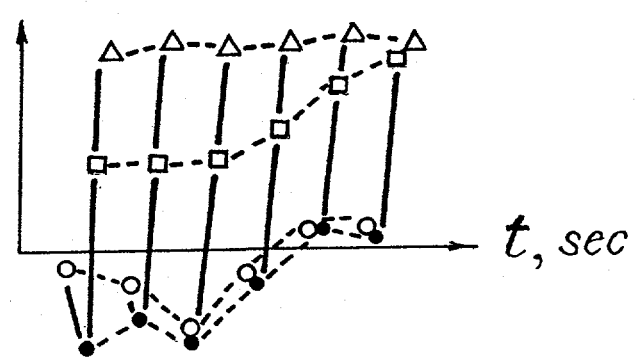
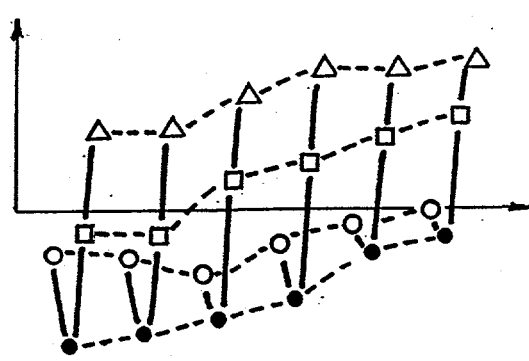
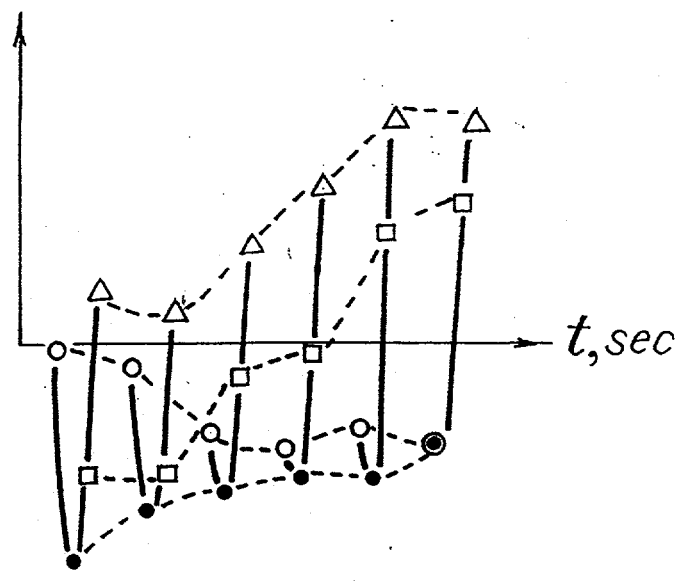


Fig. 4.11 a

$\operatorname{tg} \varphi$

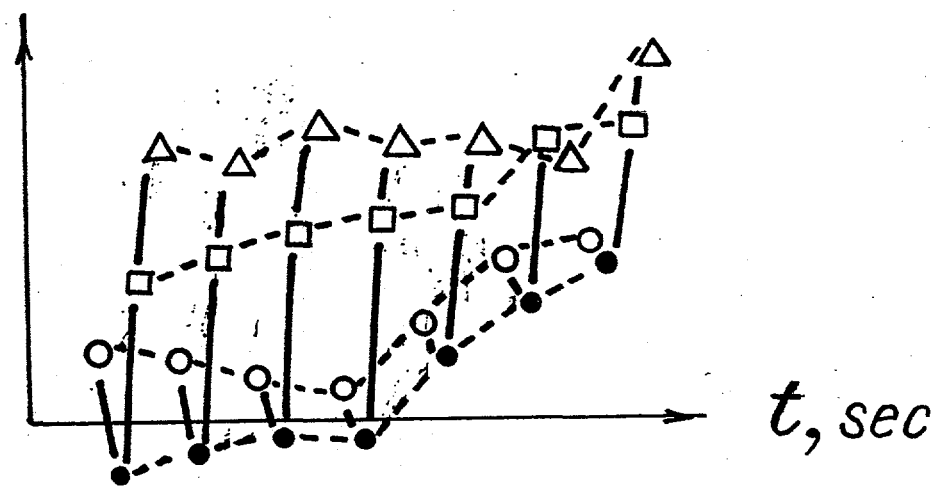
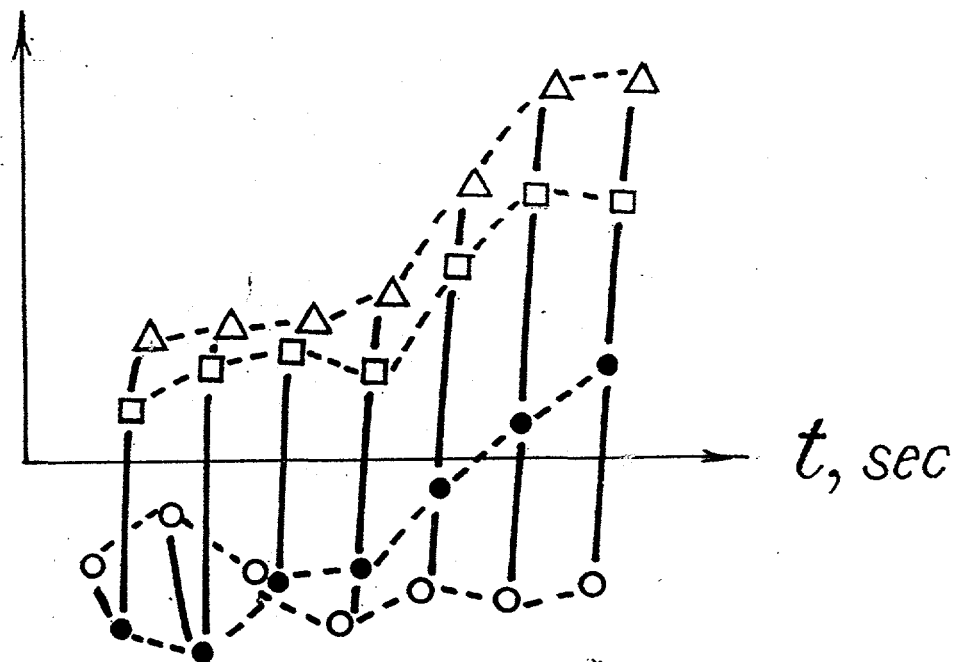


Fig. 4.11 b

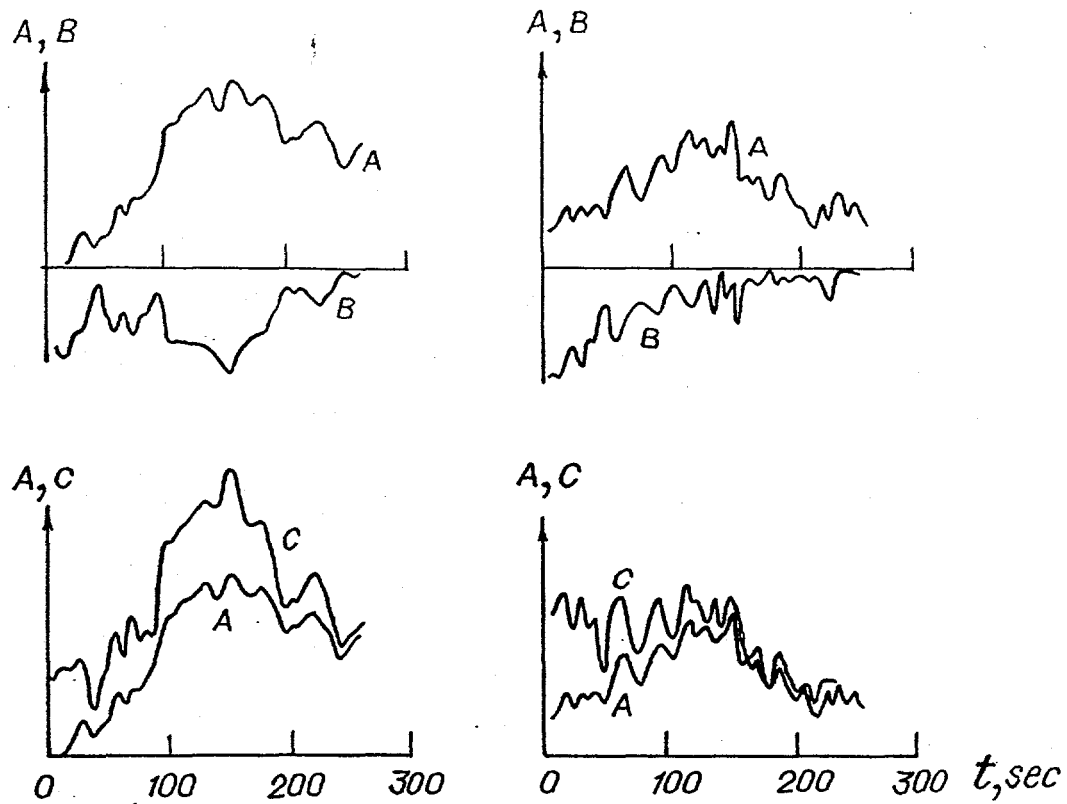


Fig. 4.12 a

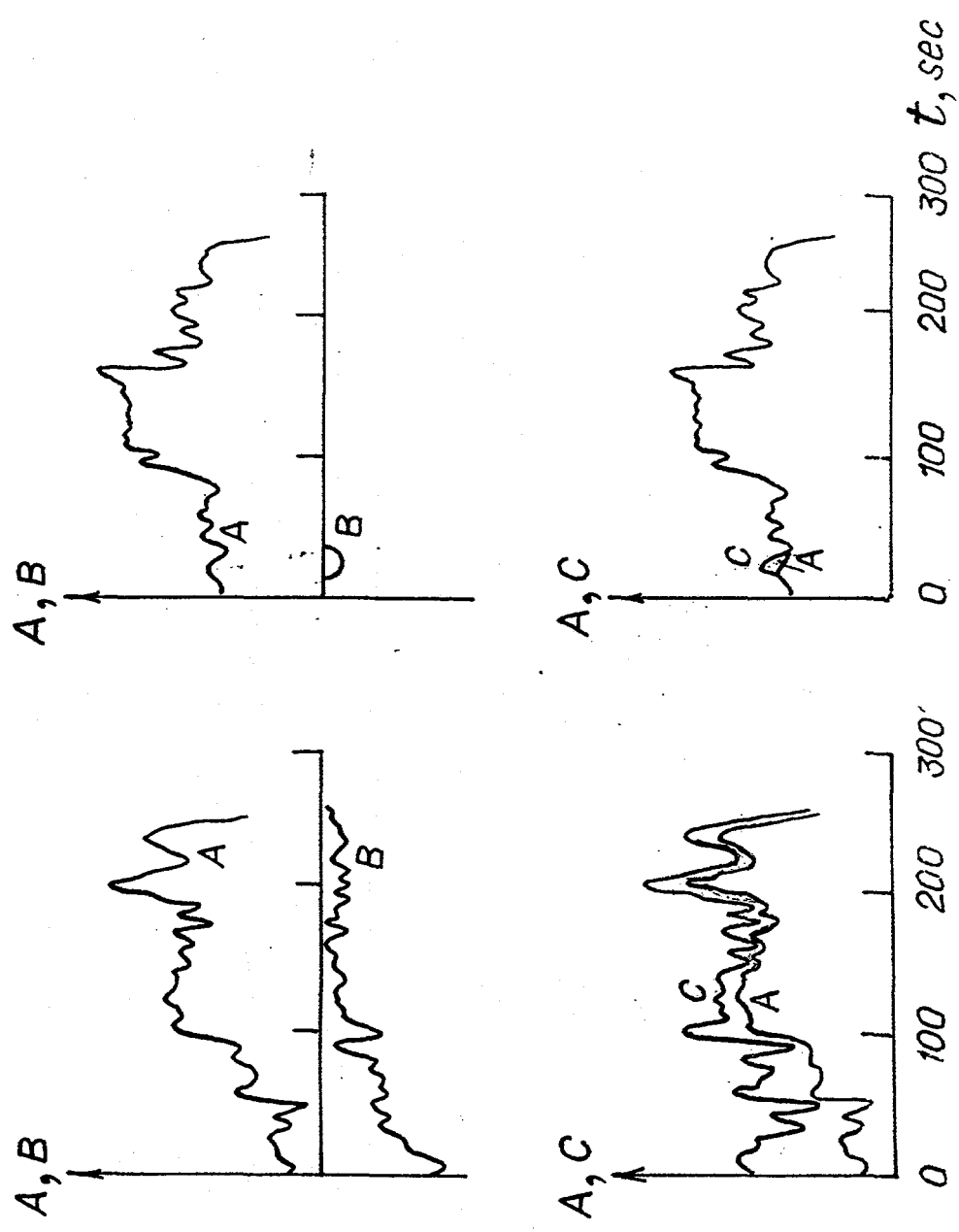


Fig. 4.12 b

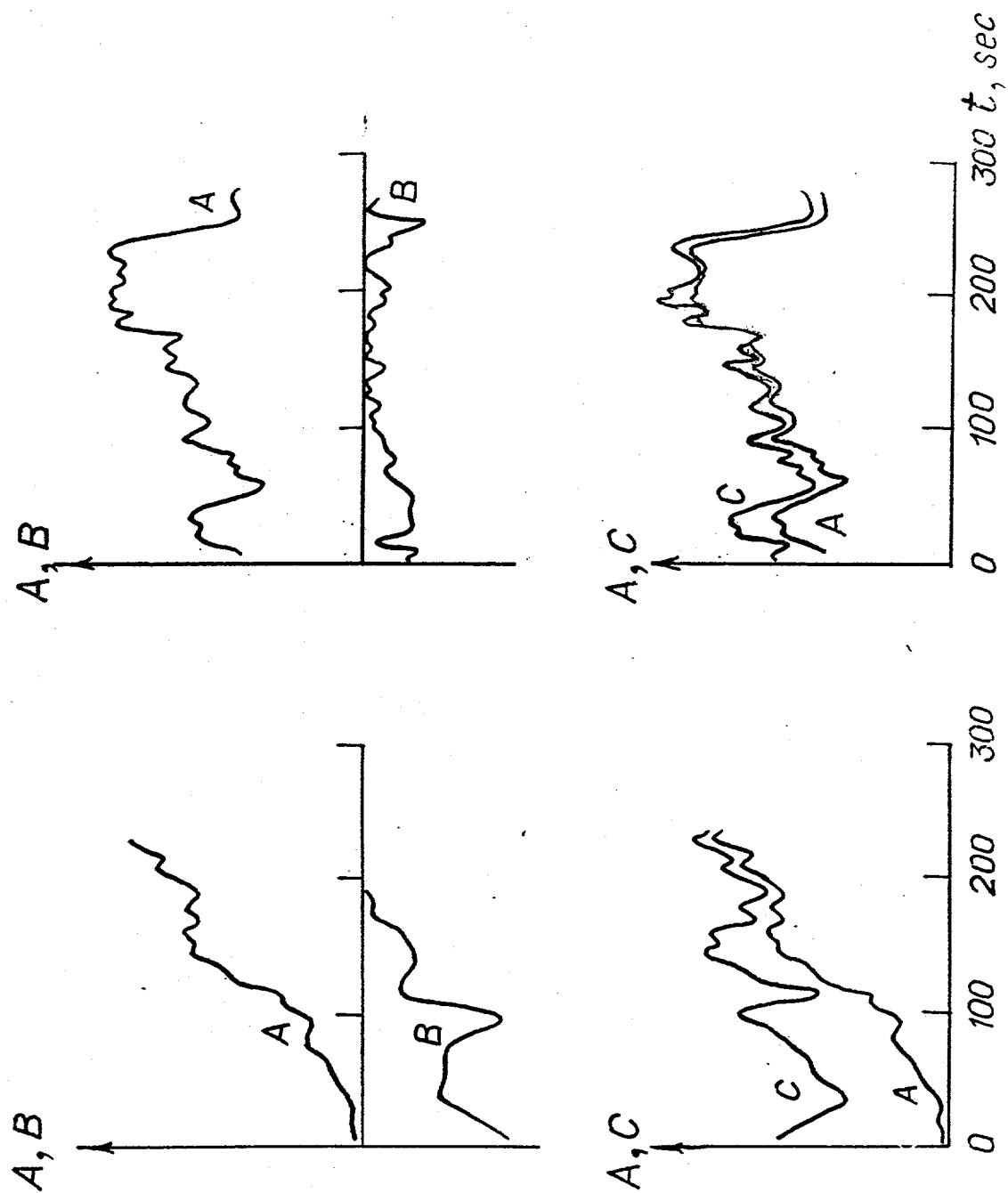


Fig. 4.12 c

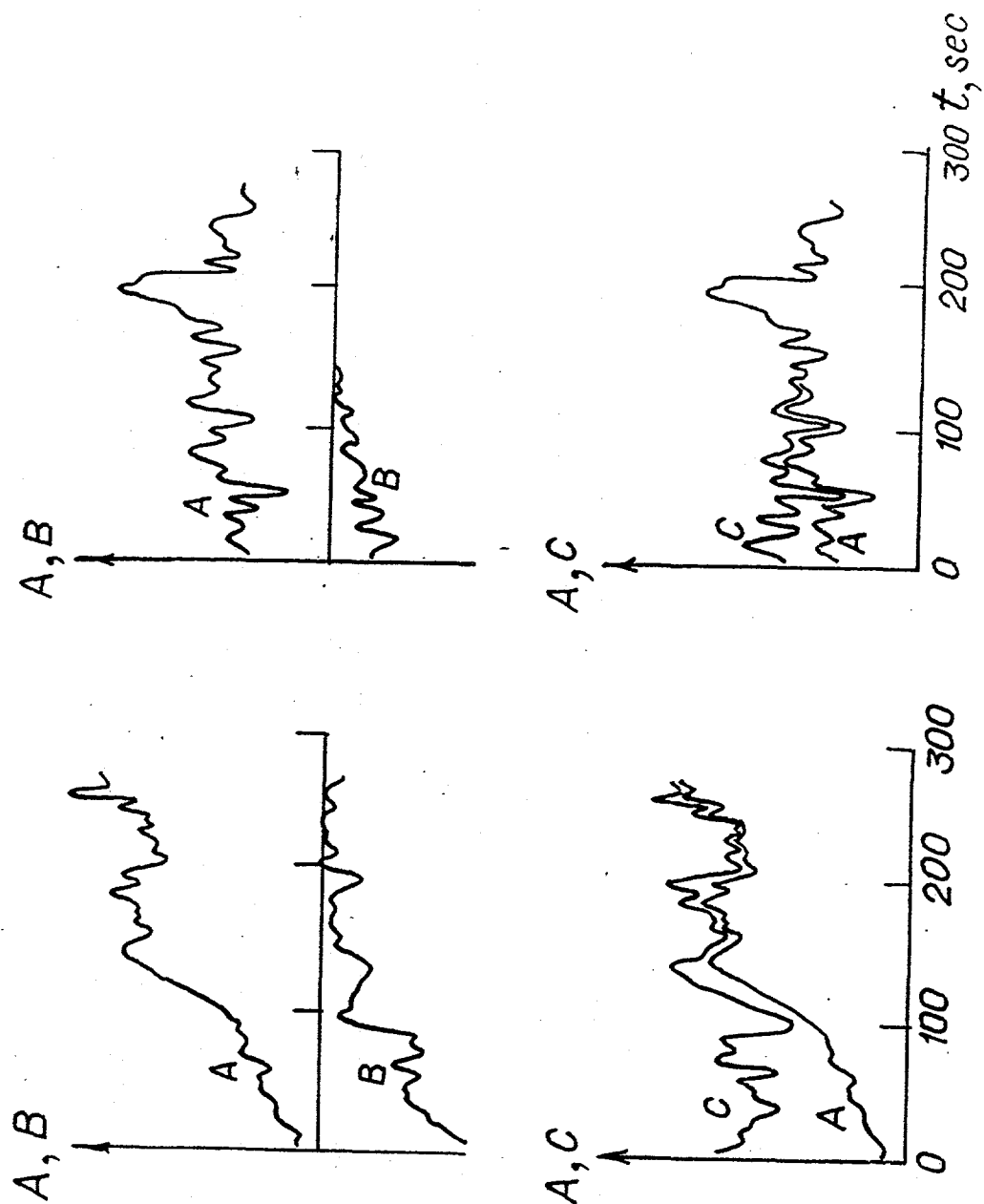


Fig. 4.12 d

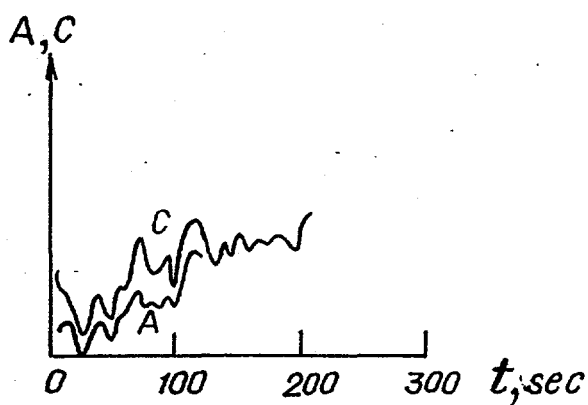
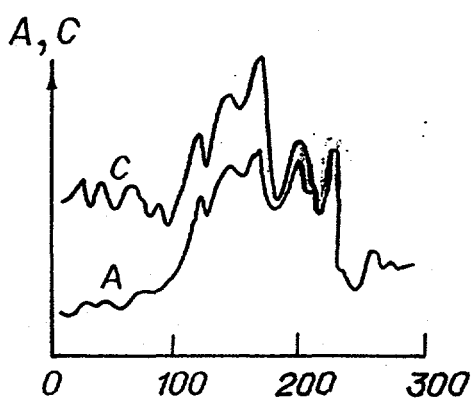
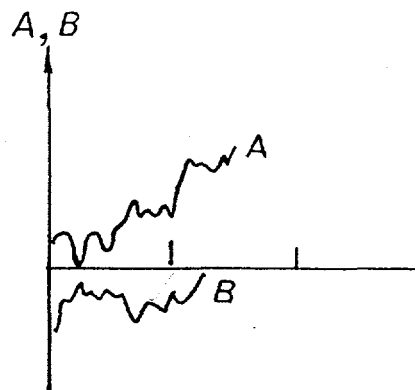
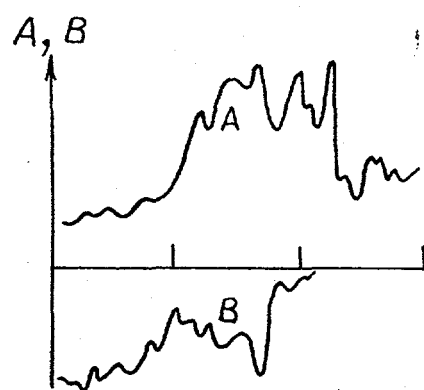


Fig. 4.12 e

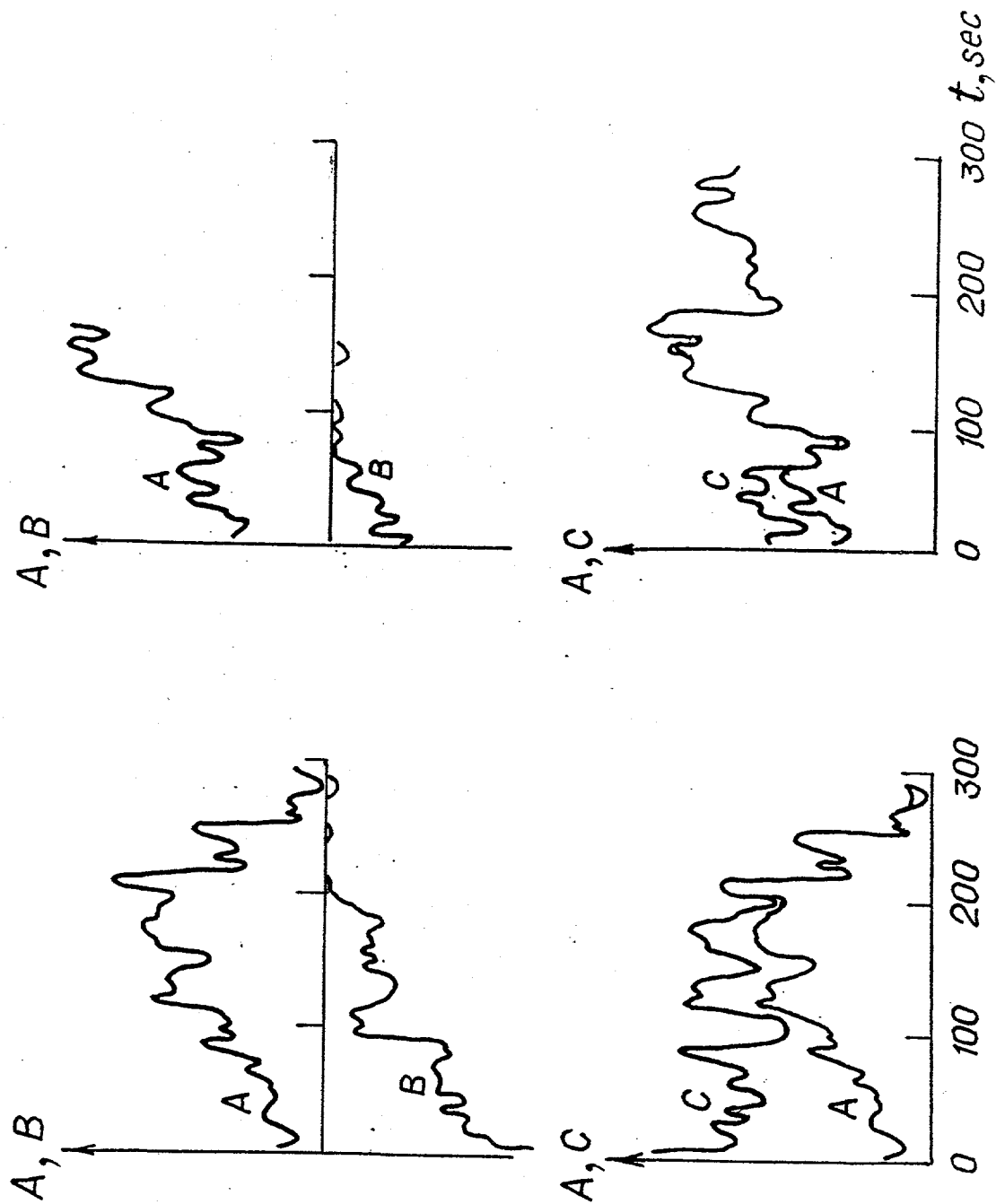


Fig. 4.12 f

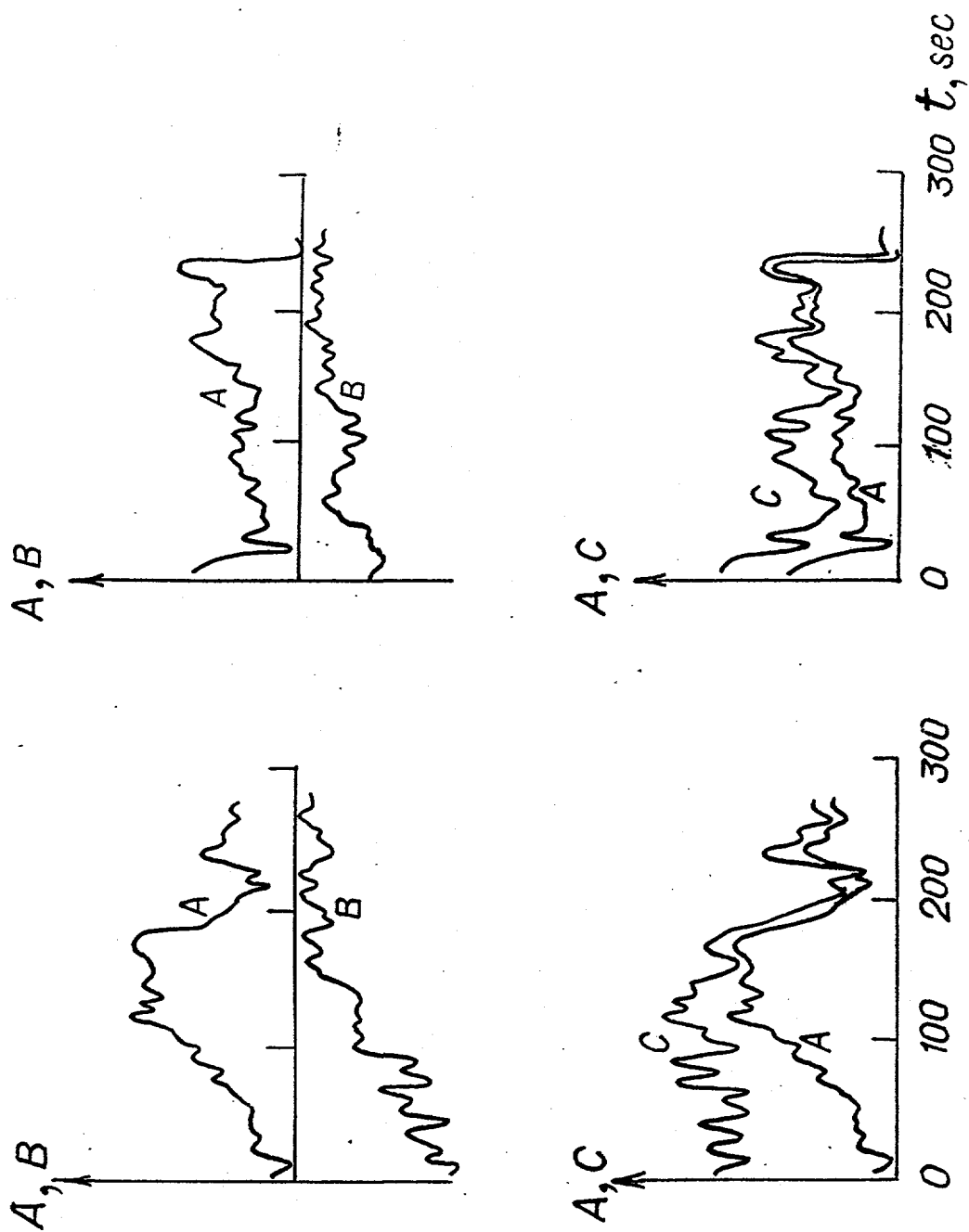


Fig. 4.12 g

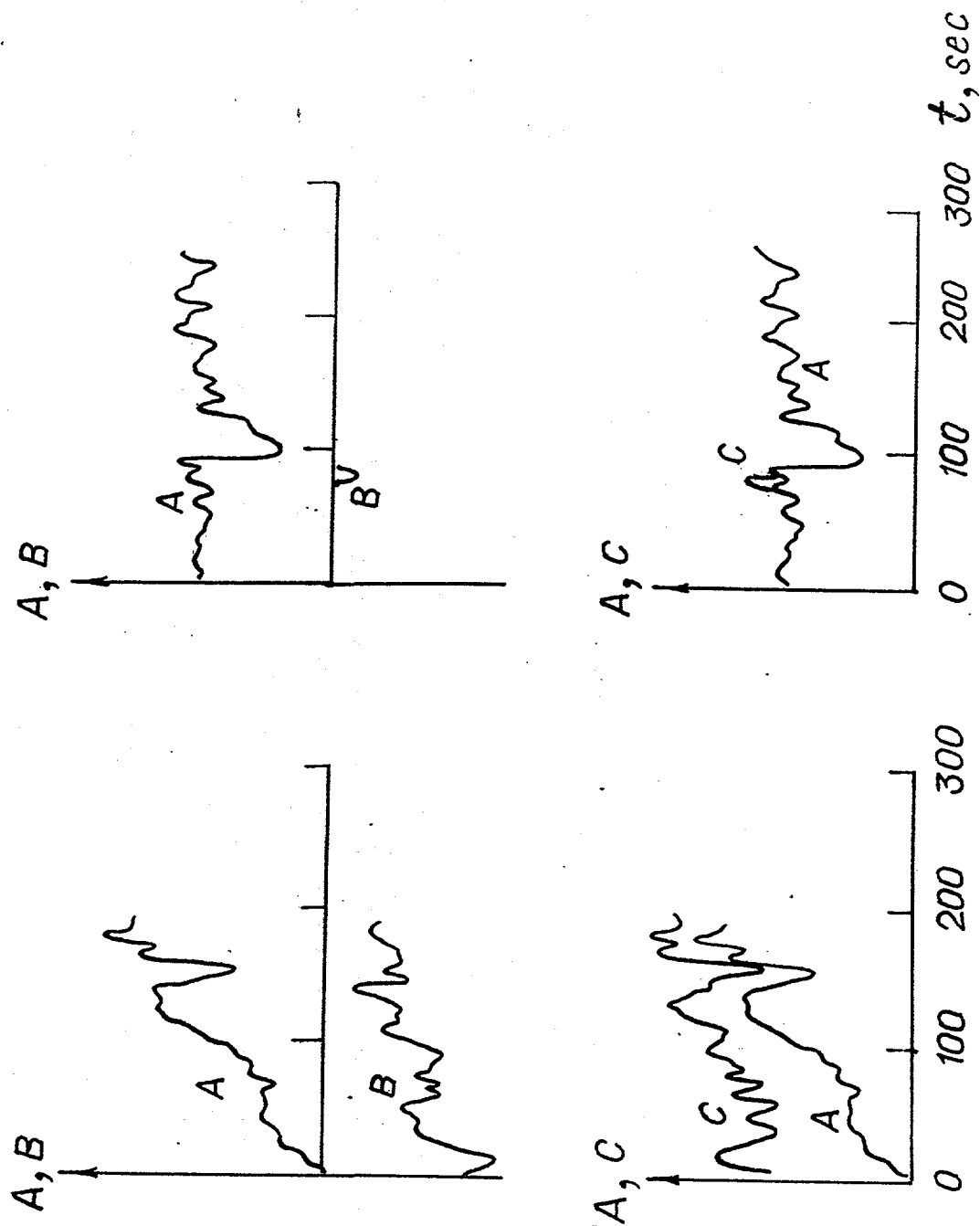


Fig. 4.12 h

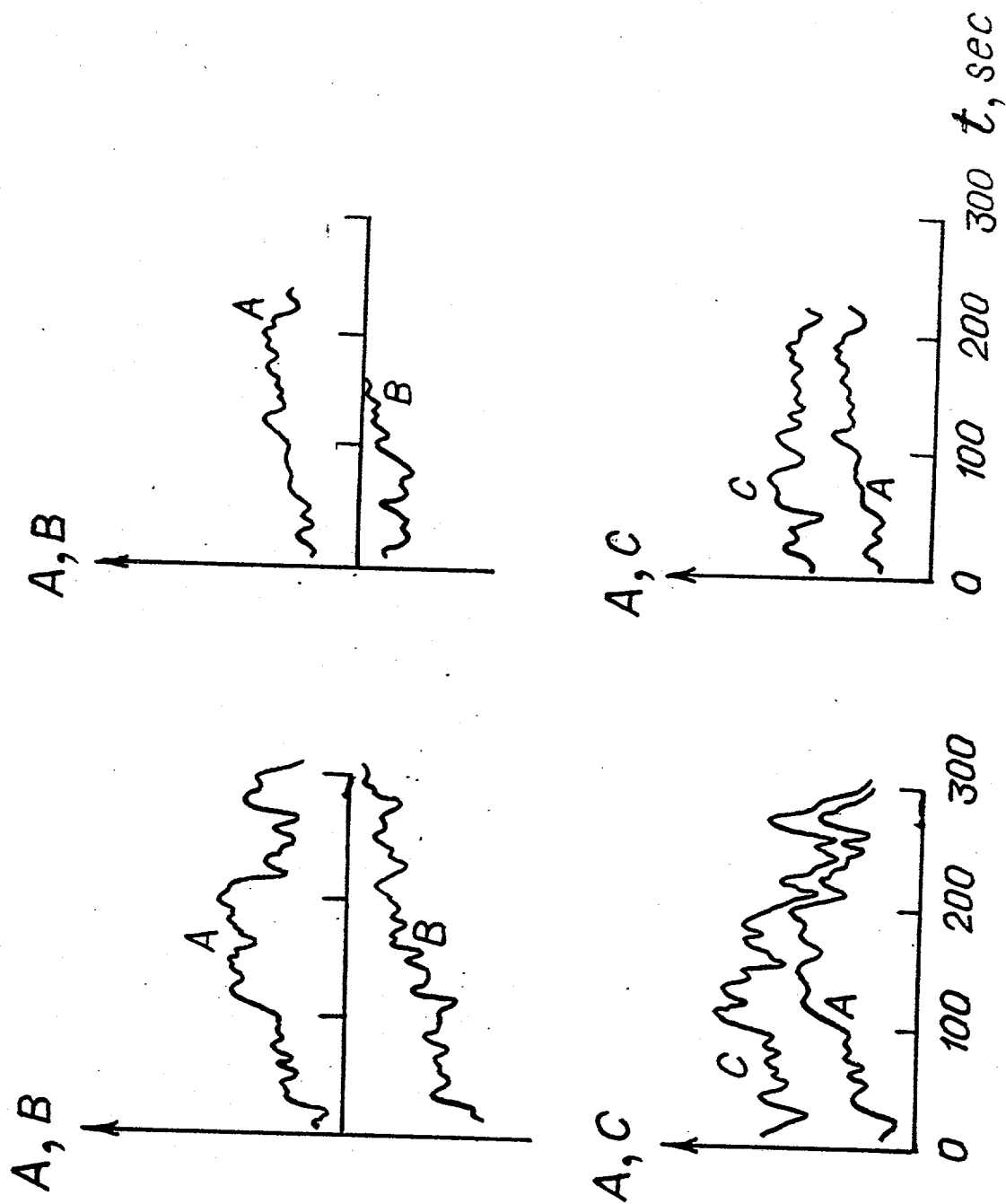


Fig. 4.121

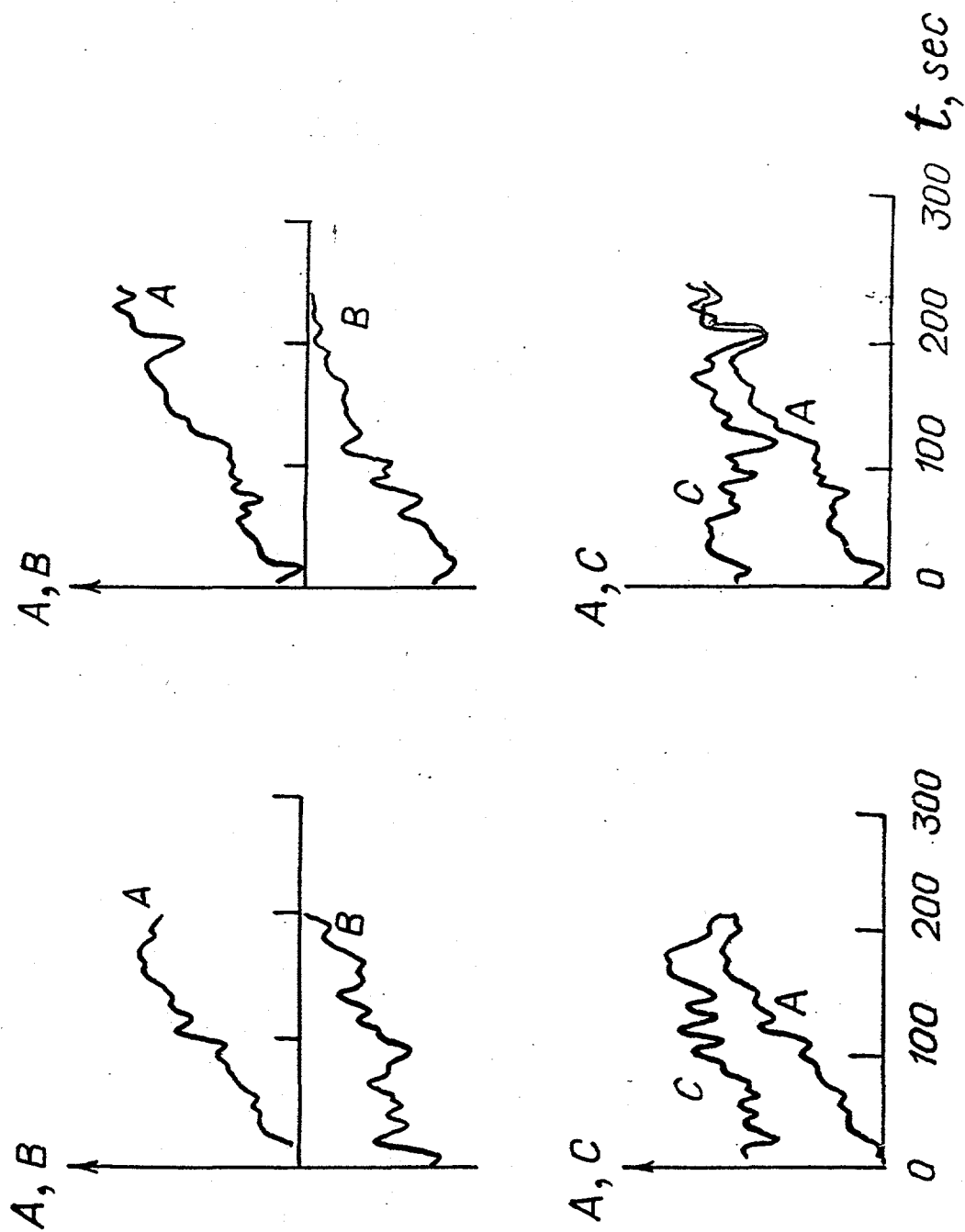


Fig. 4.12 j

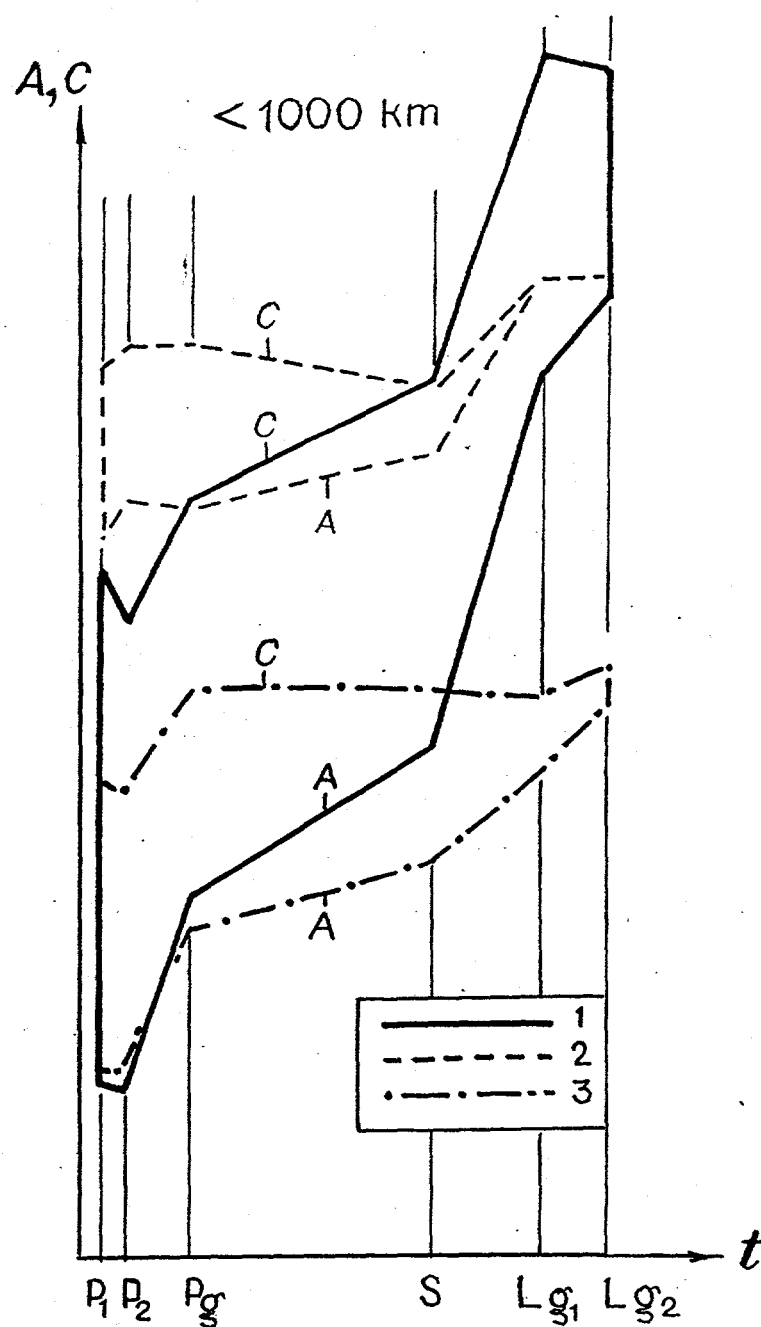


Fig. 4.13

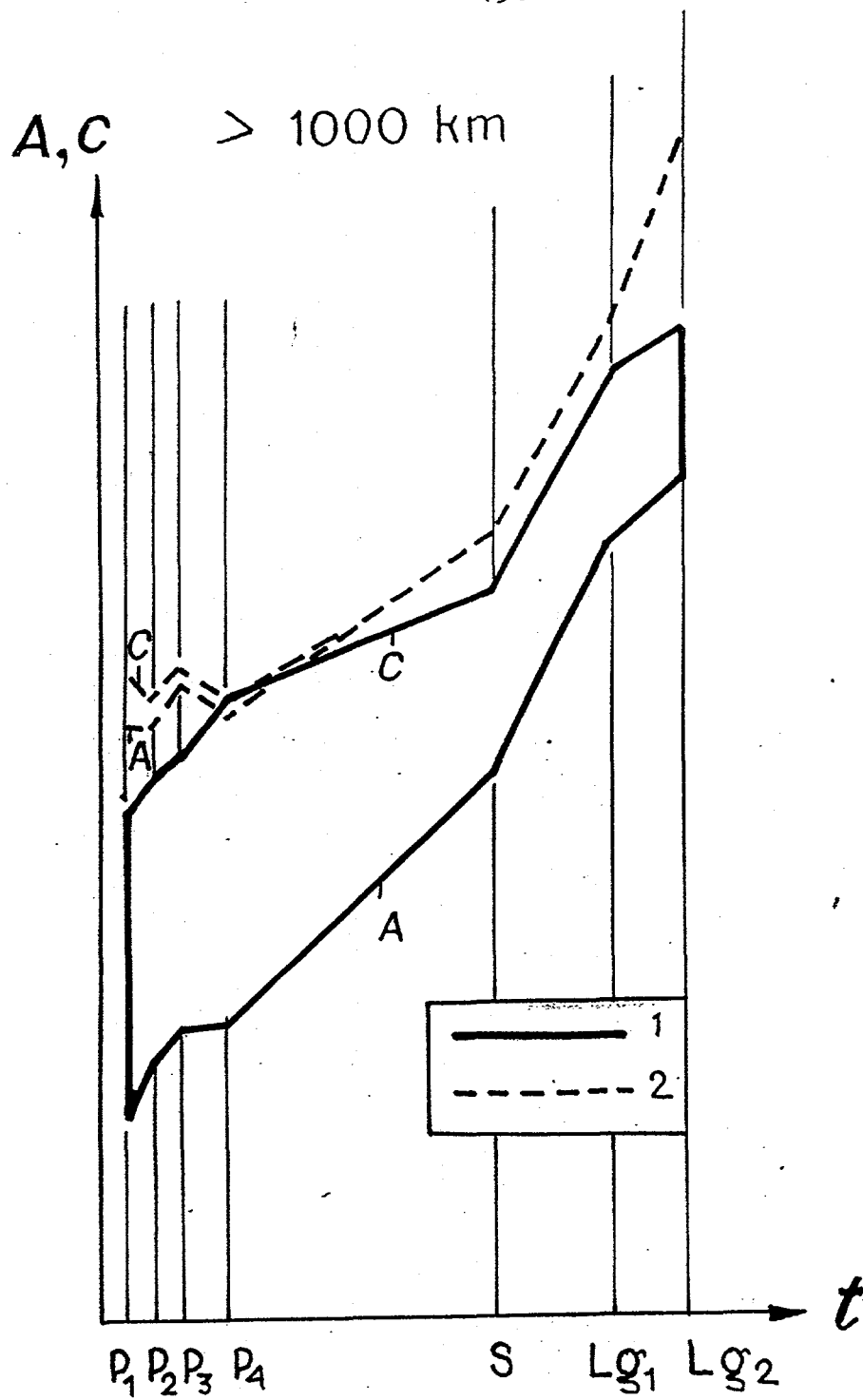
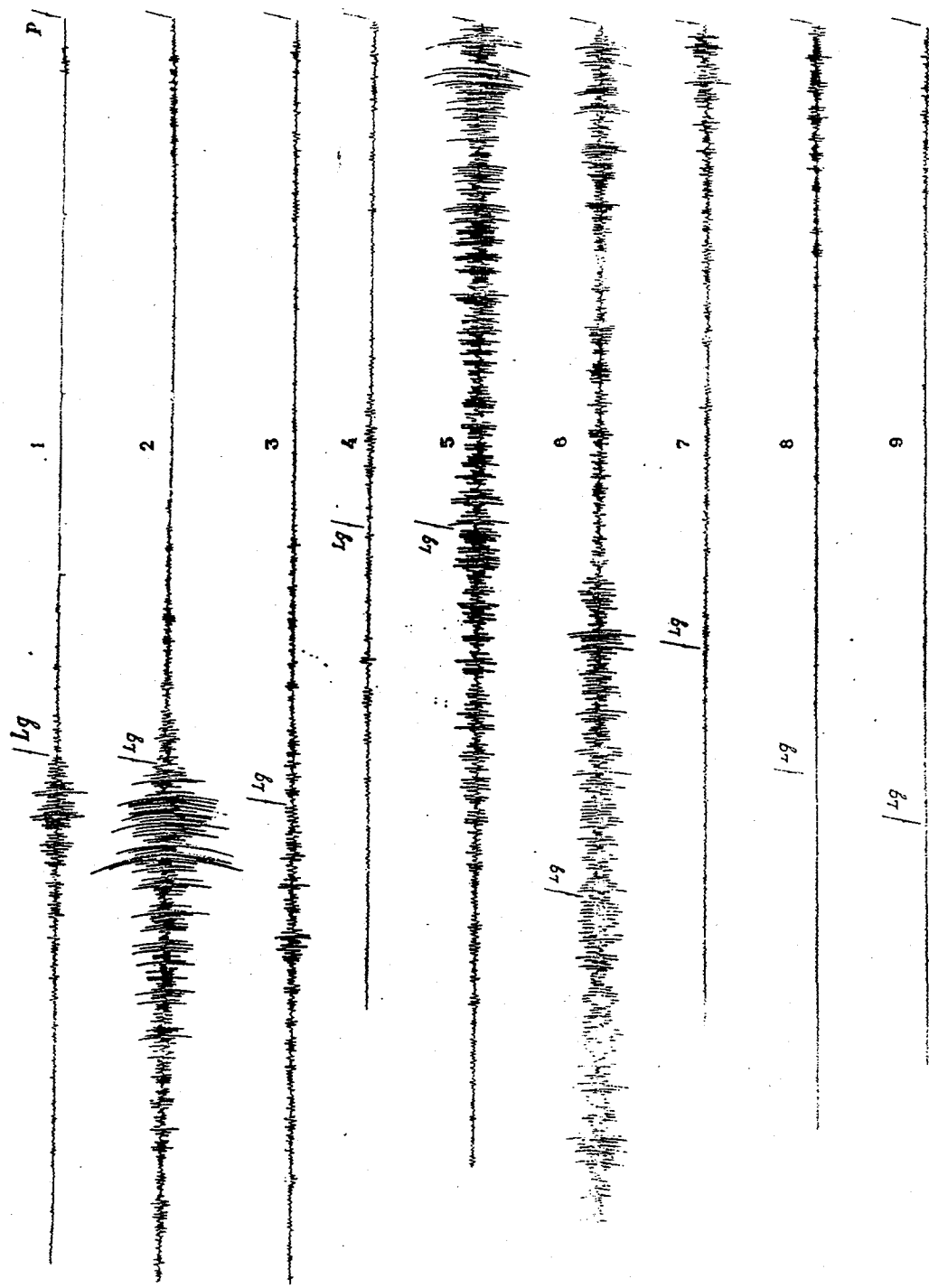


Fig. 4.14



1 min

Fig. 5.1

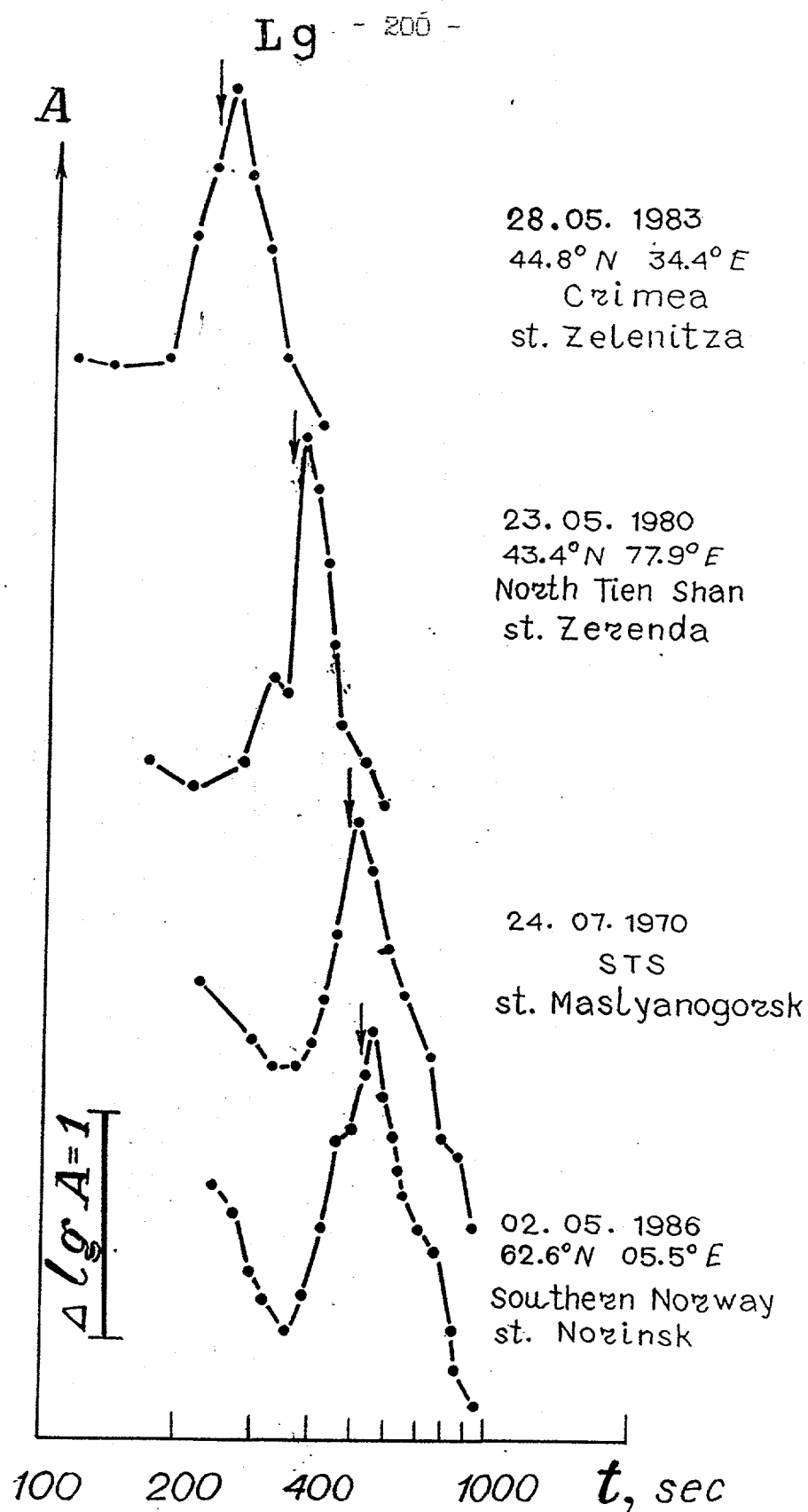


Fig.5.2

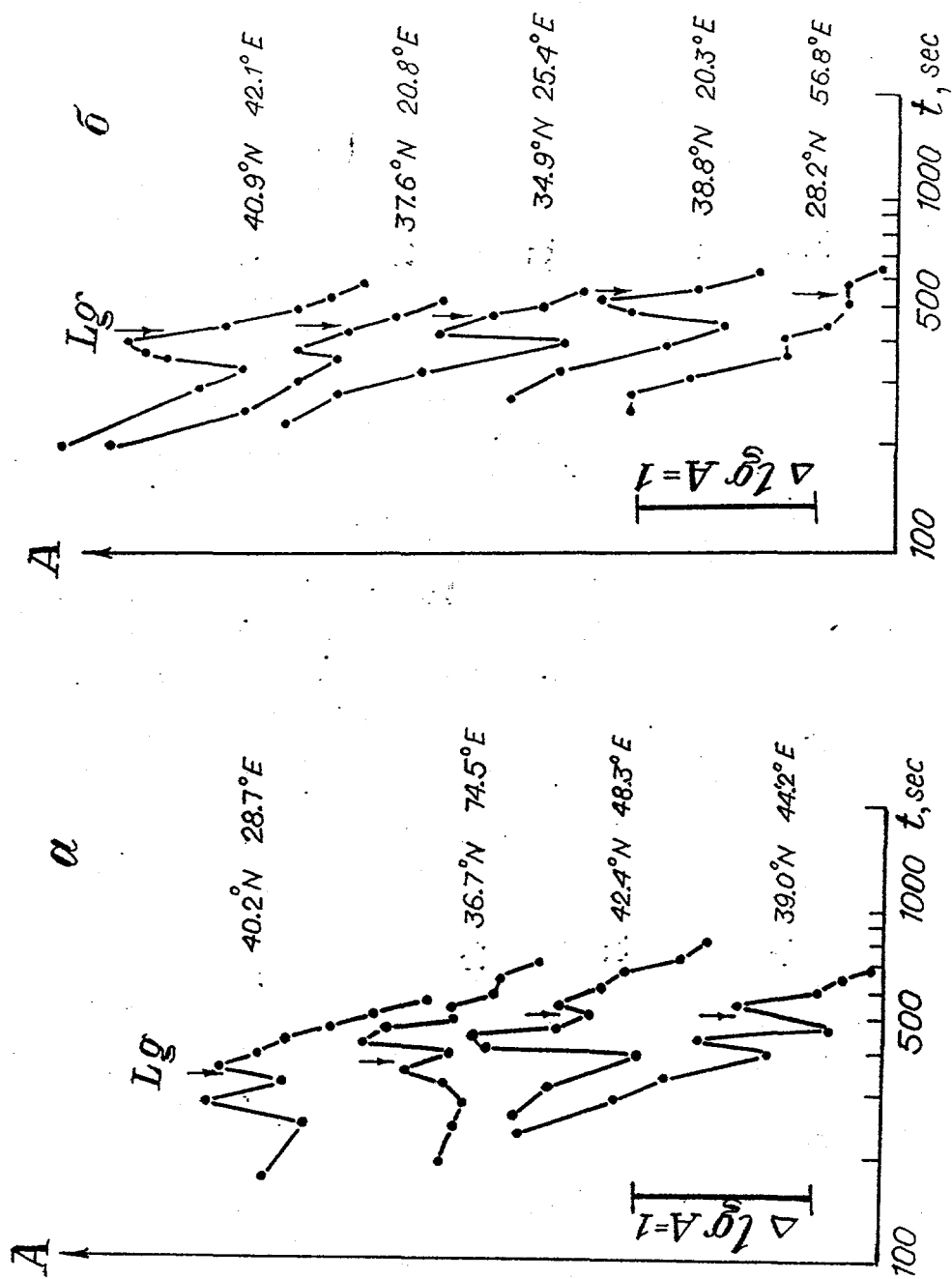


Fig. 5.3

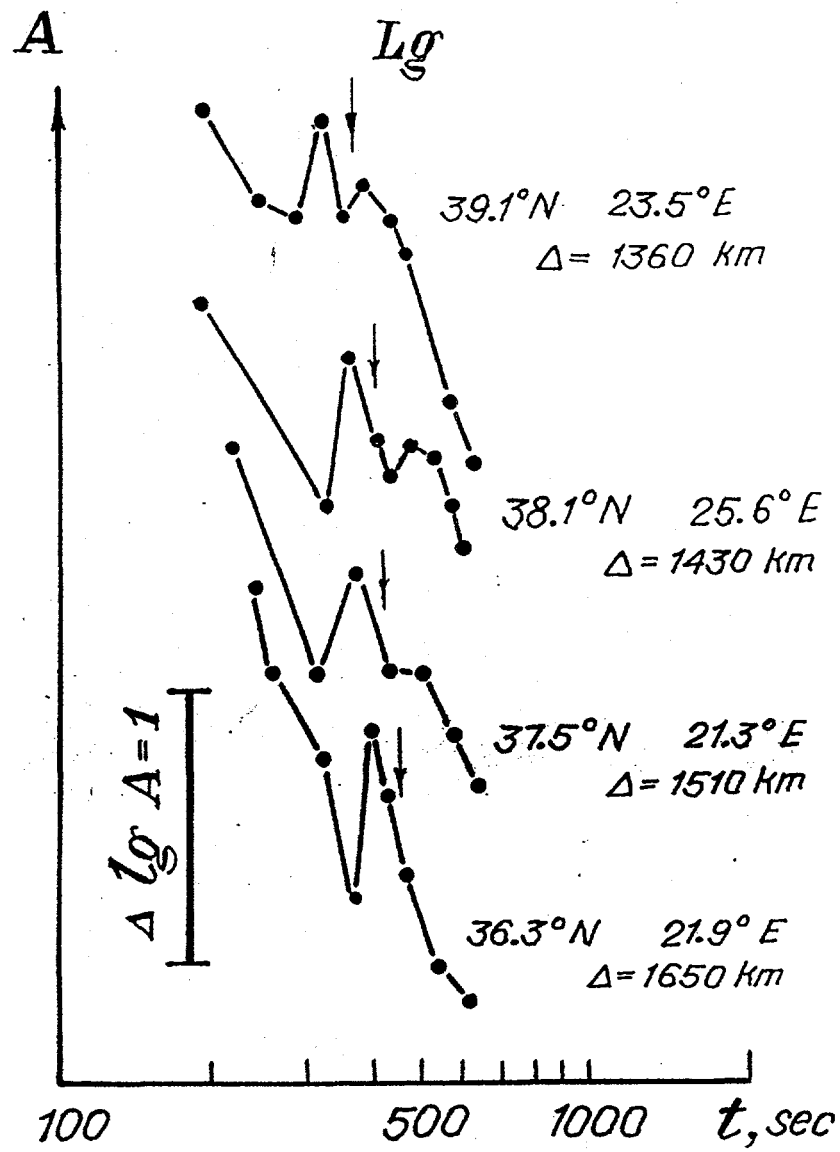


Fig. 5.4

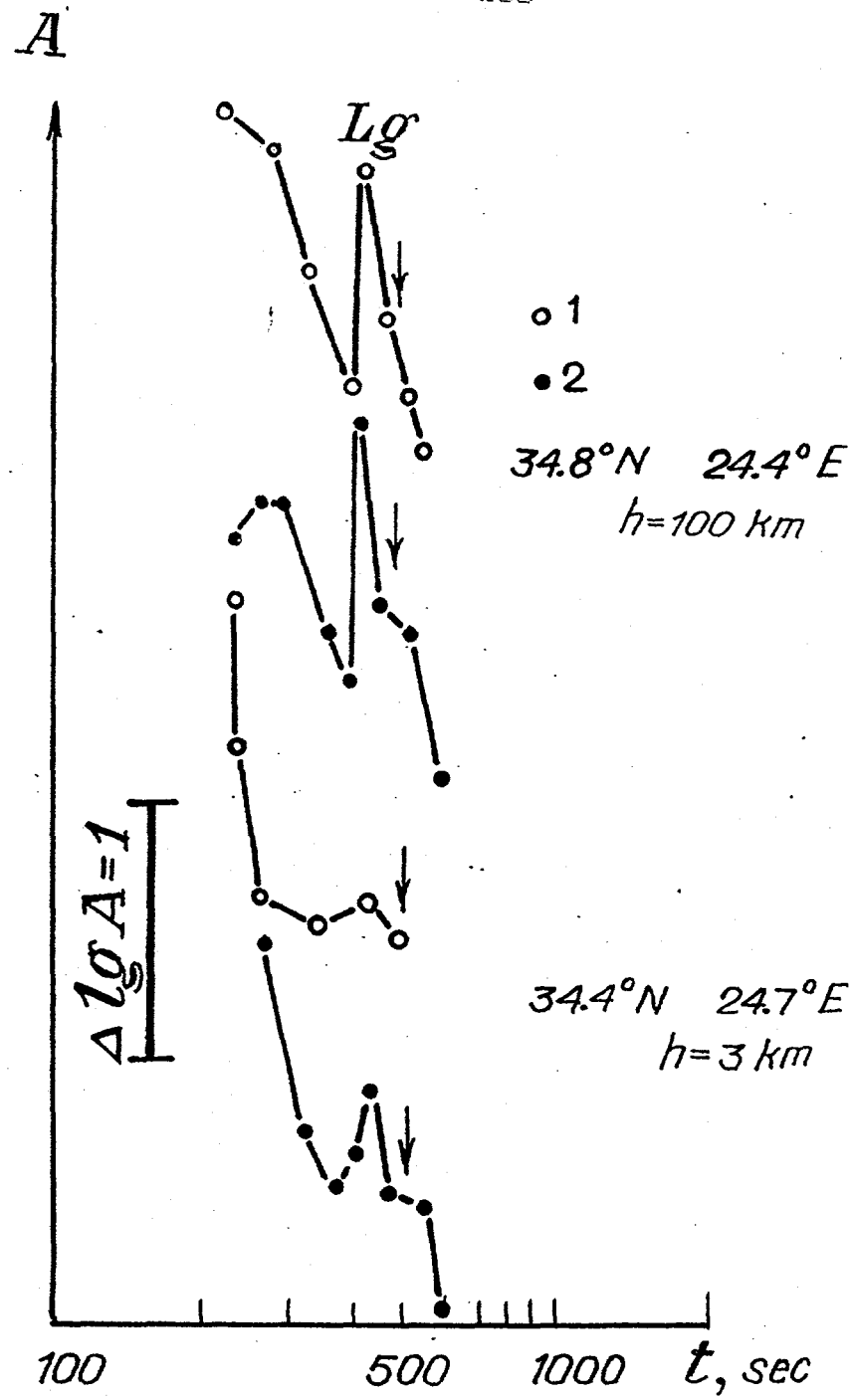


Fig.5.5

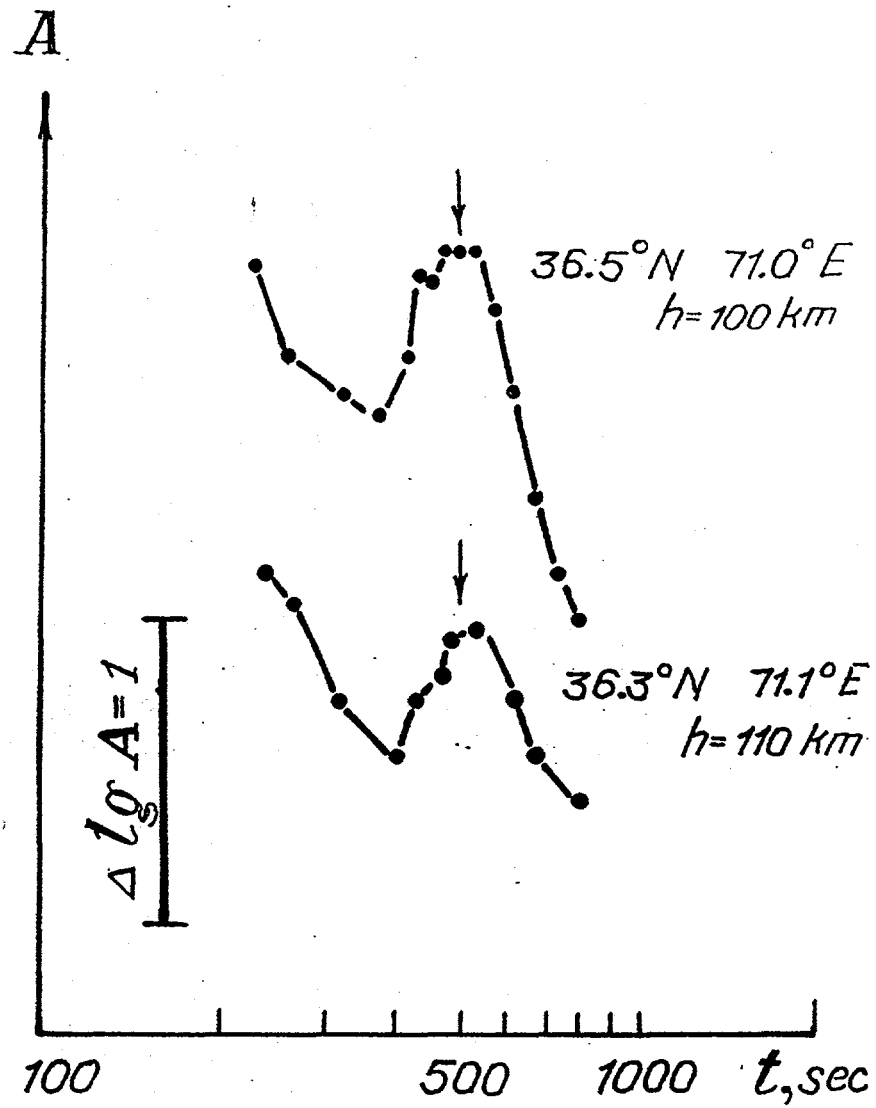


Fig. 5.6

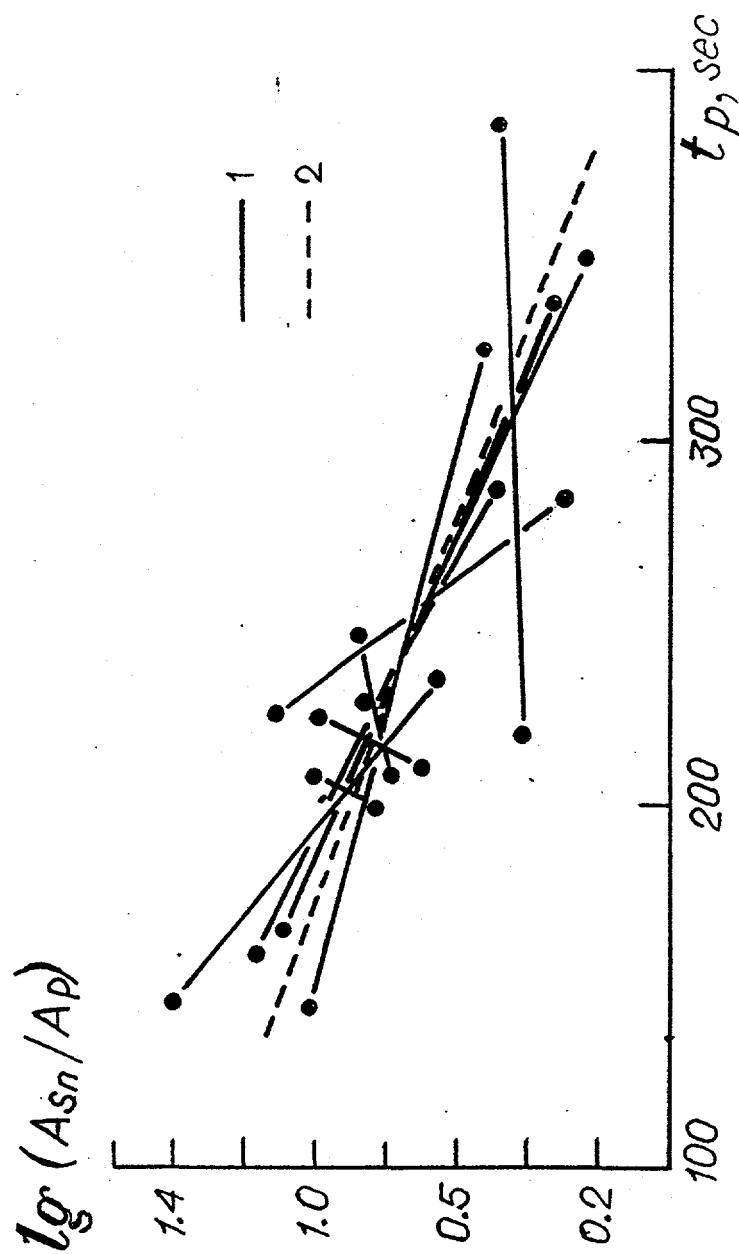


Fig. 5.7

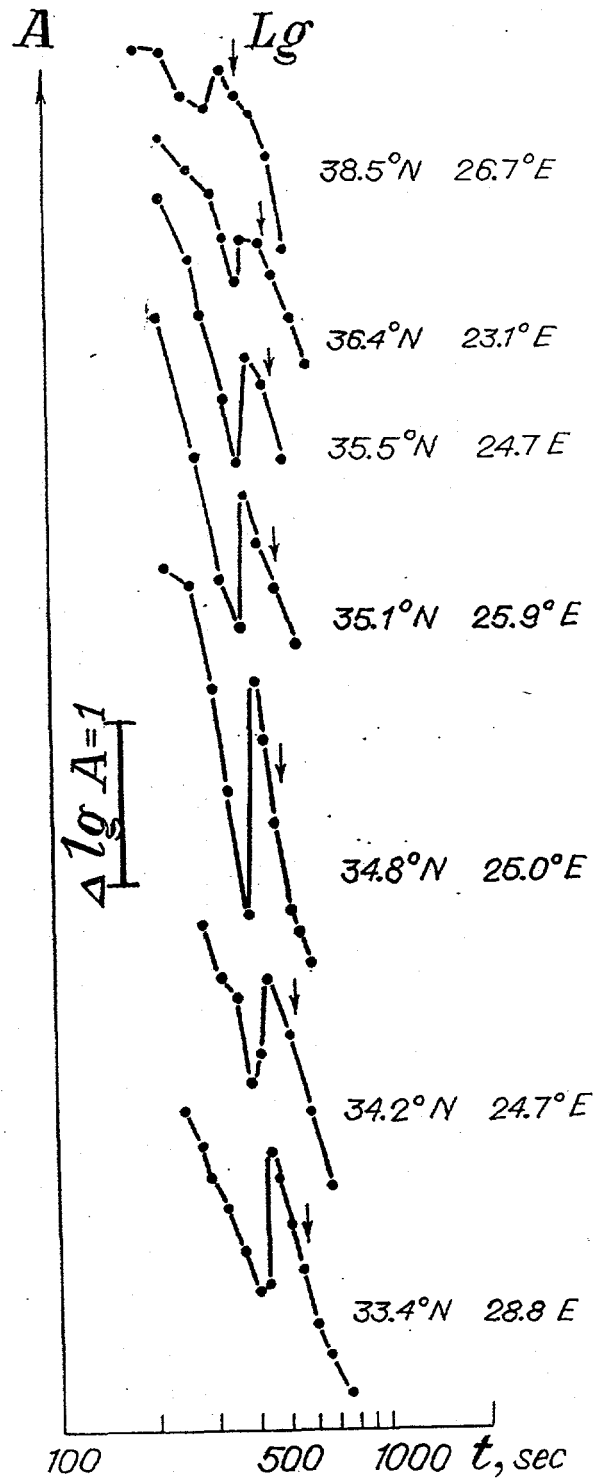


Fig. 5.8

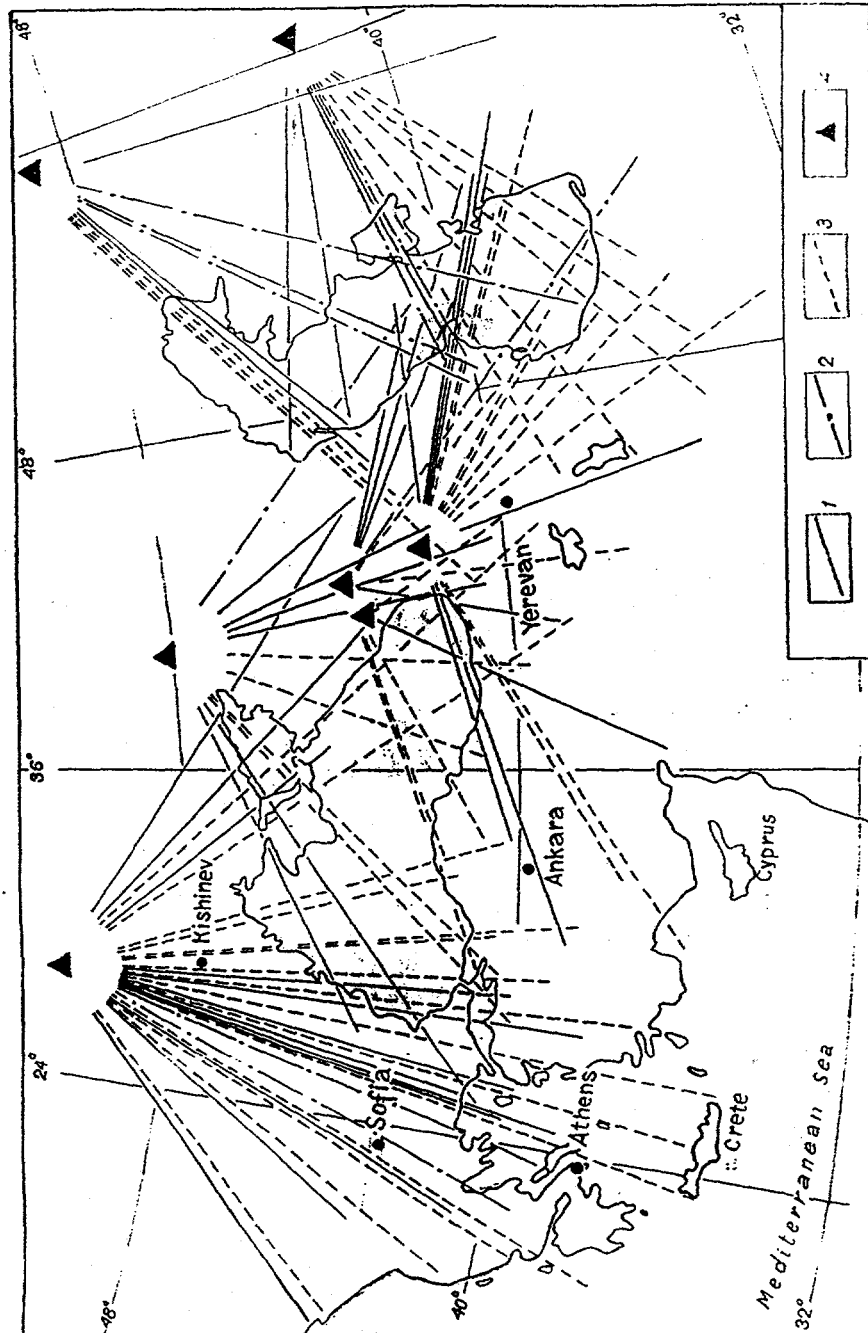


Fig. 5.9

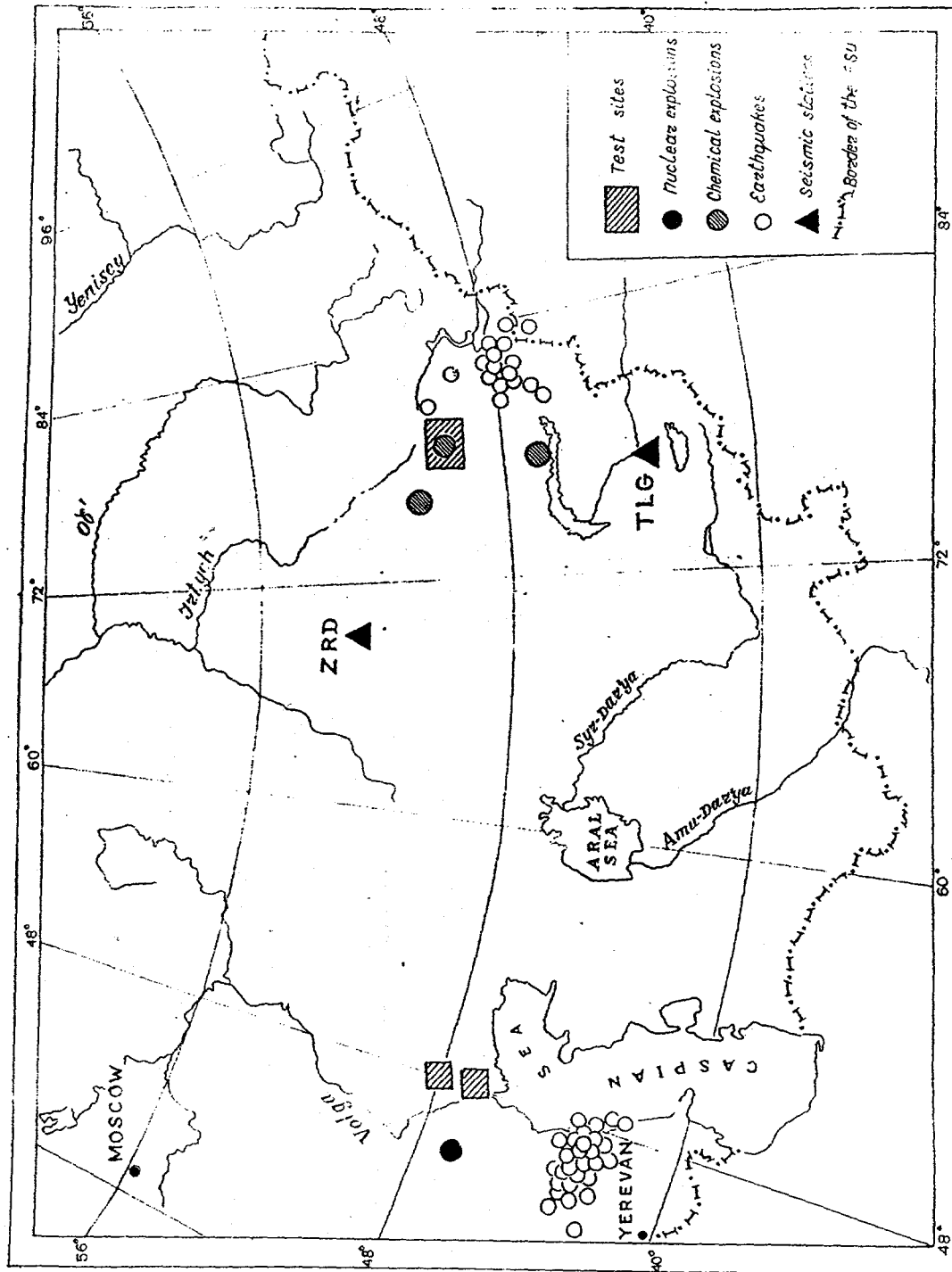


Fig. 5.10

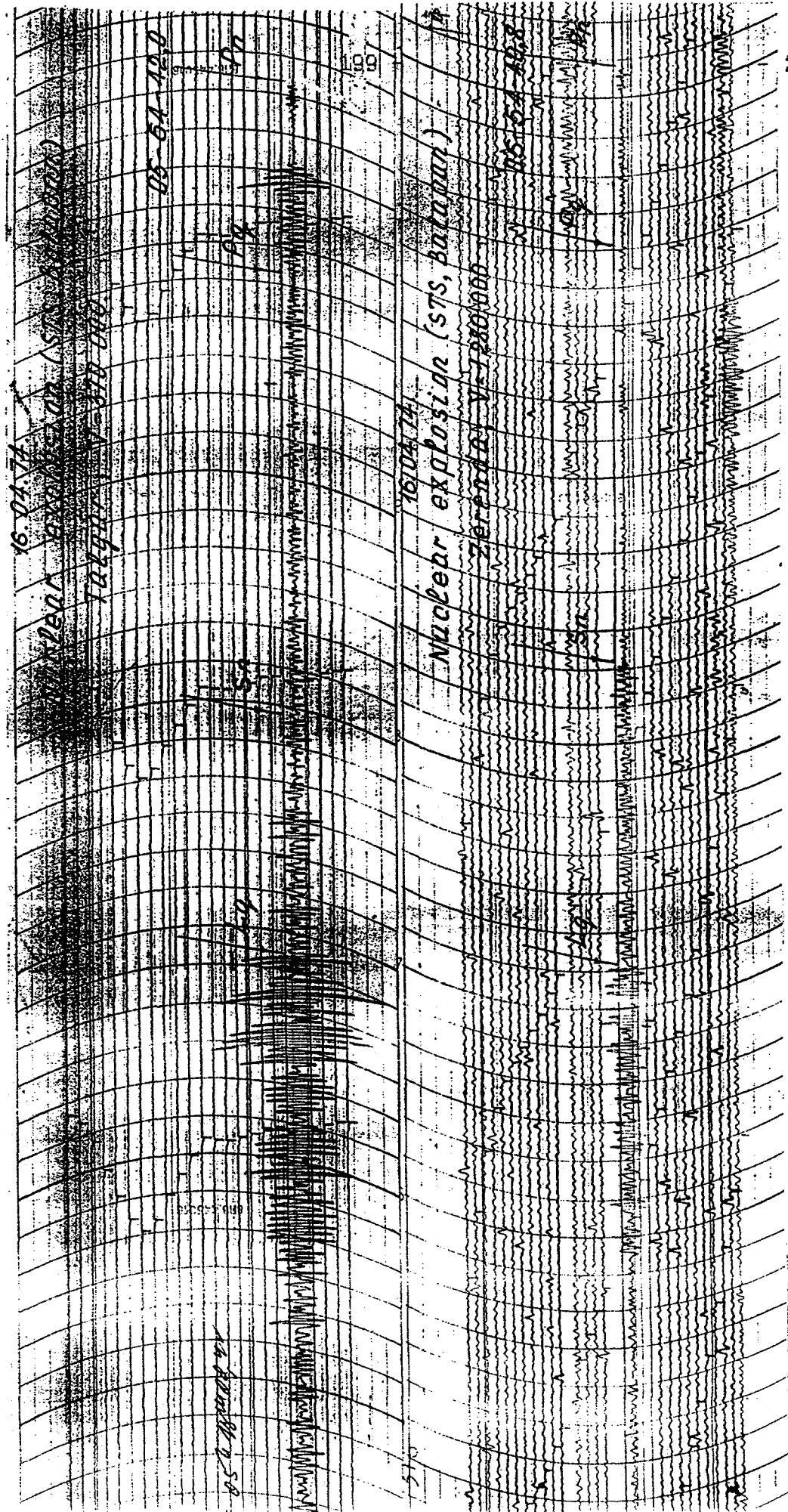


Fig. 5.11a

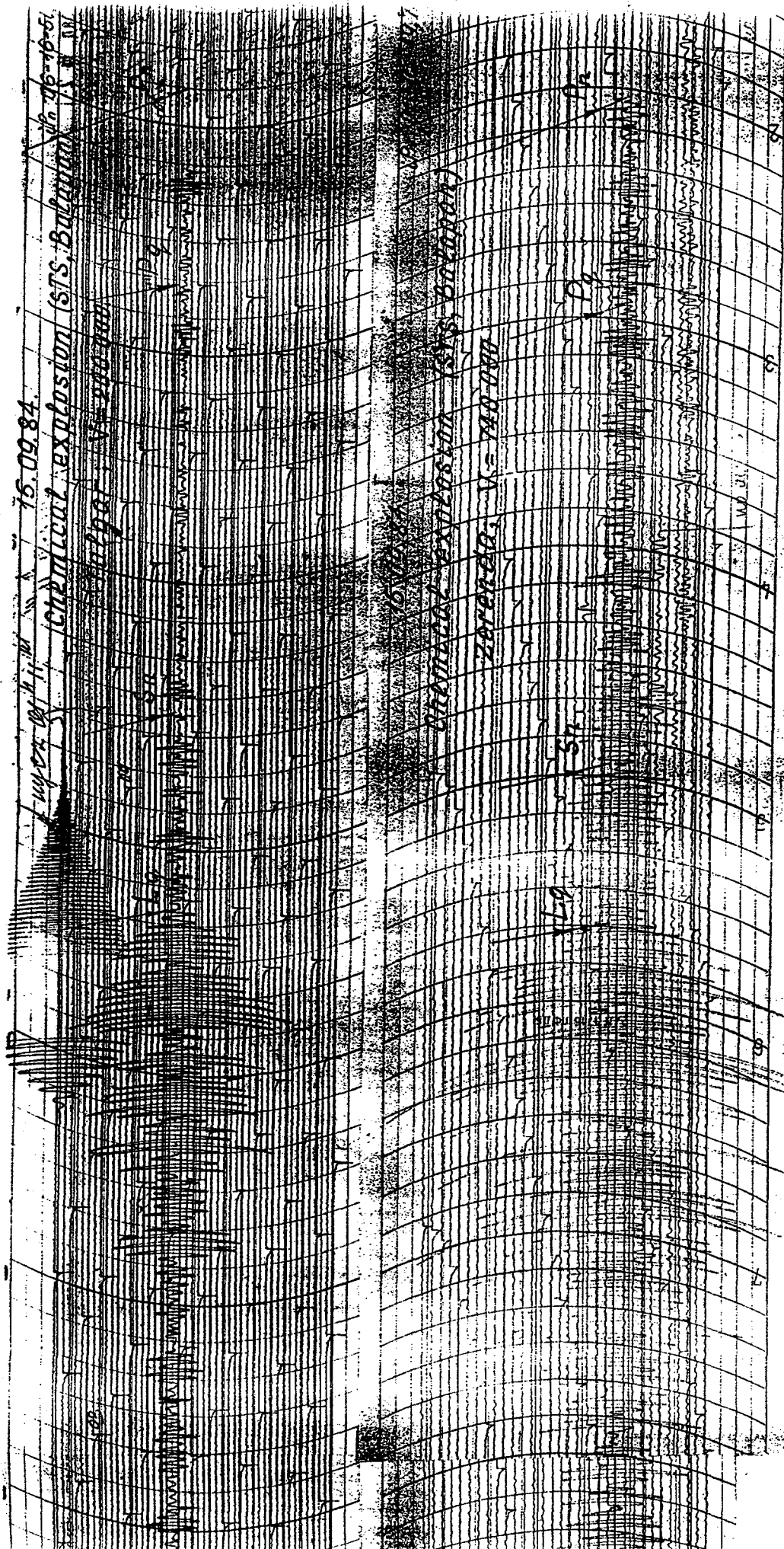


Fig. 5.110

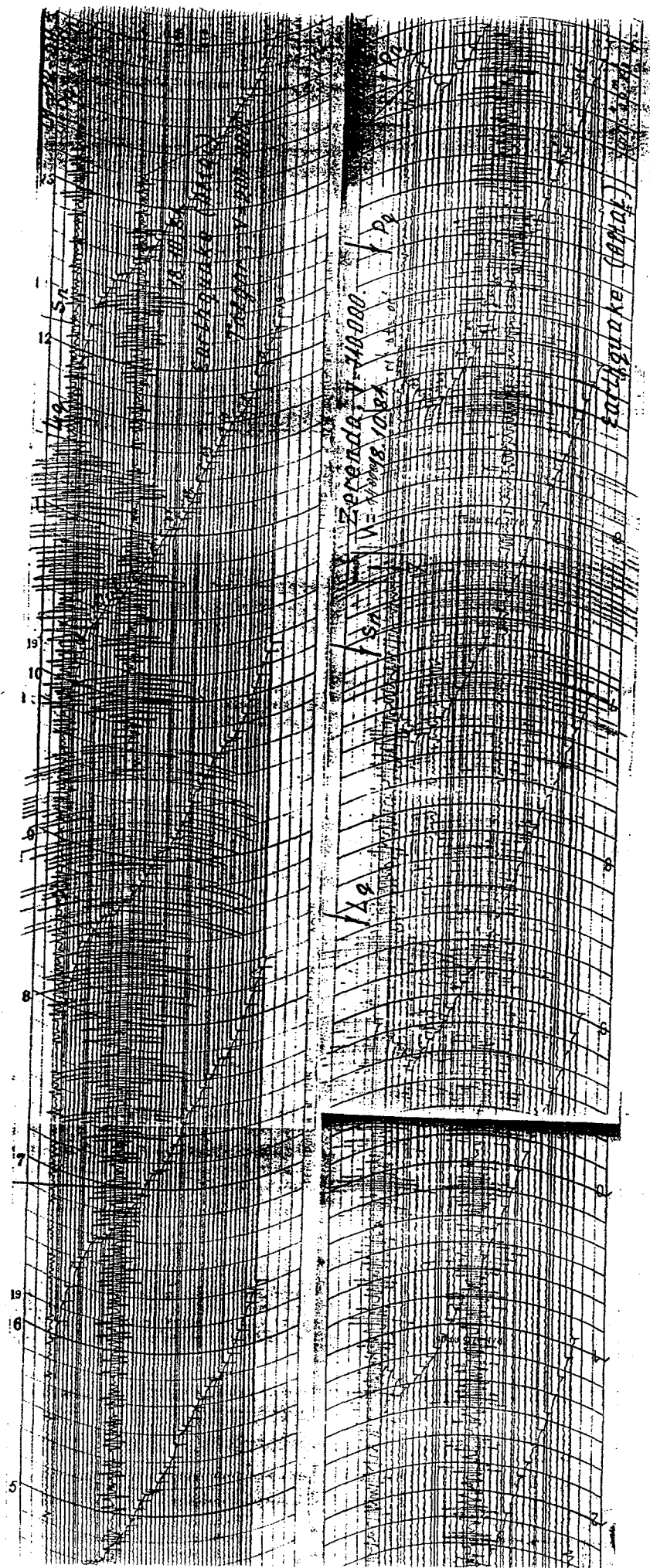


Fig. 5.110

NUCLEAR explosions (STS)
Talgar

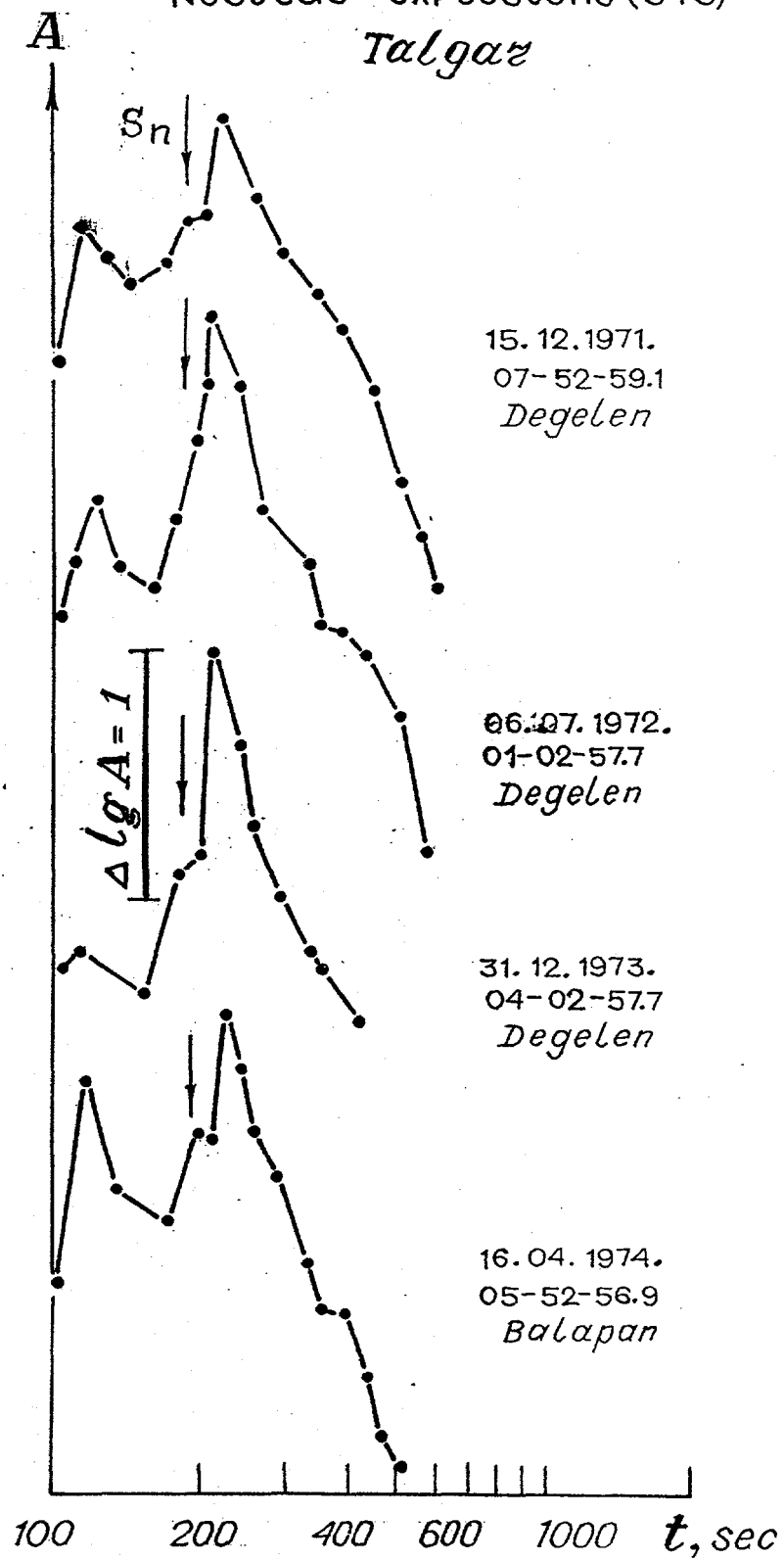


Fig. 5.12a

nuclear explosions (STS)

Zvezda

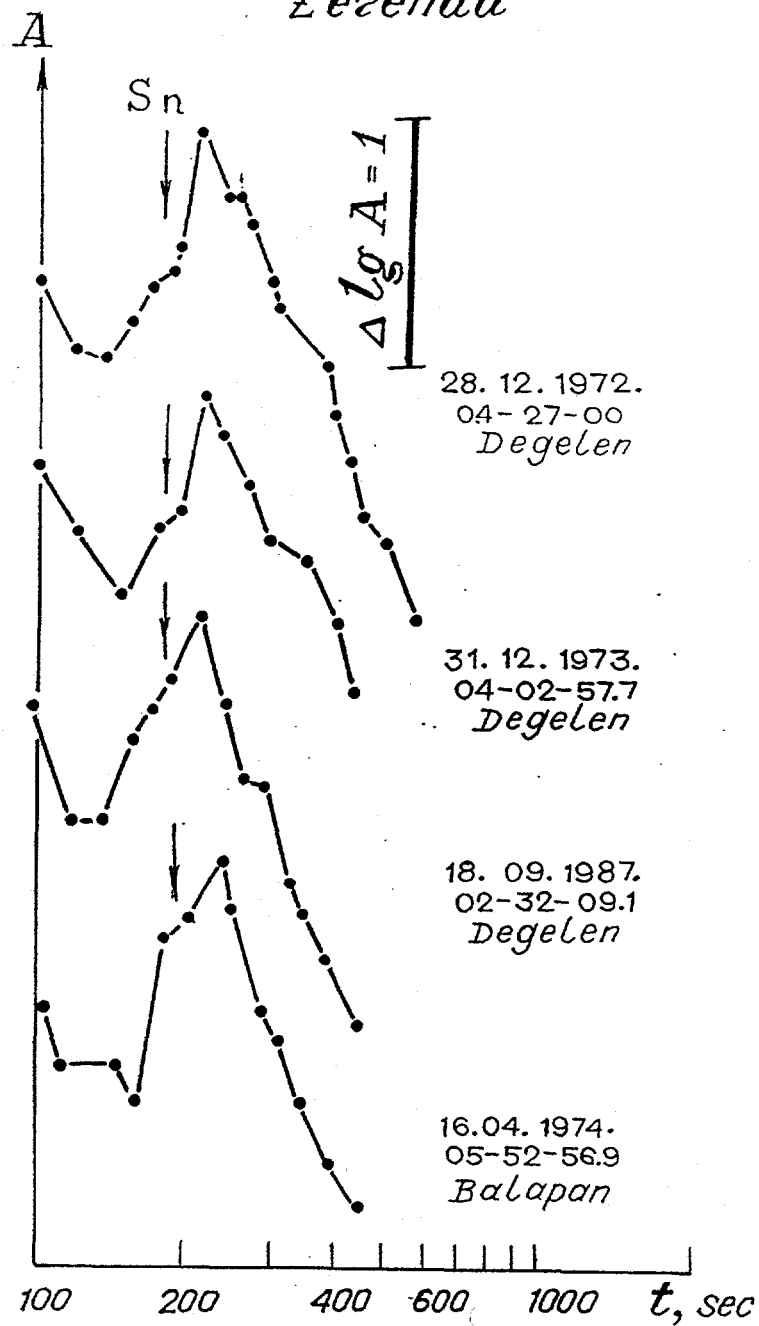


Fig. 5.12b

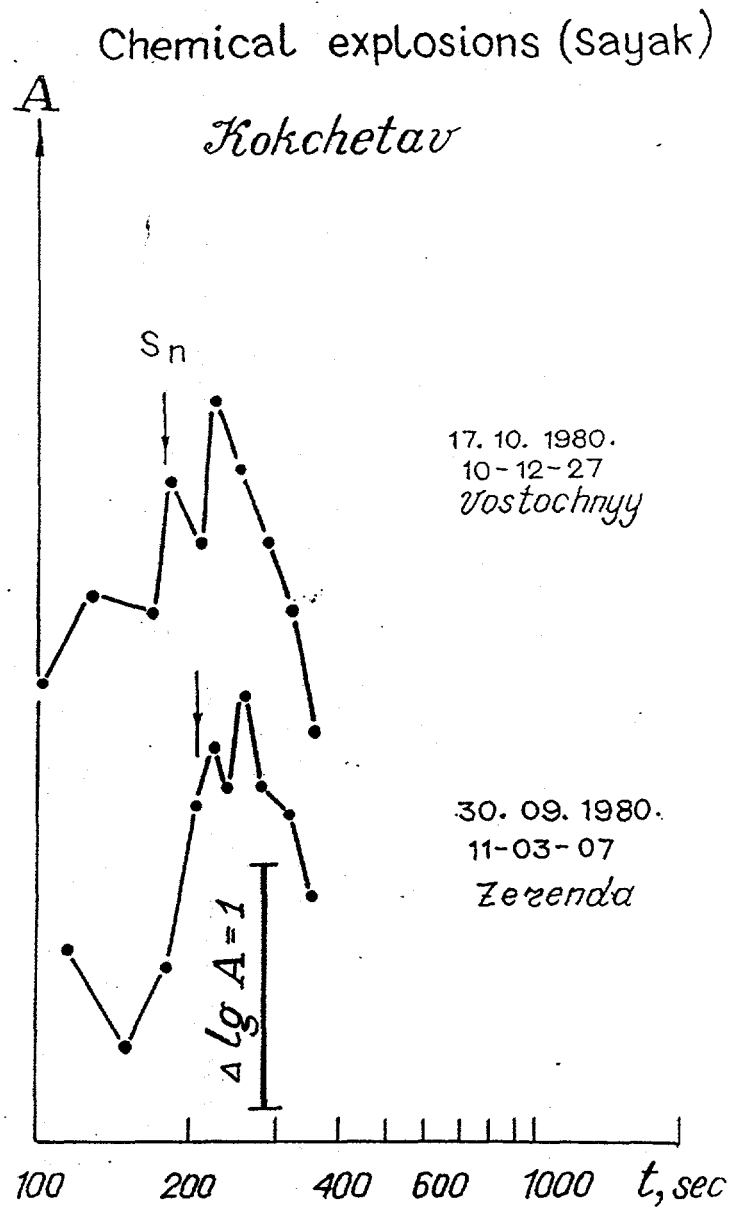


Fig. 5.12c

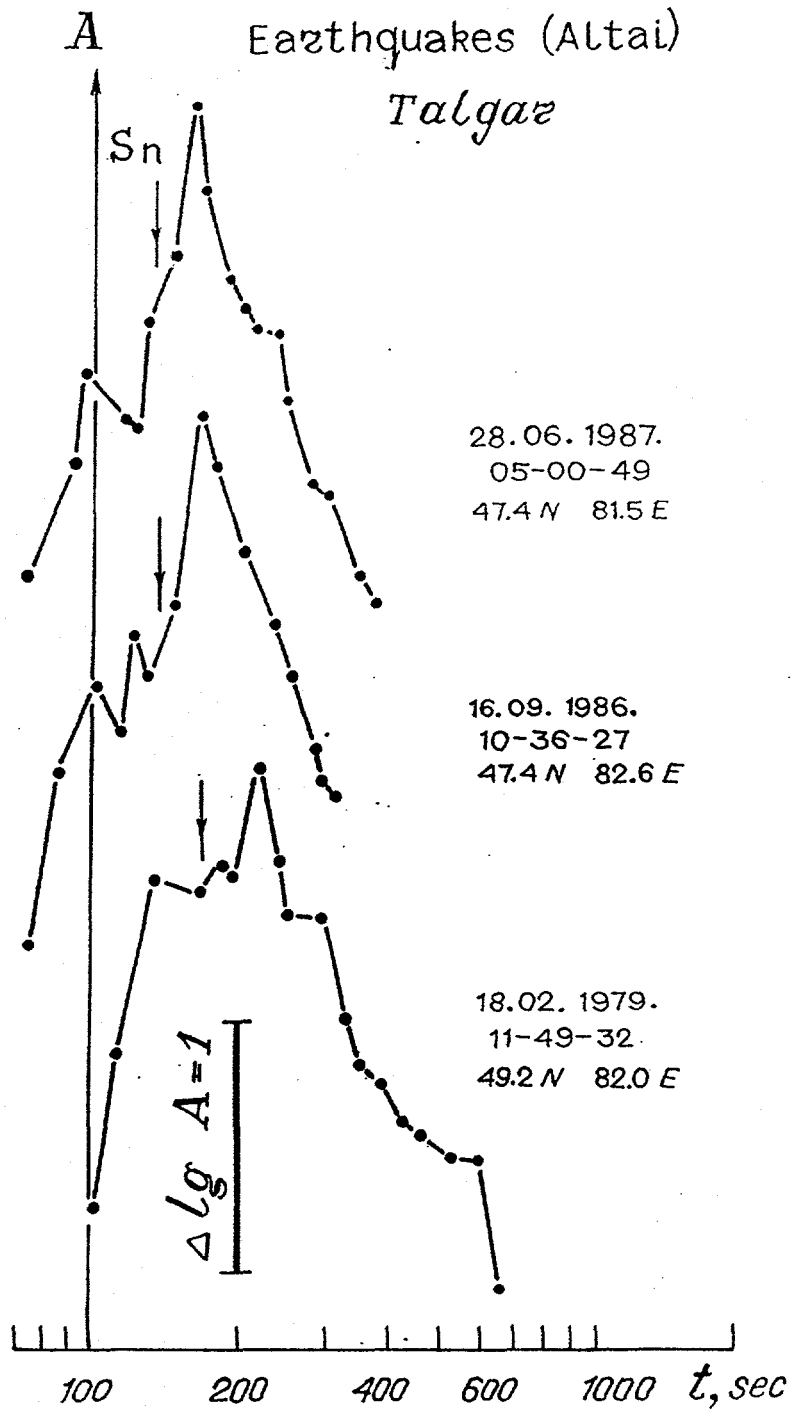


Fig. 5.12d

- 218 -
Earthquakes (Altai)
Kokchetav

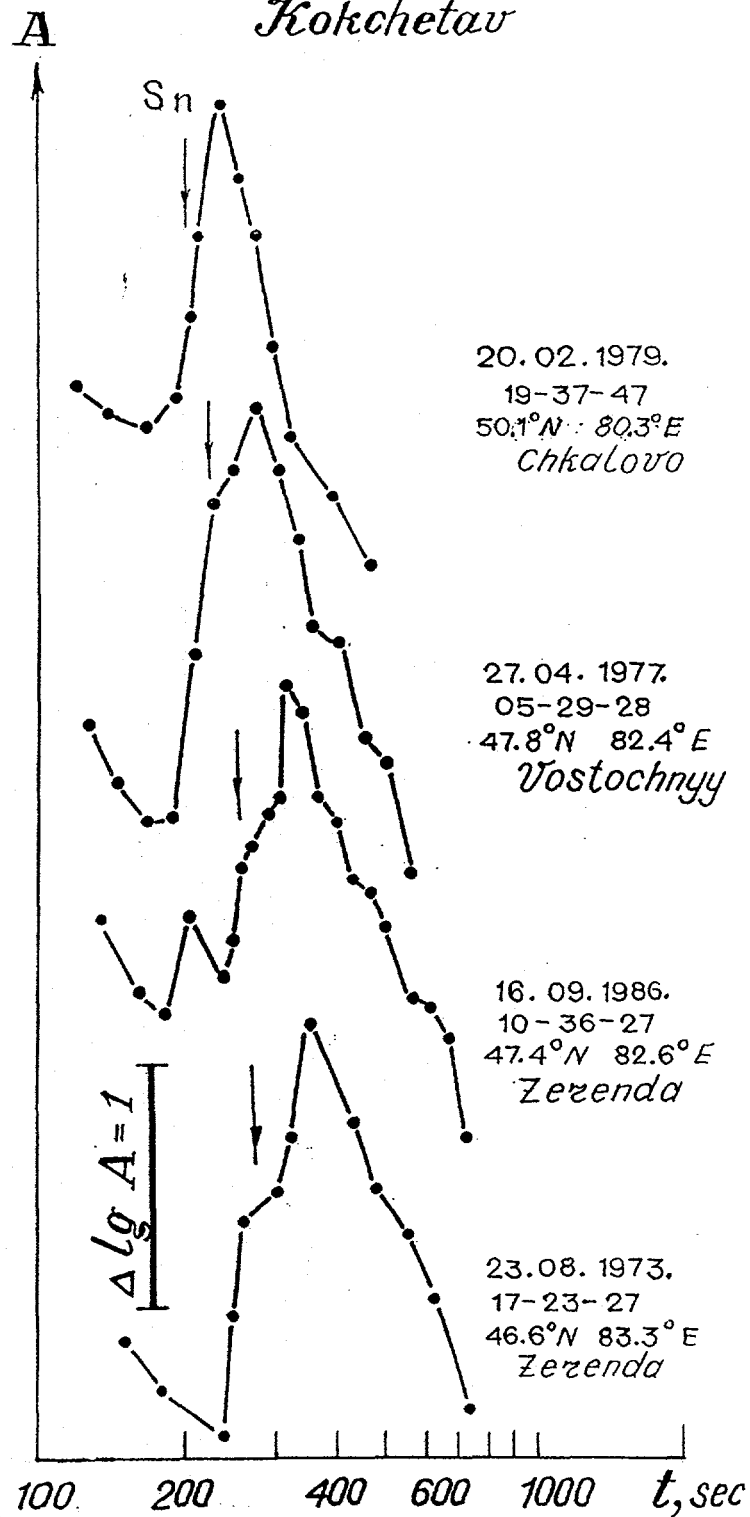


Fig. 5.12e

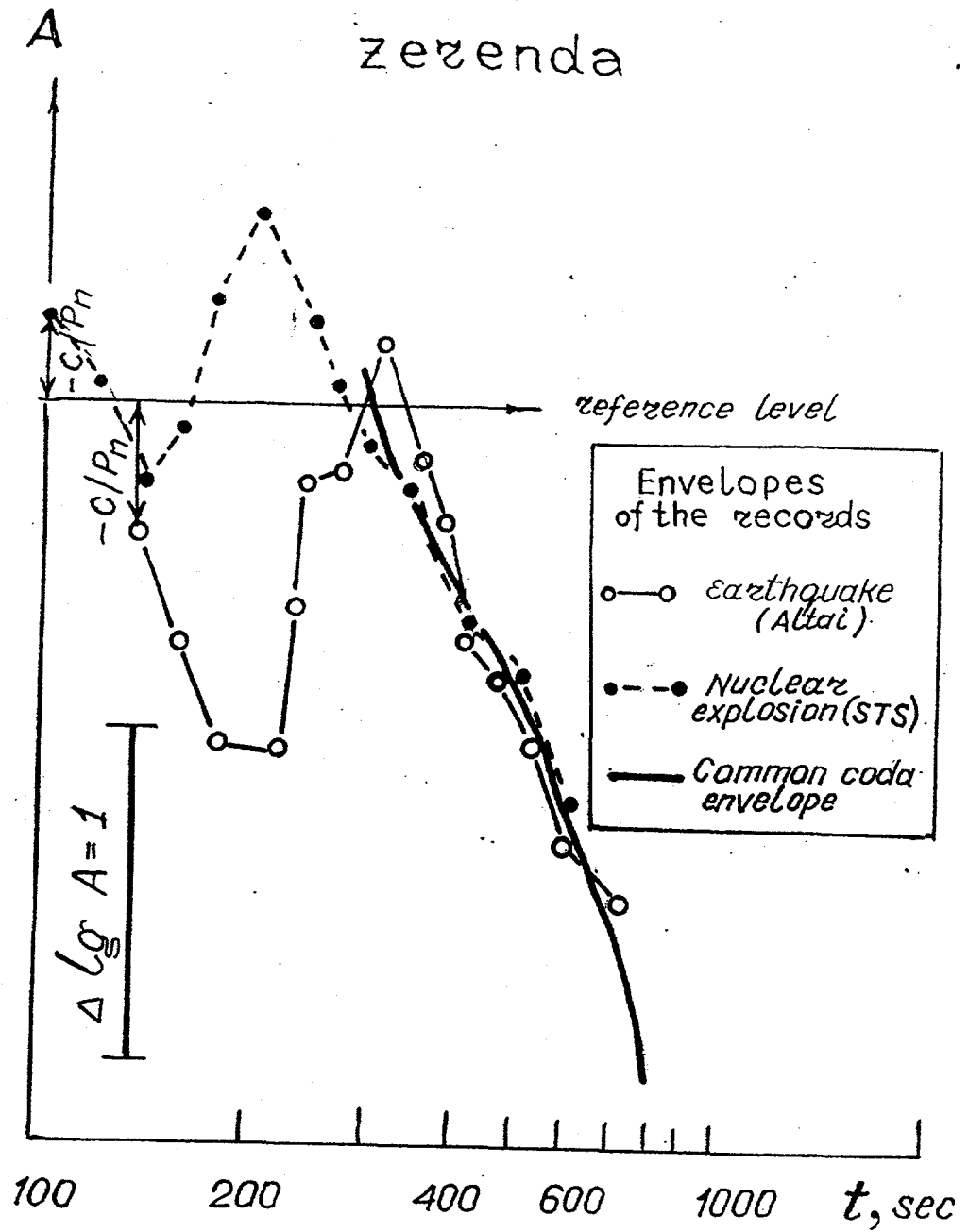


Fig. 5.13

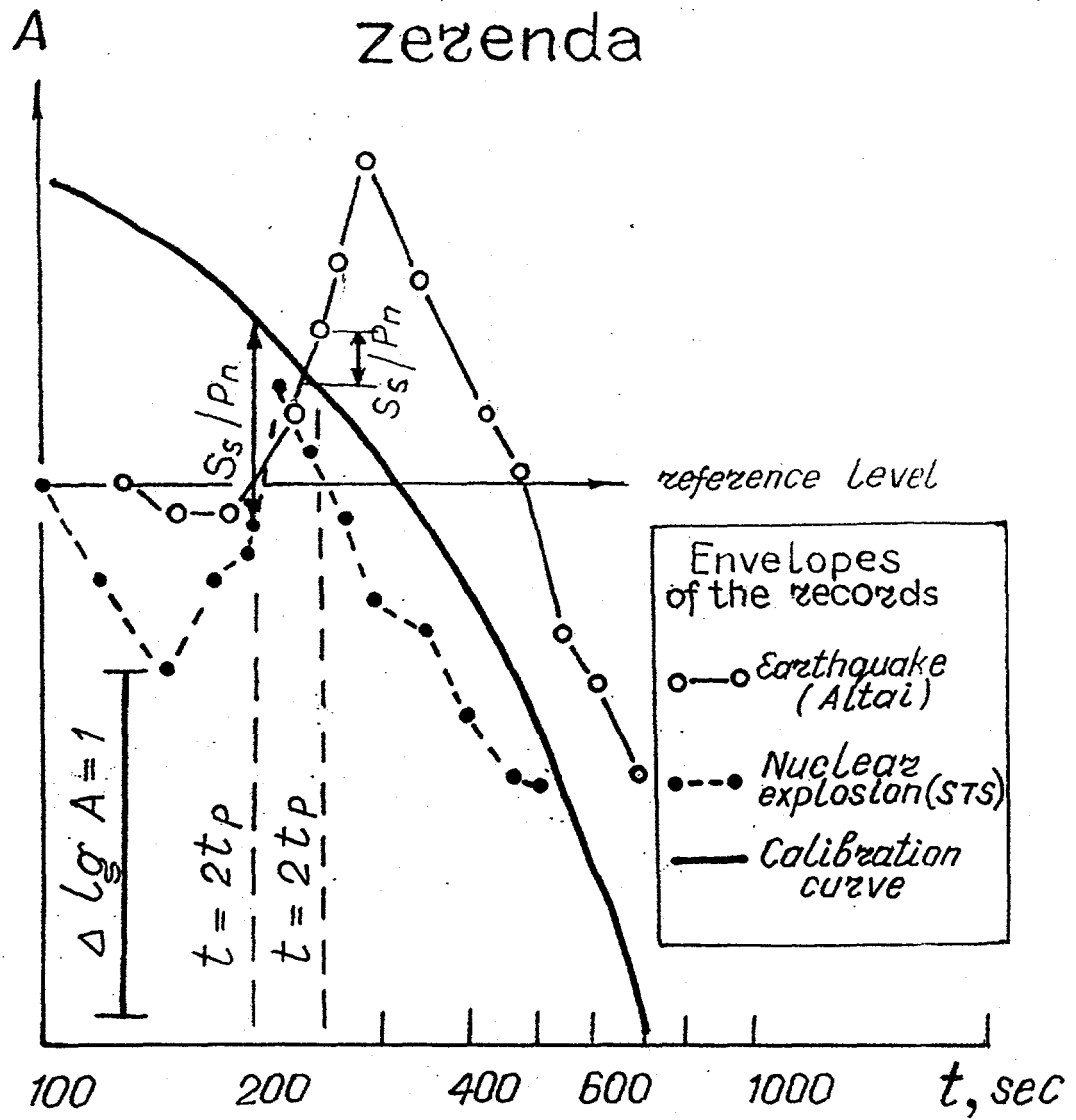


Fig. 5.14

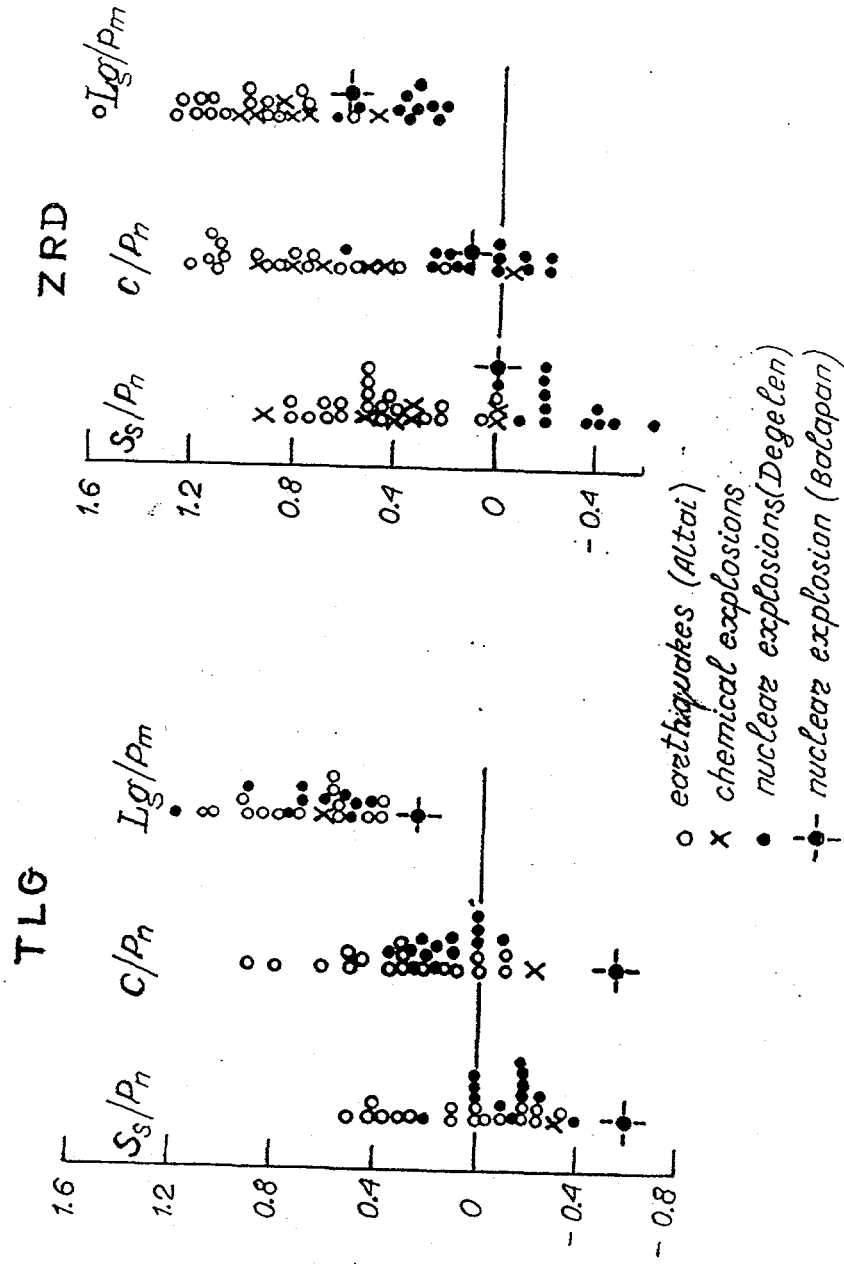


Fig. 5.15

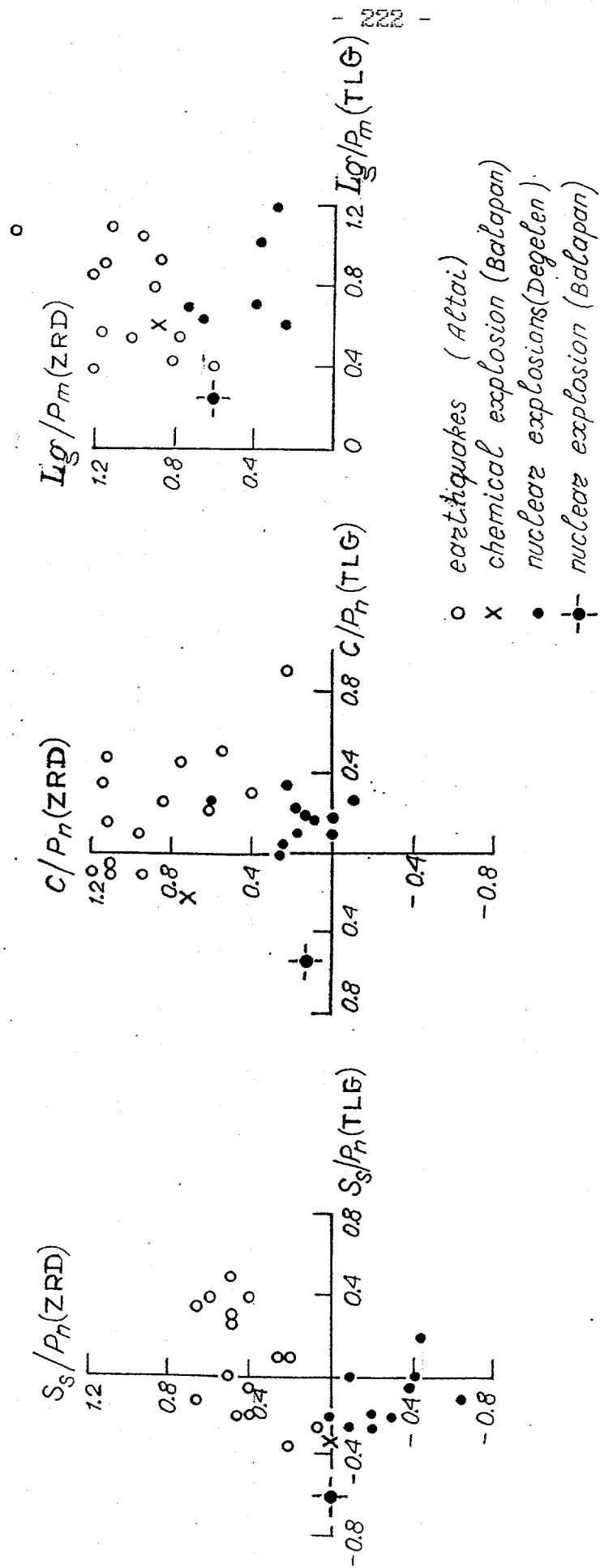


Fig. 5.16

nuclear explosions
Astrakhan', salt

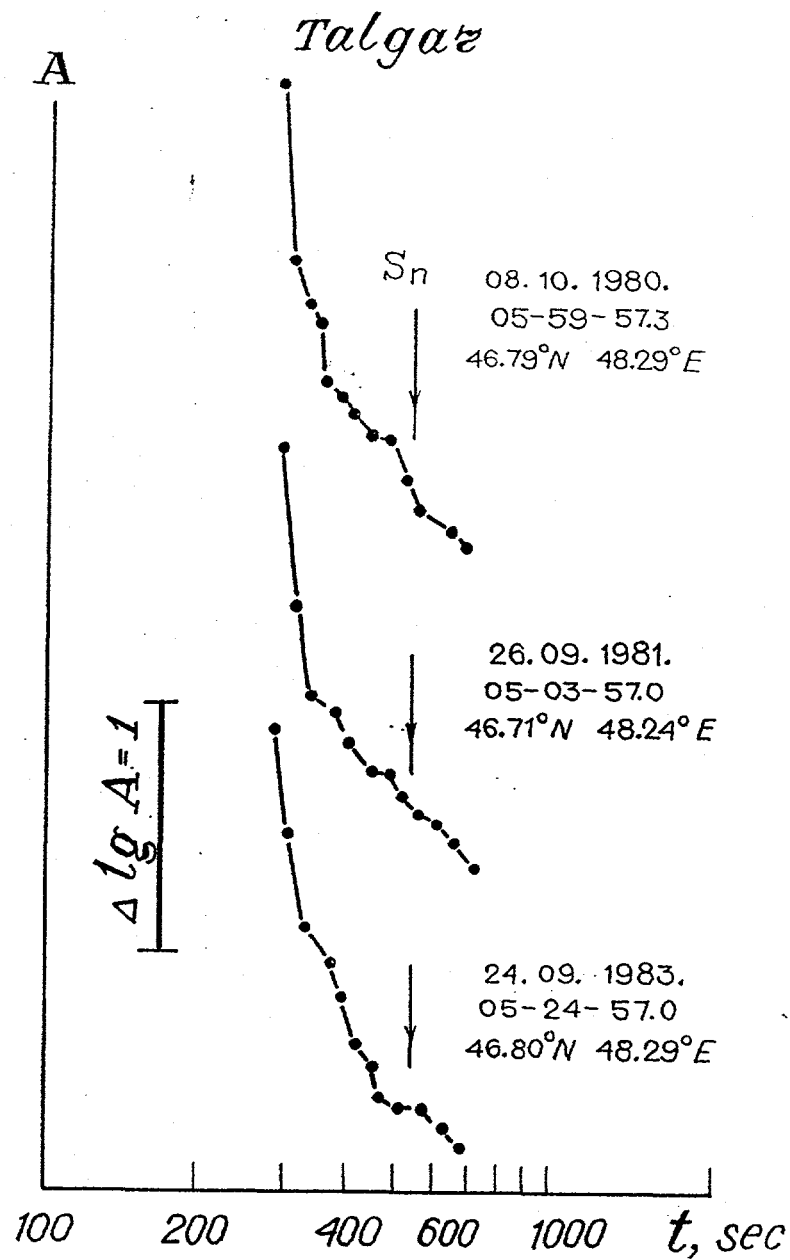


Fig. 5.17a

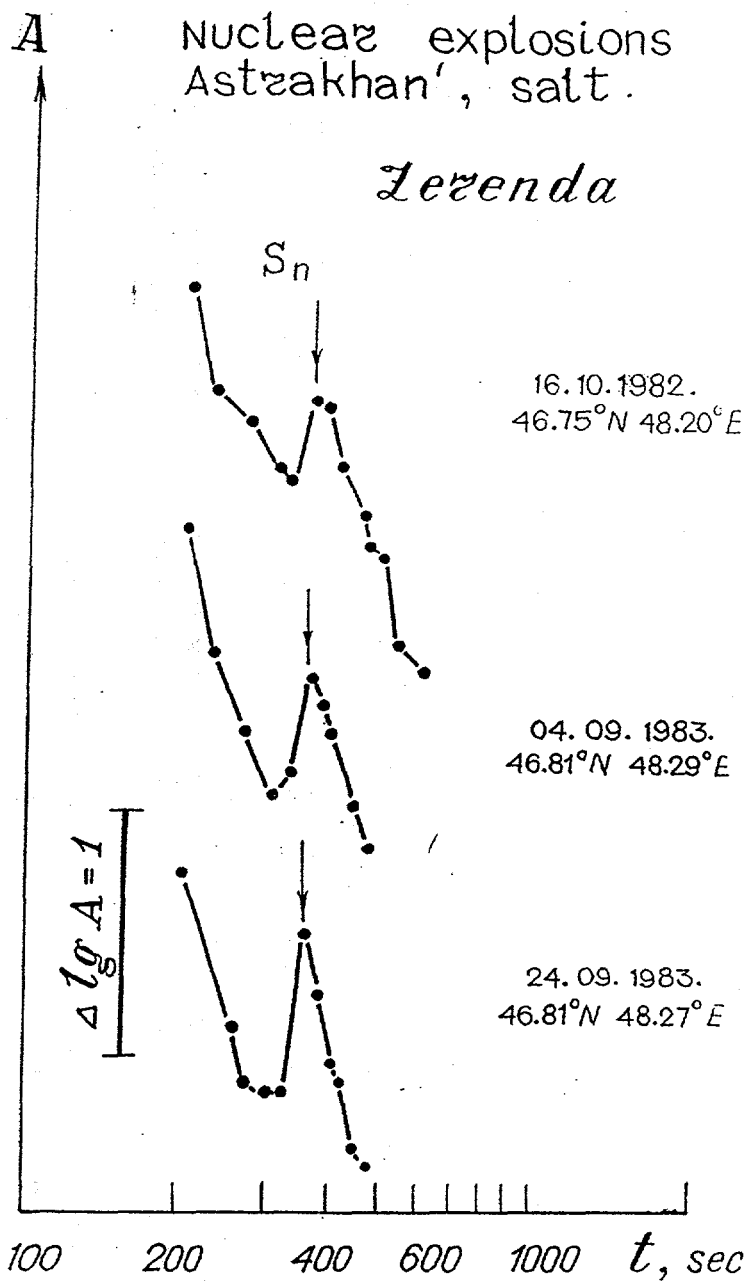


Fig. 5.17b

- 225 -
Earthquakes (Caucasus)

Talgaz

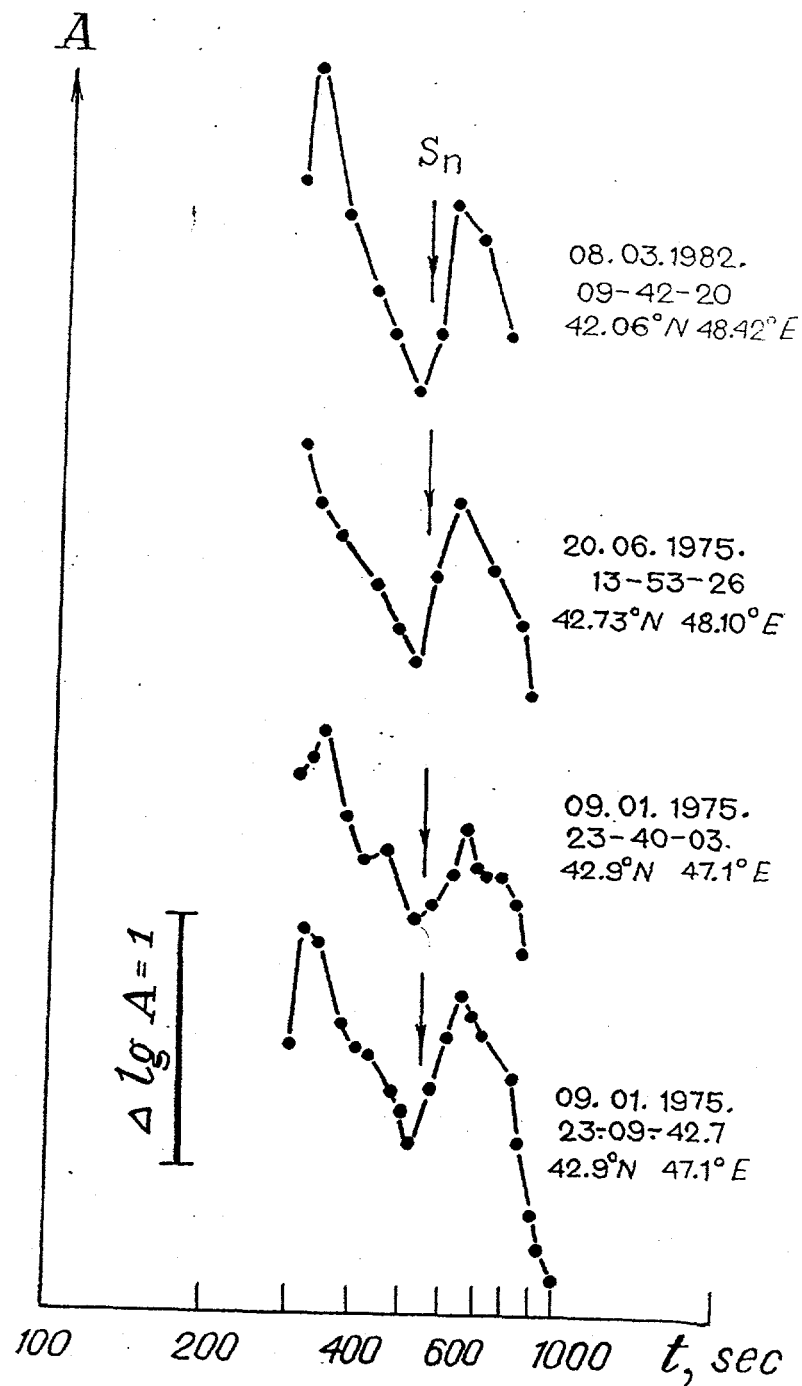


Fig. 5.17c

Earthquakes (Caucasus)

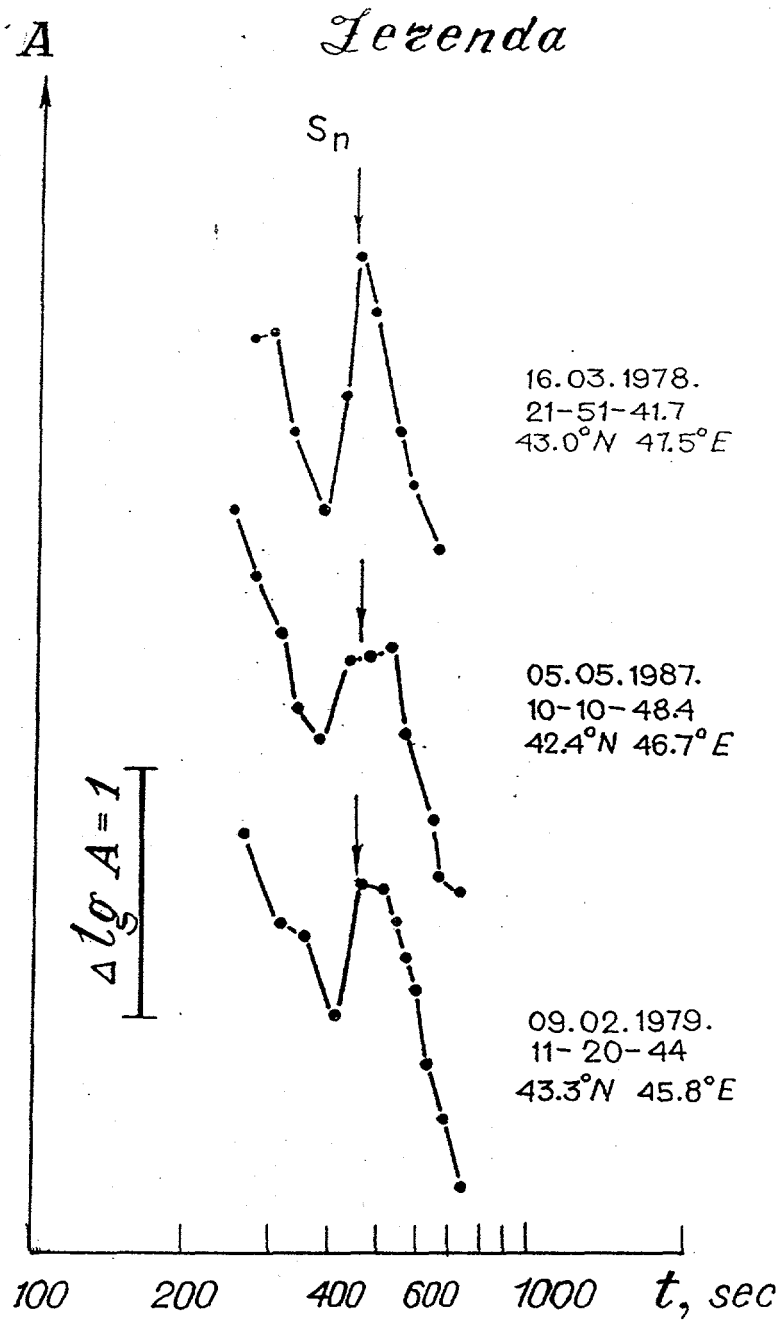


Fig. 5.17d

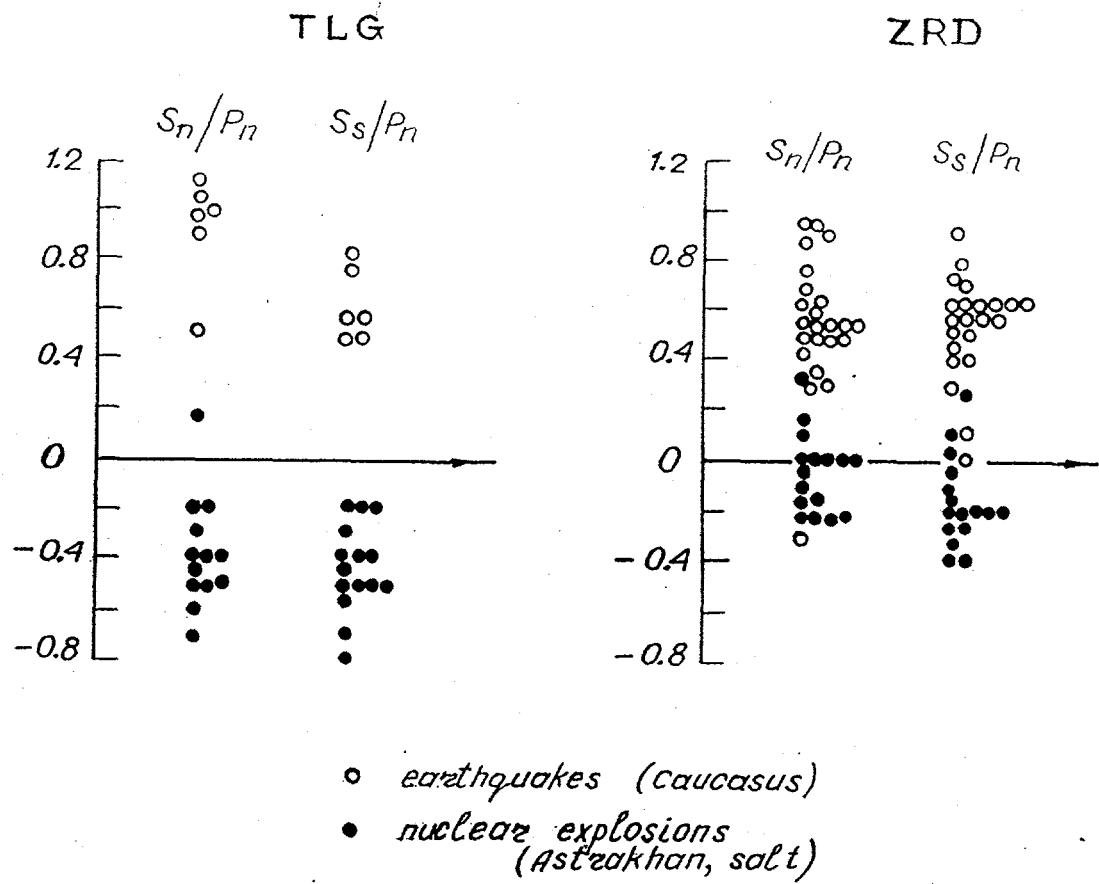


Fig. 5.18