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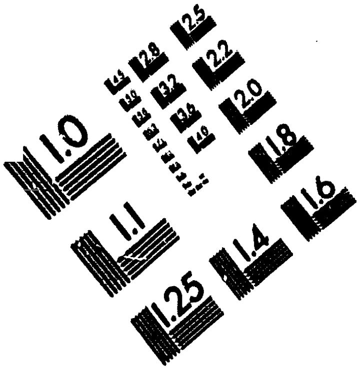

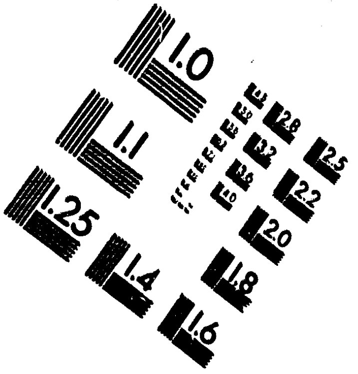

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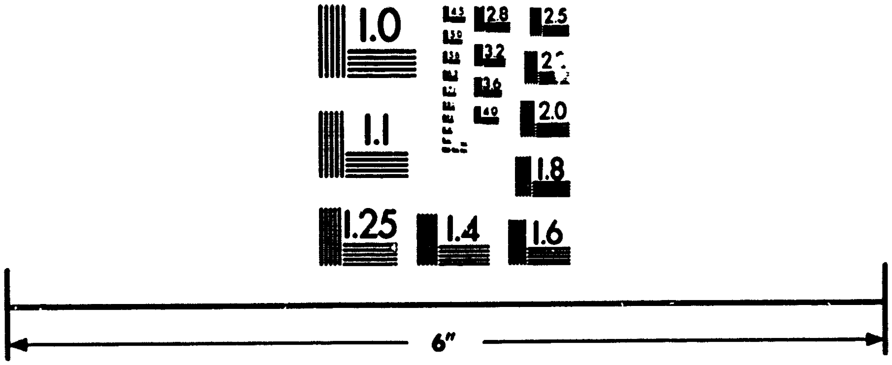

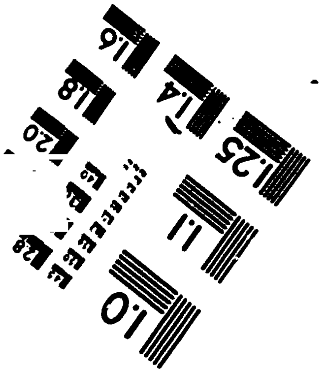

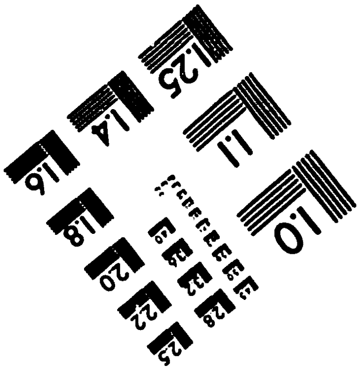

JPRS L/8374

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USSR

STUDY OF THE SEISMIC CHARACTERISTICS OF LARGE INDUSTRIAL CENTERS

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STUDY OF THE SEISMIC CHARACTERISTICS OF LARGE INDUSTRIAL CENTERS

Moscow IZUCHENIYE SEISMICHESKOGO REZHIMA KRUPNYKH PROMYSHLENNYKH TSENTROV in Russian 1978 signed to press 5 Jun 78 pp 1-188

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PART II. RADIOTELEMETRIC RECORDING

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ABSTRACT

This book investigates the development of the procedures and equipment for studying the seismic conditions of large industrial centers in seismically hazardous regions. Stationary observations in deep boreholes permitting a sharp increase in sensitivity of the equipment and centralized radiotelemetric recording which increases the accuracy of determining the coordinates of the centers in space were used as the basis for the study. A description is presented of the seismic characteristics of Alma-Ata studied by the materials of 4 years of observations.

The book is designed for geophysicists, seismologists, geologists, design engineers and builders.

There are 17 tables, 92 illustrations and 32 references.

FOREWORD

The Soviet Union has many large industrial centers located in seismically dangerous areas. In particular, these include the capitals of union republics such as Alma-Ata, Frunze, Tashkent, Dushanbe, Ashkhabad, and so on, and tens of oblast centers and cities with developed industry.

The development and construction of cities located in these regions require seismic regionalization, the statement of the problems of predicting earthquakes. They are unthinkable without further study of the seismicity of the territory and improvement of the instrument observation network. With an increase in construction intensity the requirements on the detailed study of the seismicity grow. However, the successful solution of the problem is connected with consideration of certain specific peculiarities. The basic one of them is the high level of seismic interference caused by the vital activity of large centers which limits the sensitivity of the equipment and makes it impossible to record weak local earthquakes which are of special interest during periods of "quiet" in the seismic regime. The stations located at sufficiently great distances from a city stop "noticing" weak local earthquakes even before the city has "felt" them. In addition, for all earthquakes which can be recorded, the accuracy of the constructions falls off as a result of the distance between stations. At the same time when studying the seismic characteristics of a local area it is necessary to insure high precision of all of the construction, including tracing of the zones that are seismically active at the present time.

These contradictions greatly complicate the study of the seismic characteristics of large industrial centers in seismically hazardous regions.

Accordingly, during the last decades the Institute of Earth Physics of the USSR Academy of Sciences in cooperation with the Institute of Geology and Geophysics of the Kazakh SSR Academy of Sciences has performed research in the development of procedures and equipment to study the seismic characteristics of large industrial centers. Studies have been performed in the vicinity of Alma-Ata, which is located in a force 10 zone for which a "quiet period" in the seismic activity is now characteristic. The basic areas were to increase the sensitivity of the equipment and improve the accuracy of the constructions.

It appeared that it is possible to achieve increased sensitivity of the equipment under the specific conditions of a large city by organizing observations in deep boreholes. Let us note that there is no experience in deep-well seismology in the USSR.

In order to increase the accuracy of the constructions, first of all it was necessary significantly to increase the accuracy of the time service.[1] This could be achieved by centralized multichannel recording of the signals at all stations located in the research area with a united time service. The prospectiveness of this recording was determined by one of the basic trends in modern seismology realizing the transition from observations by a network of scattered stations located at great distances (hundreds and more kilometers) from each other to observations by a large number of stations located in a comparatively small area. The groups formed in this case permit use of the directional interference procedure, correlation analysis of the waves and improvement of the resolution of the seismic methods.

The principles of this area of study were laid down by the works of G. A. Gamburtsev on the correlation method of studying earthquakes in Northern Tyan'-Shan', Pamir and Turkmenia in 1951-1953 [21, 23, 27-29].

In this book a study is made of the problems connected with the mentioned problems and also the results of 4 years of study of the seismic regime in Alma-Ata.

The first part of the book is on deep-well seismology. Descriptions are presented of the equipment and the specific peculiarities of performing stationary highly sensitive seismologic observations in deep wells (Chapter I), the laws of decrease in level of seismic noise with depth. An estimate is made of the possibility of increasing the sensitivity of the borehole observations under various seismogeologic conditions (Chapter II). It is demonstrated here that in order to increase the sensitivity and accuracy of the constructions it is significantly more advantageous to go "under the city" than away from it to the side.

The second part of the book contains a description of the Alma-Ata test area of automatic ground surface and deep-well stations and also the radiotelemetric recording system (Chapter III). A detailed description is presented of all elements of the set of radiotelemetric recording equipment. The basis for the radio channel was the system developed by V. G. Katrenko [37].

In spite of the fact that the studies were basically of a procedural nature, the data obtained as a result of operation of the test area made it possible to study the seismic conditions of Alma-Ata. These results not only confirm the effectiveness of the developed procedure but also are of independent interest (Chapter IV). A detailed description is presented of the initial material and the procedure for processing the multichannel seismograms. Considering the novelty of the operations, we have considered it expedient to present a quite large number of primary seismograms in the description.

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[1] [accurate hour's service]

In the concluding Chapter V a description is presented of the basic peculiarities of the seismic conditions. A study was made there of the effect of the observation conditions on construction of seismograms and the azimuthal deviations of the seismic beams.

The accumulated experience has shown that the developed procedures and equipment can be recommended for studying the seismic conditions of large industrial centers located in seismically dangerous zones and also to solve other problems of seismology. Therefore the procedure and equipment are described with a degree of detail which is sufficient for organization of analogous studies in other areas.

This is all the more significant in that the study of the weak local earthquakes is acquiring greater and greater interest in the problem of earthquake prediction. Thus, in the second phase of the national program of Japan for predicting earthquakes which was started in 1976, in order to record the weak local earthquakes in the vicinity of Tokyo provision was made for the creation of a test area of three highly sensitive stations, the seismographs in which will be located at depths of 2500 and 5500 meters [76].

The book was written on the basis of reports from the coworkers of the Laboratory of Deep-well Seismology Ye. I. Gal'perin, L. M. Vorovskiy, R. M. Gal'perina, P. A. Troitskiy, A. K. Trofimov, A. I. Chesnokov. The material was prepared by L. M. Vorovskiy (Chapters I, II, Chapter III, §1, 2), A. I. Chesnokov (Chapter III, §3-5), R. M. Gal'perina (Chapter IV, Chapter V, §2, 3), §1 of Chapter V was written by I. L. Nersesov, the foreword was written by Ye. I. Gal'perin and the conclusion by Ye. I. Gal'perin and I. L. Nersesov.

In addition to the authors, the research was participated in by V. P. Kharin and M. I. Moshul, and in individual phases also by P. A. Troitskiy (1970) and A. K. Trofimov (1972-1973). V. G. Katrenko was of significant assistance in organizing the radiotelemetric recording (1971). A. P. Vorovskaya, G. L. Suzdorf, L. A. Ditler and A. V. Frolova basically participated in the processing and interpretation of the materials and the formatting of the monograph.

All of the studies were performed under the direction of Ye. I. Gal'perin.

The authors express their appreciation to all of the coworkers participating in the studies and the preparation of the monograph.

PART I. DEEP-WELL SEISMOLOGY

When solving many of the problems of seismology, highly sensitive operations are the basis determining the level of investigation. This pertains, in particular, to the study of the seismic characteristics of large industrial centers. One of the possible means of increasing the sensitivity of the equipment is observation in wells or boreholes.[1] The new area is developing as deep-well seismology, and with each year it is finding broader and broader application.

The seismic noise formed basically by surface waves decreases with depths. However, even the useful signal at internal points of the medium is weaker than on the surface. This is explained by the fact that on the day surface the wave amplitude is doubled as a result of reflection from the earth-air interface. The possible gain in sensitivity of the equipment on burying the seismograph is determined by how much faster the noise level decreases with depth than the useful signal.

For the development of deep-well seismology it was first of all necessary to build equipment which could be used for observations in the wells, to study the laws of variation with depth of the seismic noise background under various seismogeological conditions and to estimate the possibilities of increasing sensitivity of the equipment for observations in boreholes. The resolvability of the seismic recording is determined not only by the signal/noise ratio, but also by the complexity of the shape of the useful signals. Therefore, along with the wave-noise distribution with respect to depth it is necessary to study the laws of variation of the shape of the useful waves. These problems are the subject of this part of the book.

CHAPTER I. EQUIPMENT FOR BOREHOLE OBSERVATIONS

Observations in deep wells are connected with a number of specific peculiarities of both a technical and theoretical nature. On the one hand, the

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[1] Here and hereafter we shall use the word sensitivity to mean useful sensitivity, that is, maximum amplification that can be realized with an admissible noise level.

decrease in seismic noise level with depth makes it possible to increase the sensitivity of the equipment. On the other hand, as a result of high temperature and pressure, long length of the cable and other reasons, the equipment noise increases. In addition, the performance of the observations in the boreholes is connected with ecological difficulties. The basic means of increasing the signal/noise ratio under these conditions is the low-noise equipment which has been developed and used for short-term (vertical seismic profile) and stationary observations.

§1. Deep-Well Seismometers

Before the beginning of the described research in the Soviet Union there were no low-frequency seismometers for stationary seismological observations in deep wells. Comparatively few observations of a reconnaissance nature were performed in 1961-1962 using ground seismometers designed for regional studies (NS^{-3} with a natural frequency of 2-4 hertz). However, during the first years after the beginning of studies (1966-1967) low-frequency seismometers were developed for seismological observations in deep wells. For deep well observations of both short-term, profile and stationary type, seismometers of two types were used which were developed at the Institute of Earth Physics of the USSR Academy of Sciences -- the SBU-V (designed by G. L. Shnirman) and SD-1F (designed by N. Ye. Fedoseyenko).

The SBU-V seismometer. The deep-well vertical magnetoelectric SBU-V seismometer (a high-gain, vertical seismometer) is designed for recording the vertical component of the seismic oscillations in deep, specially equipped wells [59]. The general view of the seismometer without the protective case is shown in Fig 1, a. In the upper part of the device there is an automation compartment which provides for performance of the instructions transmitted over the logging cable from the control panel located on the surface. In the lower part of the device there is a pendulum compartment. The pendulum system (Fig 1, b) is in the form of the mass M and the extension arms P_1 and P_2 on which the operating coils K_1 and K_2 are fastened. The entire system is suspended on a cylindrical coil spring П with zero length so that the axis of rotation of the pendulum and its center of gravity are in the same horizontal plane. On oscillation of the pendulum, the operating coils are shifted in the annular radial gaps of the two magnetic systems rigidly connected to the base of the instrument (not shown in the diagram).

The basic parameters of the seismometer are as follows: coil resistance about 300 ohms, the oscillation period is regulated from 0.8 to 1.2 seconds, the reduced length is 11 ± 2 cm, the electromechanical constant is no less than 11 Webers/rad, the moment of inertia of the pendulum is $7\cdot10^{-3}$ $kg\text{-}m^2$, the sensitivity on a frequency of 2 hertz is 0.5 mv/micron, the damping is 0.4, and the operating temperature range is from 0 to +80°C. The container insures a seal at a pressure to 20 MPa. The seismometer set includes the following: the seismometer itself, the ground control panel, the feed unit and the connecting cable. The ground control panel permits remote realization of the following operations: locking and unlocking of the seismometer; switching the system on and off regulating the position of equilibrium of the pendulum; measurement of the natural oscillation period of the pendulum; feeding of the calibration pulse to the coils. The panel feed can be realized either from the 24 volt storage batteries or the 220 volt AC network.

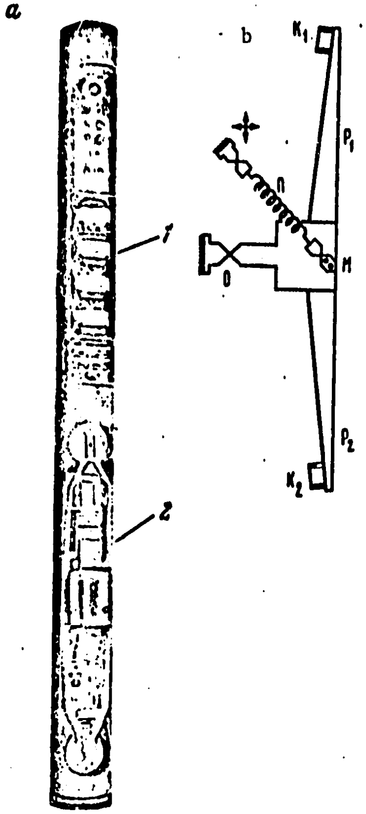

Figure 1. SBU-V Seismometer
a -- General view with automation (1) and pendulum (2) compartments; b -- schematic of the pendulum.

Although the SBU-V seismometer is designed for stationary observations it is necessary to note that it has been used successfully for profiling, withstanding more than 500 cycles of unlocking, swinging and locking without any significant failures. During the stationary observations the SBU-V seismometer can operate for years. In practice all of the stationary observations were performed by the SBU-V seismometer.

SD-1F Seismometer. This seismometer [57] is a device with a magnetic cushion and zero reduced length. The testing of the seismometer and the development of the control system for it were carried out with the participation of the authors of this paper. The structure and the operating principle of the seismometer are obvious in Fig 2, a. Two magnets (stationary 6 and moving 3 distributed on springs of the membrane type 11) are turned with the like poles toward each other. The moving magnet is the pendulum of the seismograph. In the gaps of the two magnetic systems there are operating coils: a stationary coil 12 rigidly connected to the housing of the device and located in the gap of the moving magnet, and the moving coil 14 which is fastened to the moving magnet and in the gap of the stationary magnet.

The pendulum of the instrument (the moving magnet) is adjusted and suspended by using additional magnets: astasing 1 and supporting 2. The instrument is locked by pressing the pendulum into the extreme lower position which is realized remotely using a reversible electric motor 15 fed a direct current from the day surface.

The basic parameters of the seismometer are as follows: amplitude range of oscillations of the inner mass ±5 mm; damping 0.4; resistance to the operating coil 600, damping coil 400 ohms; the period of the natural vibrations is 1 second; the coefficient of electromechanical coupling of the operating coil is 1.2 volt-seconds/cm.

For remote control of the seismograph (the seismometer) a control panel was used which has been developed and manufactured by V. G. Katrenko. The panel is made up of four basic units: the pulse generator, stabilizer, pre-amplifier and switching devices (Fig 2, b).

By using the panel it is possible to feed a voltage to the electric motor of the seismograph and test pulses to the calibration coil of the pendulum, to switch the input of the pre-amplifier and the operating coils of the pendulum, and to monitor the feed conditions. The pendulum is unlocked by feeding a voltage to the electric motor 15 (Fig 2, a) which drives the locking mechanism. When swinging the pendulum, its position is controlled by heteropolar adjustable pulses generated by the pulse generator.

The period of the seismograph is determined and regulated directly in the well using a panel specially manufactured for this purpose. The electric response of the pendulum system to the test pulse is amplified by the high-resistance DC amplifier and is fed to the pointing indicator. After swinging the pendulum and establishing the required period, the seismograph is switched to the operating amplifier, and the control pulses are fed to the recorder tape. The amplitudes of the pulses of opposite polarity must be strictly the same in this case.

The SD-1F device which is structurally simple and easily controlled can be used successfully for deep-well observations of the profiling type when multiple repetitions of the unlocking-swinging-locking cycle are required.

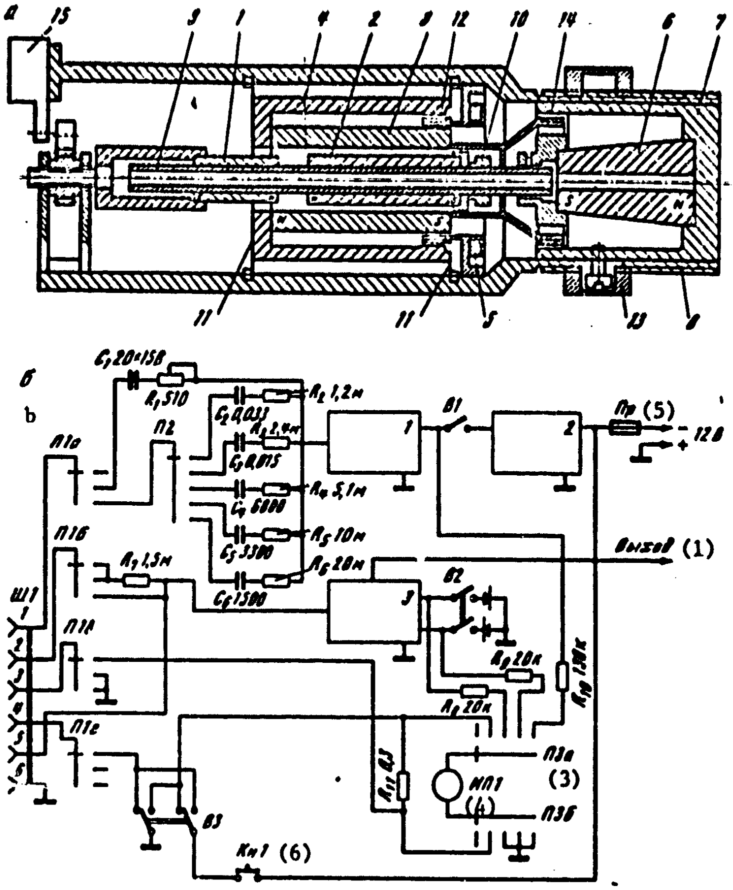

Figure 2. SD-1F Seismometer
a -- general view: 1 -- astasing magnet, remotely controlled electric motor, 2 -- supporting magnet, 3 -- principal magnet, 4 -- magnetic circuit of the upper converter, 5 -- calibration coil, 6 -- principal magnet of the lower converter, 7 -- magnetic circuit of the lower converter, 8 -- housing, 9 -- guide rod, 10 -- split bushing for regulating the position of the supporting magnet, 11 -- diaphragm type springs, 12 -- operating coil, 13 -- nut for regulating the position of the magnet and the magnetic circuit of the lower converter, 14 -- moving operating coil, 15 -- MKM or MSV electric motor;
b -- control panel electric circuit: 1 -- pulse generator, 2 -- stabilizer, 3 -- preamplifier.

Key:
1. output; 2. Sh1; 3. P3a, P3b; 4. IP1; 5. Pr; 6. Kn1.

It must be noted that, as the experience of 5 years of observations has indicated, the sensitivity of the existing seismographs cannot be considered sufficient. For ground observations in the different phases of the research -- profile, semistationary and stationary -- series seismometers of the SM-2M, NSP-2 and VEGIK type were used. Inasmuch as all of them are manufactured in series, they are described in the literature [5], and they have long been widely used in seismic research, their characteristics and parameters are not presented.

Protective Housings and Clamping Devices. The protective housing of the deep-well instrument is designed to protect the elements of the instrument from the extreme environment. For both of the deep-well seismometers -- the SBU-V and the SD-1F -- field protective housings were used which were covered by plugs on both ends. The upper plug or head of the protective housing is designed to seal the housing, connect the instrument to the cable and place the electric leads connecting the cable strands to the instrument circuitry in it. A specially developed standardized head was used in which conical insulators with internal electric leads were inserted in the plug bridge. The inside volume of the head (just as in the series SBU-V) was filled with chemically neutral castor oil which prevents access of water or drilling mud to the electric lead. The seal of the seismograph housing was realized using rubber sealing rings. The lower plug of the protective housing is designed only for sealing the housing. The protective housings with a universal head that were used demonstrated good reliability and operation not only in the case of short-term but also long-term stationary observations lasting several years.

For the observations at any given depth and "disconnection" of the device from the day surface (when it is necessary to slack the cable), a clamping device was used which serves simultaneously for rigid fastening of the seismometer to the well walls. Out of the many types of existing clamping devices, a mechanical type unit was selected as the simplest one, not requiring additional cable strands. The basic part of the device is the spring (one or two springs, depending on the weight of the well unit) mechanically released on raising the device and holding it at the required depth. The displacement of the instrument in the well is from bottom to top in the closed position. With proper adjustment the unit operates quite stably and reliably.

§2. Preamplifiers

In connection with the difficulty of improving the sensitivity of deep-well seismometers, it appeared expedient to amplify the electric signal directly at the point of installation of it for which a preamplifier was installed. The following basic requirements are imposed on the preamplifiers operating in deep wells and combined with seismometers (the deep-well preamplifier): a) minimum dimensions; b) low natural noise level at operating temperature; c) operating stability; d) feed economy.

It is necessary to note that the difficulties in using the existing amplifiers during stationary observations at depths of about 3000 meters and temperatures of more than 100°C are determined primarily by the temperature characteristics of the amplifiers and the natural noise level.

Several types of amplifiers were tested in the various stages of the observations, in particular, the KSE and the RV3-T. For observations at low temperatures (to 50°C) corresponding to depths of 1000 to 1300 meters, a preamplifier with negative feedback was used which was developed at the Earth Physics Institute of the USSR Academy of Sciences (Fig 3, a). The amplifier has the following parameters:

Input impedance, kilohms	about 2
Noise reduced to the input, microvolts	no more than 0.5
Transmission coefficient with respect to voltage, K_{Π}	200
Feed voltage, volts	1.5
Intake current, milliamps	0.5
Operating temperature range, °C	from -15 to +45
Operating frequency range	from 0.6 hertz to several kilohertz

The circuit diagram of the preamplifier combined with the SBU-V seismometer is shown in Fig 3, b. Although the preamplifier itself has small dimensions, placement of it in the housing of the seismometer simultaneously with the two Mars or Saturn type power supply elements has involved some structural changes. It was installed in the lightning protection compartment, removing the dischargers.

The duration of the continuous stationary observations by the deep-well seismometer with the preamplifier is basically limited by the discharge time of the feed elements and amounts to about 1 year. Then the instrument must be lifted out of the well and the power pack replaced. In order to avoid excessive lifting and lowering operations, a power pack has been developed which is placed in the seismometer and is fed from the surface.

The schematic diagram of the power pack is depicted in Fig 3, c. It is a square-pulse generator assembled from two transistors. A 6-volt DC voltage is fed from the surface, it is converted by the generator to the high frequency square voltage. On being picked up from the secondary windings of the Tr-1 transformer, it is rectified, filtered and fed to the preamplifier power supply circuit. The current intake by the unit is 10-13 milliamps.

In order to avoid feeding high voltage to the power pack and preamplifier from the control panel of the SBU-V seismograph (as a result of which they can be put out of order), the RPS-20 type PO relay is introduced into the circuit diagram (Fig 3, b). This relay disconnects the power pack and the preamplifier input from the control lines during the operations of locking (unlocking) and swinging the pendulum of the seismograph.

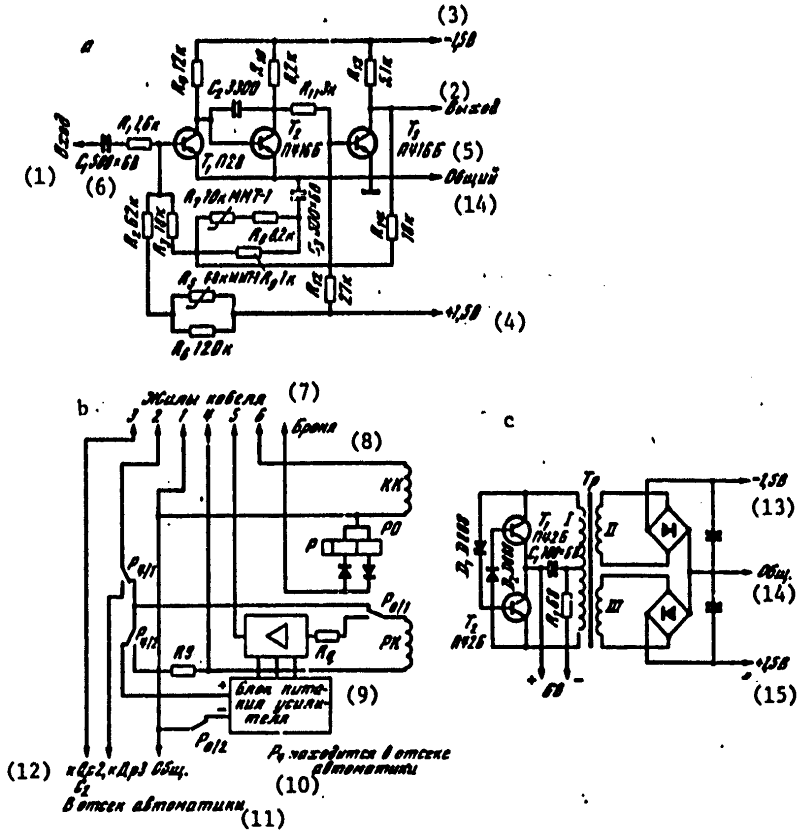

Figure 3. Preamplifier
a -- schematic diagram; b -- circuit diagram with SBU-V seismometer; c -- circuit diagram of the power pack

Key:

1. input
2. output
3. -1.5 volts
4. +1.5 volts
5. P416B
6. $C_1$500x6V
7. cable strands
8. armor
9. amplifier power pack
10. P_4 is located in the automation compartment
11. to the automation compartment
12. kDr2, kDr3, common
13. -1.5 volts
14. common
15. +1.5 volts

The placement of the preamplifier directly at the observation point permits the transmission of a sufficiently amplified signal over the cable to the surface and at the same time makes it possible to decrease the electrical inductions significantly and increase the sensitivity of the equipment.

§3. Amplifying and Recording Unit

The electric signal of the seimometer amplified at the observation point by a preamplifier is fed over the KBG-8 or KSB-6 logging cable from the borehole to the amplifying and recording equipment.

Devices developed at the Earth Physics Institute of the USSR Academy of Sciences were used as the power amplifiers in the different observation stages. The recording was done by the RV3-T type visible recorders [1]. Standard pen recorders were connected at the output of the device.

In parallel with the visible recording by the pen recorders at some of the observation points a recording was made by a ChISS frequency selection seismic station with octave filters (the resonance frequencies of the filters were 1.4, 2.8, 5.6, and 11 hertz). The recording was made on photographic paper using the RS-II recorder. The block diagram of the seismic recording channel and frequency characteristics are shown in Fig 4. At the automation stations included in the test area, the recording was made by a radiotelemetric unit which is described in Chapter III.

The control of the amplification and stability of the characteristics of the deep-well seismic channels was carried out using the calibration signal of the constant amplitude magnetic generator (MGPA).

Thus, the situation with instrument support of deep-well seismology is as follows:

1. The existing sets of equipment for the seismic observations in deep wells normally operate at temperatures to 50°C which in the vicinity of Alma-Ata corresponds to depths of 1200-1300 meters.

2. The use of a preamplifier directly at the point of installation of the seismometer in the well essentially increases the useful sensitivity of the equipment.

3. The sensitivity of the deep-well seismometer is insufficient for observation in deep wells. For profile well observations it is expedient to use the SD-1P seismometers distinguished by simplicity of control, and for prolonged stationary measurements, the SBU-8 seismometers which are stable and reliable in operation.

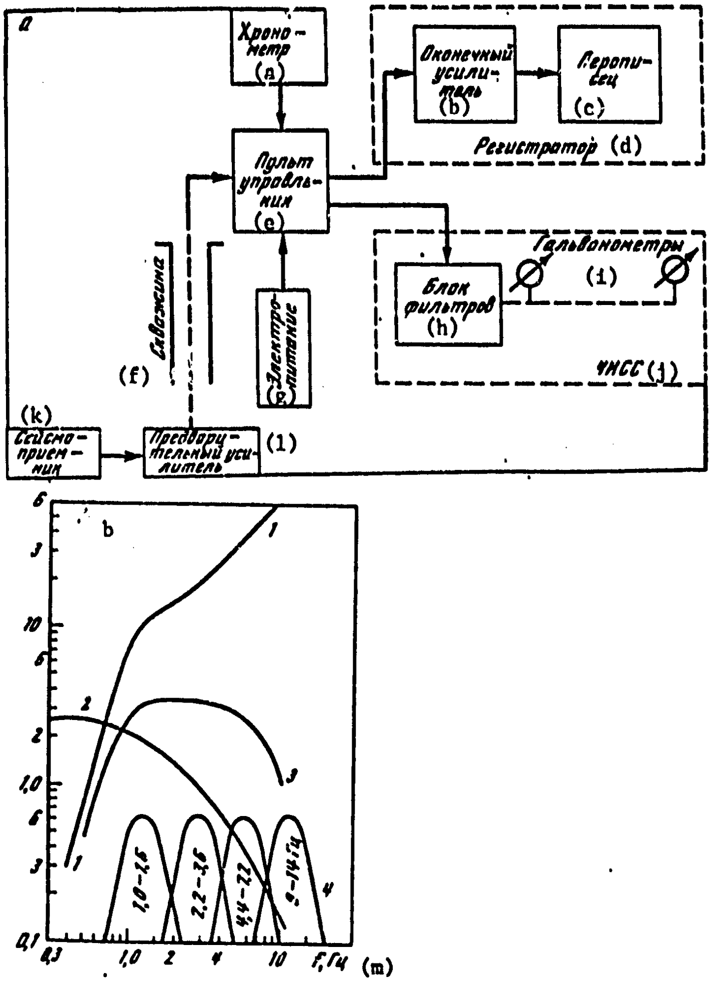

Figure 4. Seismic Channel
a -- block diagram; b -- frequency characteristics of the seismometer (1), the amplifying and recording channel (2), the entire channel (3) and the reproduction filters of the ChISS [frequency selection seismic station] (4)

Key:

a. Chronometer
b. Terminal amplifier
c. Pen recorder
d. Recorder
e. Control panel
f. Borehole or well
g. Electric power supply
h. Filter unit
i. Galvanometers
j. ChISS [frequency selection seismic station]
k. Seismograph
l. Preamplifier
m. f, hertz

4. For the further development of deep-well seismology it is necessary to improve the deep-well equipment. The basic areas here are the following developments: a) single component and triple component deep-well seismometers with a natural oscillation period of 5 seconds, the sensitivity of which is 20-40 times greater than the existing one; b) amplifiers with low noise level and channel multiplexing equipment for transmission of information from the well over the small-core cable; c) versions of the deep-well equipment with thermal stability to 120°C.

CHAPTER II. SENSITIVITY OF DEEP-WELL OBSERVATIONS AND STRUCTURE OF THE SEISMOGRAMS

At the present time the operations with respect to increasing the sensitivity of seismic operations are developing in two areas.

The first of them is connected with wave selection by certain parameters characterizing the wave field. Here, in addition to the traditional wave selection with respect to frequency, the wave selection with respect to the direction of propagation and velocity is acquiring more and more significance in recent times. In procedural respects it is connected with groups of seismographs located along the line or on the observation plane. In addition, wave selection with respect to the polarization attribute (the polarization filtration) has developed which is based on wave separation at the point with respect to the direction of motion or with respect to the nature of the trajectory of motion of the particles of the medium. The sensitivity increases significantly on combination of both types of wave selection with respect to direction of propagation and polarization of the waves [16].

The second area is based on the removal from the surface, that is, the observations in the wells [17]. In each specific situation, depending on the goals of the research, the nature of the wave interference and observation conditions, different methods of improving the useful sensitivity or combinations of them can be selected.

When studying the seismic characteristics of large industrial centers, the specific observation conditions greatly complicate and sometimes exclude the possibilities of using the methods based on wave selection with respect to direction of propagation. At the same time, the wave interference primarily made up of surface waves gives rise to effectiveness of the second area. Therefore when studying the seismic characteristics of local sections of large industrial centers the seismic observations in boreholes acquire special interest. This chapter discusses this area.

Let us characterize the state of the art with respect to the available published data and thus describe the experimental studies performed by the Earth Physics Institute of the USSR Academy of Sciences in wells drilled to a depth of 3000 meters basically in terrigenic deposits and located in areas with high (Alma-Ata, Tashkent) and low (the village of Chilik) noise levels and also in shallow (to 100 meters) wells revealing the crystalline foundation.

When estimating the sensitivity of the equipment it is necessary first of all to discover the laws of variation with depth of the level of seismic noise and useful signal.

The variation in noise level with depth was investigated by the method of vertical seismic profiling (VSP) [15]. However, the background interference not only changes with depth, but it is also characterized by great variability in time. In order to study the time laws, long-term semistationary and stationary observations were performed in the wells. During these observations a large number of different earthquakes were recorded in a number of wells at different depths.

The performed observations made it possible to estimate the possible gain in sensitivity during the deep-well observations and also to compare the shape of the recording of individual wells and the structure of seismograms obtained at different depths and on the day surface.

§1. State of the Art with Respect to Seismological Observations in Boreholes (Brief Survey of Published Data)

In the last 20 to 25 years studies were made abroad (especially in the United States and Japan) with respect to the development of seismologic observations in wells. Sets of deep-well equipment were developed, and studies were made in areas of different structure in the depths range from several tens to 6000 meters. It is necessary to note that in the published materials the data on possible gain in sensitivity of the equipment are presented only in some of the first papers; primary attention in the majority of the papers has been given to the wave interference characteristics and a discussion of their nature.

One of the first papers on estimating the possibility of increasing the sensitivity of the equipment during recordings in wells must be considered to be the experiment of [80] performed to isolate waves reflected from the Mohorovichich surface. The observations performed in three boreholes at depths of 1000 meters demonstrated that the natural noise background at the surface is appreciably greater than at depth. Thus, whereas on the surface the noise level reached 40 microvolts, at a depth of 1000 meters it was about 4 microvolts, and in one of the wells it was 1 microvolt and did not differ from the natural noise of the amplifier. The fact of a decreased noise level with depth indicated the important role of the Rayleigh waves in surface noise. The results of these observations have confirmed the theoretical proposition of the possibility of increasing the sensitivity of the equipment by burying the seismograph.

The seismological observations in wells began to develop quickly at the end of the 1950's. This was promoted to a great extent by the special studies to compare the recording additions in cased and uncased wells, which demonstrated that under the condition of a well-cemented well and a reliably clamped seismograph the recordings in the frequency range of 15-70 hertz were not distorted by the effect of the casing [71]. The complete identicalness of the recordings in the cased and uncased wells was also proved and, at the same time it was demonstrated that the cased wells cemented to the head did not distort the recordings in the frequency range from 1 to 10 hertz. These results greatly simplified further studies, for the recording in an open well is always fraught with the danger of losing the seismograph and failure of the well itself.

For convenience of investigation, all of the borehole observations can be provisionally divided into three groups: observations in shallow wells (to 100 meters) [66, 77, and so on], medium-deep wells (to 600 meters) [77, 78, and so on], and deep wells (more than 600 meters) [64, 70, 72-75, and so on]. The drilling of shallow wells is appreciably cheaper and observation simpler in connection with which the evaluation of the feasibility of increasing the sensitivity here is of special interest. The observations in deep wells are coupled with great technical difficulties caused by increased pressure and temperature.

Let us present the basic observation results.

Observations in Shallow and Medium-Deep Wells. The most complete studies of noise in shallow wells are presented in reference [66], which permitted its authors to formulate certain conclusions.

Apache Well (Oklahoma). This area is one of the "quietest" places in the continental United States. The depth of the borehole is 18.3 meters. The weathering zone is very thin, and the ground seismometers were installed directly on limestone. The background in the period range of 0.3-1.4 seconds is made up almost completely of oscillations with a period of 0.5 seconds; the 0.5-second spectral peak has a mean amplitude of about 0.2 nm^2/hertz. On a still day no significant difference was observed between the noise level on the surface and in the well. The probability of the occurrence of a background of the given or smaller amplitude is illustrated in Fig 5, a by which the decrease in noise level connected with wind at a depth of 18.3 meters is obvious. From the histograms of noise of different periods on a still day with a wind velocity of 20-40 km/hr it follows that the noise is represented basically by oscillations with a period of 0.5 seconds; the insignificant predominance of the long-period component in the borehole by comparison with the surface is noticeable. The depth of the borehole is insufficient for complete disappearance of the wind noise.

Wichimo Mountain Well. The surface and deep-well seismographs were installed on bedrock (granite). On a still day the background interference level on the surface differs little from the background interference level in the borehole. During windy weather with a wind velocity of 30 km/hr at depths

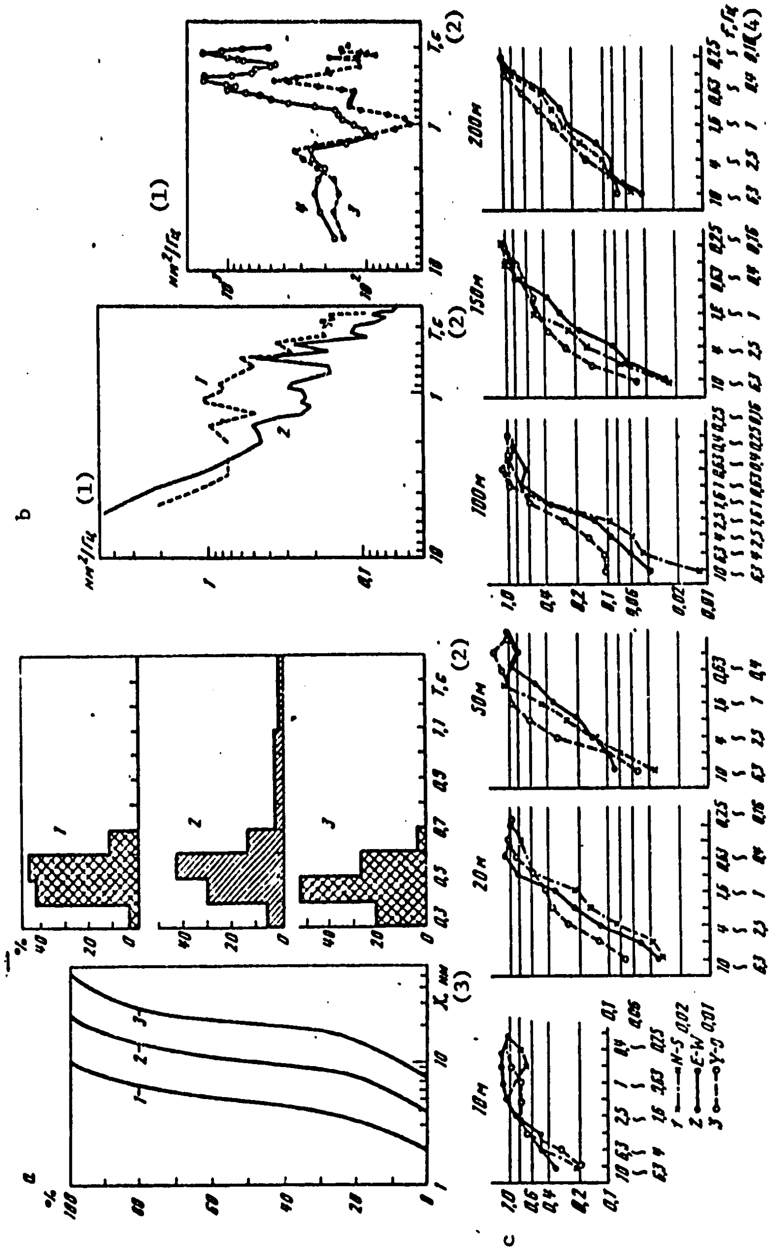

Figure 5. Noise in Small and Medium Boreholes

[See following page for legend and key]

[Legend and key for Fig 5, preceding page]

a -- probability of occurrence and percentage content of noise in the period range of 0.3-1.4 seconds at the surface and at a depth of 18.3 m (Apache, Oklahoma): 1 -- still day, surface and a depth of 18.3 meters, 2 -- wind velocity 20-40 km/hour, depth 18.3 meters, 3 -- wind velocity 20-40 km/hr, surface;
b -- energy spectra of the noise in the Pinedale well (Wyoming) on the surface (1) and at a depth of 32 meters (2) and in the Winner well (South Dakota) at night (3) and in the daytime (4);
c -- amplitude ratios of the noise shifts in the well at different depths and on the surface (Japan) for different frequency intervals (1, 2 -- horizontal components, 3 -- vertical component).

Key:

1. nm^2/hertz
2. T, sec
3. X, nm
4. f, hertz

of 61-36 meters, no wind interference was detected; at a depth of 18 m only an insignificant part of the background is connected with wind.

Pinedale Well (Wyoming). A well 61 meters deep was drilled in shaly clay having a longitudinal wave velocity on the bottom of $V_p=3.0$ km/sec. On a still day the background level with respect to 50% probability level decreased with depth and at the bottom was 0.7 of the surface value. The amplitude of the useful signal at the same depth decreased to 0.9 of the surface amplitude. Table 1 shows the results obtained when analyzing the recording at different depths. At a depth of 61 meters the noise connected with wind is not observed in practice.

The peak in the borehole noise spectrum (Fig 5, b) between 0.7 and 0.4 seconds is caused by the fact that the noise connected with wind does not diminish at this shallow depth.

Table 1

V, км/ч (1)	$A_{\text{пов}}$, нм ($H=0$) (2)	(3) Скважина		$A_{\text{скв}}/A_{\text{пов}}$ (6)
		(4) $A_{\text{скв}}$, нм	(5) H, м	
0-8	2,5	2,0	32	0,8
35-50	6,5	2,8	32	0,43
0-8	2,7	2,0	46	0,74
30-35	4,0	2,3	61	0,58
50-60	6,8	2,3	61	0,34

Key: 1. V, km/hr; 2. $A_{surface}$, nm; 3. borehole; 4. $A_{borehole}$, nm; 5. H, m; 6. $A_{borehole}/A_{surface}$

Winner Well (South Dakota). The level of microseismic background in this area is very high -- 26 nm; therefore the "wind" background is not isolated on the surface recordings. The decrease in background with depth takes place on the average from 20 nm at the surface to 16 nm at a depth of 56 meters and 5 nm at a depth of 302 meters. The mean amplitude of the signal at a depth of 302 meters was 0.33 of the surface amplitude, and therefore the signal/background ratio increased by only 1.9 times. The peak at 0.35 seconds at night (Fig 5, b) is appreciably less than in the daytime, and this indicates the "cultural" origin of the background.

In the opinion of the author of reference [66], a reduction in background level with removal from the surface is explained by a decrease in intensity of both surface waves and volumetric waves. The decrease in amplitudes of the surface waves in the presence of a low velocity zone takes places especially rarely. The decrease in the noise with depths, which is especially fast in the upper part of the section, is also caused by a decrease in the noise of "wind" origin.

Tokyo Meteorological Institute [78]. When studying noise at depths of 10, 20, 50, 100, 150, and 200 meters the following results are obtained,

1. The decrease in noise level is more significant for high frequencies, which is obvious from Fig 5, c. The noise amplitude ratios in the well and at the surface for different frequency intervals are indicated. For example, for a depth of 50 meters (vertical component) the noise amplitude ratio in the well and at the surface is about 0.05 in the frequency range of 6.3-10 hertz.

2. The low-frequency noise amplitudes (less than 0.5 hertz) decrease weakly with depth.

3. Significant improvement of the signal-noise ratio is achieved at a depth of 50 meters. In general the optimal depth depends on the geological structure, andfor each area it must be determined experimentally.

4. The noise connected with a passing series of transport vehicles or with falling of heavy weights is not sensed by the borehole instrument even at a depth of 50 meters.

In reference [77] a description is presented of the observations in boreholes 64 meters deep (Nokogiriyama) and 380 meters deep (Hongo) performed to increase the signal/noise ratio when recording microearthquakes in a frequency range of 5-100 hertz. The noise ratio at the surface to the noise in the well 64 meters deep is equal to two, and in a well 380 m deep, 10. The signal/noise ratio at a depth of 64 meters is only somewhat greater than on the surface, and at a depth of 380 meters, three times greater. The useful signals are recorded more clearly in the boreholes; therefore it is expedient to observe microearthquakes in the well even if it is not very deep.

Observations in Deep Wells. A detailed analysis of the observation materials in three deep wells is presented in reference [65].

Grapevine Well (Texas). The Grapevine Well is 3040 meters deep, it is cased, and the cement is raised 304 meters from the bottom. The noise characteristic in the well is shown in Fig 6, a. The curve for the decrease in noise amplitude depth is constructed with respect to the 50% probability level. The greater part of the noise is in the period range of 0.3-0.6 seconds. The noise decreases rapidly with depth and approaches a constant value of 1.5 nm; this is caused, in the opinion of the author, by the volumetric waves, the noise level from which, in contrast to the surface waves, does not change with depth.

The Hobart Well (Oklahoma) is about 3000 meters deep, it is cased, and the cement is raised 304 meters from the bottom. With respect to the noise variation curve with depth (Fig 6, b) it is obvious that to a depth of 2130 meters the law of variation of the noise amplitude is the same as in the Grapevine Well, which indicates the same type of wave. Lower down, the noise level again begins to increase. This depth corresponds to the low-velocity layer, and the increase in noise level can be connected with wave guide phenomena.

Orlando Well (Florida). The Orlando Well (Florida) is 2080 meters deep, it is cased and cemented 945 meters from the bottom. The surface noise is highly unstable as a result of low-frequency interference (0.3-0.5 sec) connected with the activity of man. At depth the long-period noise predominates (0.8-1.5 seconds). Along the curve (Fig 6, b) the noise variations with depth constructed by the 50% probability level it is obvious that the noise decrease corresponds to the damping of primary mode of the Rayleigh waves. A sharp improvement of the signal/noise ratio for high-frequency signals is a characteristic feature; the high-frequency noise almost completely disappears at a depth of 1975 meters.

In the opinion of the author of [65], observations in three wells demonstrated the following:

1) The noise level decreases with depth; the degree of the decrease depends on the frequency and the seismogeological characteristic of the section;

2) The amplitudes of the useful signal decrease with depth and reach a minimum at a depth equal to half the wavelength reflected from the surface;

3) The Rayleigh waves predominate in the noise;

4) The recording divisions in each well are different, and the estimation of the gain in sensitivity for each of them must be especially determined. In general, the submersion of the seismographs will permit us to obtain a signal/noise ratio of the same order as in the "quietest" continental areas.

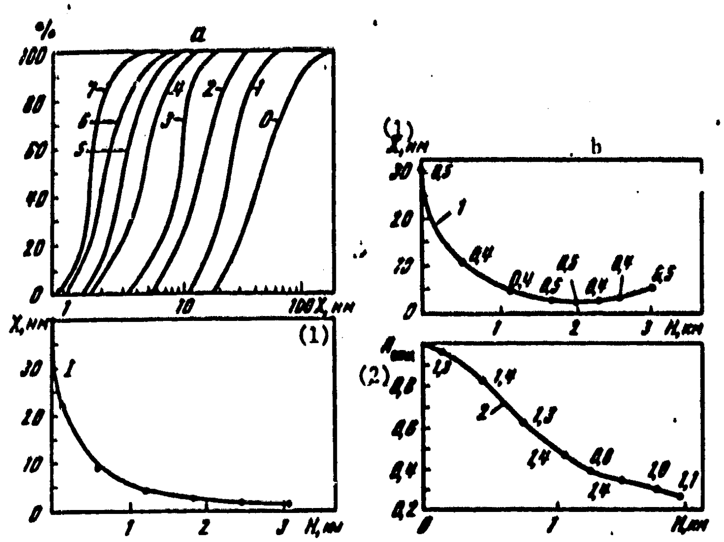

Figure 6. Noise in Deep Wells
a -- probability of occurrence of noise and variation of it with depth in the Grapevine Well (Texas) in the period range of 0.3-1.3 seconds: 0 -- surface, 1 -- 0.2, 2 -- 0.5, 3 -- 0.6, 4 -- 1.3, 5 -- 1.8, 6 -- 2.4, 7 -- 3.0 km. Curve I was constructed for a predominant period of 0.3 seconds;
b -- the absolute and relative noise amplitudes in the Hobart Well (Oklahoma) (curve 1) and the Orlando Well (Florida) (curve 2). The numbers at the dots are the predominant periods.

Key:

1. X, nm
2. $A_{relative}$

Nature of the Noise. If the laws of variation of the noise level in the well according to the data of various authors agree among each other, then the opinions of the authors diverge in the problem of the nature of the noise. In some papers [64, 74, 75] the noise is interpreted as a combination of different modes of the Rayleigh wave, in [69] and other papers the basic properties of noise are explained from the point of view of the stationary compression waves. In reference [67] where the results of many years of studying the noise background in the wells with different geological structure are summed up, the nature of the seismic noise is explained as a mixture of volumetric and surface waves. Defined combinations of different types of waves correspond to different period ranges. Thus, the ratios of the noise spectra at the surface and at a depth of 5200 meters and also the theoretical curves of the first three Rayleigh modes and P-waves for normal angles of incidence for the Fort Stockton Well (Texas) permit the author to consider that the cause of the noise in the well can be the presence of different types of waves in the adjacent period ranges and also the presence of Love waves. The results obtained in the Pinedale Well (Wyoming) are explained best of all by a combination of P-waves and the basic Rayleigh mode.

For the Apache Well (Oklahoma) the experimental amplitude-depth ratios in the period range of 2.0-0.8 seconds agree well with the theoretical curves and the P-waves in the Rayleigh mode. The autocorrelation analysis of the recordings after digital filtration performed to separate these two cases demonstrated that the noise is made up of surface waves. The noise in the period range of 0.8-0.3 seconds is usually connected with respect to its nature to the closeness of populated places and their greater "cultural"[1] activity. The noise spectra for the Grapevine Well located near the large industrial center of Dallas, Texas, are characterized by a vast decrease in noise with depth which is determined by the primary Rayleigh mode. At depths where the amplitude of the primary mode is small, the amplitude-depth ratio can be explained either by a combination of higher modes or by volumetric waves and interference of two types of waves.

Reference [82] contains a description of the observations in the Grapevine Well performed simultaneously by four three-component devices located at depths of 139, 1062, 1951 and 2885 meters. The results obtained confirm the fact that the seismic noise is made up of a set of Rayleigh wave modes, but, in addition, different Love wave modes are also present. The volumetric waves were not detected in the area which is connected with the presence of a high level of "cultural" noise. It is noted that in the areas where there is no high level of "cultural" noise, the volumetric waves make a significant contribution to the seismic noise.

In addition to the above-noted basic works, others [72, 73, 79] are known in which studies were made of the seismic noise and its nature. As a result of analyzing the published papers it is possible to draw the following conclusions.

The noise level decreases with depths; at great depths the differences in noise intensity for different areas and variability of noise with time within the limits of one section are appreciably less than on the day surface. The degree of decrease in noise with depth for different areas is different and depends on the frequency and the seismogeological characteristic of the section. The fastest decrease in noise with depth is observed in the areas with a high level of "cultural" noise. For low-noise areas, the decrease in noise with depth is observed only for the high-frequency components of the spectrum. In the individual sections of the well against a background of general decrease in noise, local buildup of the noise can be observed connected with the waveguide phenomena.

The signal level decreases with depth and reaches a minimum at a depth equal to half the wave length.

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[1] ["Cultural" is used throughout to refer to noise generated by especially as in cities.]

Useful Sensitivity of the Borehole Stations. This index must be specially estimated. The greatest gain can be obtained in areas with high ground noise level. In all cases the submersion of the seismograph makes it possible to obtain a signal/noise ratio of the same order as for ground observations under the most favorable conditions.

The signal/noise ratio at a depth of 100 meters increases by 3-4 times for frequencies of 2-10 hertz. The number of isolated earthquakes in the presence of borehole observations increases by 2.2 times.

The application of complex vertical systems is effective only for areas with a high level of ground noise and a sharp decrease in them with depth. Here the signal/noise ratio can reach values of 15-25 decibels.

§2. Laws of Variation of Noise Level with Depth

The observations were performed by the VSP [vertical seismic profiling] method in wells located in different areas with respect to noise level. The Tashkent and Alma-Ata Wells are located under conditions of high ground noise level connected with the vital activity of large industrial centers. In the Novo-Alekseyevskaya Well the high noise level is connected with a concentrated source located nearby (the building materials combine) and the Chilik Well is located under high noise level conditions.

Observations in Large Industrial Centers. Tashkent. This borehole is designed specially for geophysical measurements and it was drilled in 1968. It revealed Quaternary, Neogenic, Paleogenic, Cretaceous and Triassic-Jurassic deposits and went into the Paleozoic at a depth of about 2400 m. The basic observations were performed in June and October of 1970. The results of the observations of different series agree with each other.

According to the graphs of the variation of maximum noise amplitudes with depths (Fig 7, a) it is obvious that on the day surface the noise level is very high and fluctuates at different times of day with broad limits. Whereas in the daytime (the dotted curves) it reaches 1000 nm, at night (the solid curves) it is a total of 80 nm.

With an increase in depth, the interference background diminishes. The sharpest decrease in noise level is observed in the upper part of the section. At a depth of 350-400 meters the noise level already decreases by approximately 1-1/2 orders. At greater depth the decrease in noise takes place appreciably more slowly. In the depth range of 400-1000 meters the interference background diminishes on the average only by 2 times.

In the depth range from 1000 to 1800-1900 meters, a total of two series of observations were made at different times. The interference level decreases still more slowly here, and at maximum depths at night it is 2.5-3.0 and 9-10 nm.

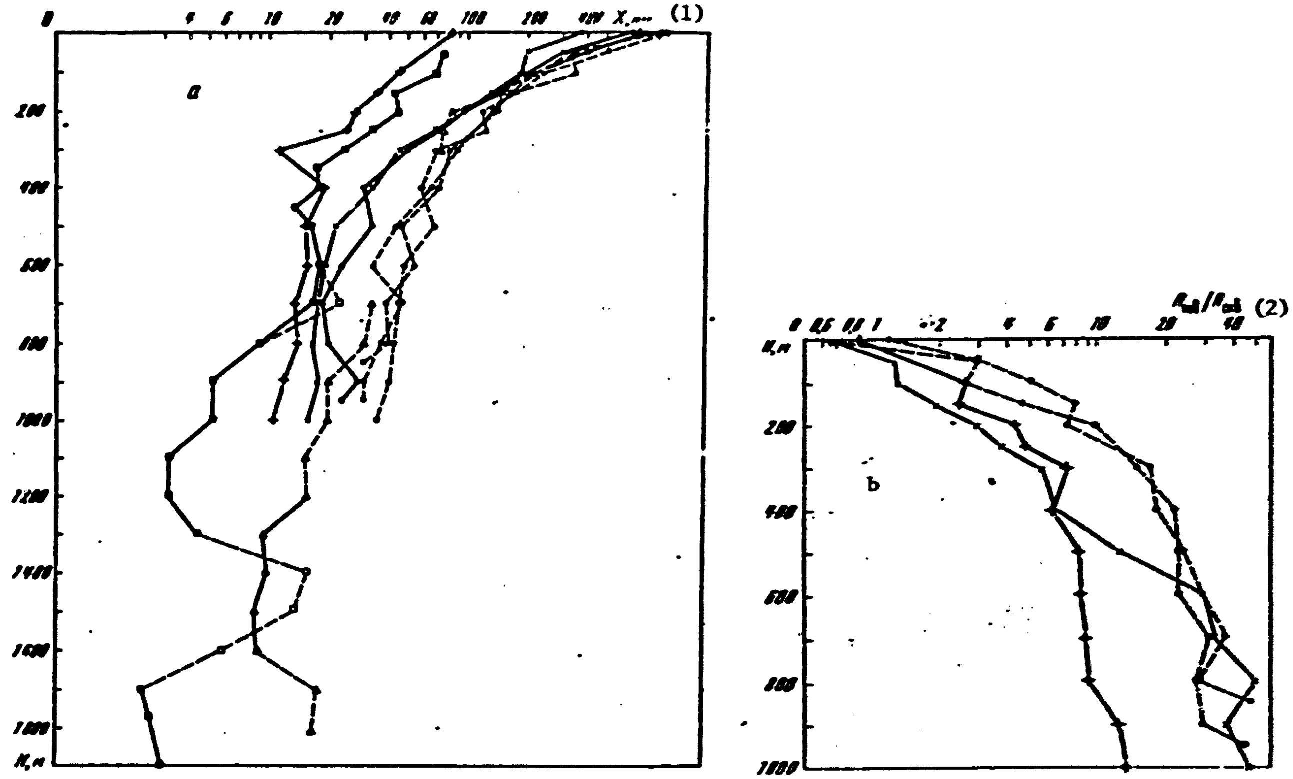

Figure 7. Interference background at night (solid curves) and in the daytime (dotted curves) in the Tashkent Well for different situation series

a -- maximum interference level as a function of depth; b -- background amplitude ratio on the surface and at depth

Key:

1. X, nm; 2. $A_{surface}/A_{well}$

A stable difference is observed in the noise background level at night and in the daytime. On the day surface the noise background level in the daytime can be an order higher than at night. With an increase in depth this difference diminishes, and in the depth range of 300-1000 meters the ratio of the background noise level on the average is two.

The minimum noise background both on the day surface and at internal points of the medium was observed at night on a holiday. For this series significantly smaller decrease in noise amplitude with depth is characteristic than for the other nighttime observation series.

For comparison with the background amplitudes on the surface and in depths synchronous recordings were made of the borehole and ground seismographs. The variations in background ratio on the surface and at depth are presented in Fig 7, b. For the day series the ratio in the upper part of the section increases sharply at first. Thus, in the depth range of 0-200 m it varies by more than an order. With a further increase in depth it grows significantly more slowly, and in the 200-1000 meter range it triples in all.

At night the ratio of the noise amplitude in the well and on the surface in the upper part of the section increases more slowly, and the value of ten is reached only at a depth of about 400 meters. At greater depths the "night" and "day" graphs coincide. The Sunday observation series for which minimum noise amplitude ratios are characteristic constitutes an exception. At a depth of 1000 meters this ratio is 14, at the same time as for the remaining series it is 50.

A comparison of the graphs constructed with respect to the maximum amplitude level and with respect to the average maximum amplitudes indicates that the average values are smaller than the maximum values for approximately 20-30%.

The predominant interference wave periods on the day surface amount to about 0.2 seconds. At the internal points of the medium already beginning at 50 meters, the periods are equal to 0.3 seconds, and they vary very slowly with depth. At night the predominant noise period is somewhat greater than in the daytime.

Alma-Ata. A well 2000 meters deep was drilled in the terrigenic coarsely clastic deposits for which continuous increase in velocity with depth is characteristic. In the upper part this growth takes place more sharply, and with depth, the velocity buildup gradient decreases. The curves for the amplitude variation in the depth range of 0-950 meters for three daytime observation series and four nighttime series (Fig 8, a) indicate that the observations of the different series agree well with each other, grouping quite narrow bands into two: day and night. The interference background in the daytime and at night differs on the average by two times, and the nature of the amplitude decrease with depth is approximately the same. In the upper part of the section (50-250 meters) a sharp decrease in noise with depth is observed: the noise amplitude decreases at night in practice by an order (from 270 to 25 nm), and in the daytime by a halforder (from 220 to 40 nm). In the depth range of 250-950 meters the noise amplitude decreases a total of 3-3.5 times (from 40 to 13 nm in the daytime and from 25 to 7 nm at night).

The statistical processing of the 10-second noise recording interval of the daytime series made it possible to construct the probability curves for the occurrence of noise of given or lower amplitude (Fig 8, b). By the curves it is obvious that, for example, at a depth of 150 meters the probability of occurrence of noise with an amplitude of 40 nm and less is 60%. At a depth of 850 meters it is possible to expect a shift of 8 nm or less with the same probability of 60%. For the same depth the probability that the background amplitude will not exceed 17-18 nm will be equal to 100%.

For comparison, in the same figure the data are part of the curve obtained in the Grapevine Well (Texas, USA) in which a very large volume of work was done to study noise. Comparison shows that on the surface the noise level in Alma-Ata is essentially higher than in the Grapevine Well. Thus, whereas the probability of the occurrence of noise with an amplitude of 100 nm or less in Alma-Ata at a depth of 50 meters is 15%, on the surface of the Grapevine Well it is more than 90%. At the same time at a depth of 650 meters the probability curves differ in practice little. The difference in interference levels obviously is explained by the fact that the Grapevine Well, in contrast to the Alma-Ata Well, is a distance of about 50 km from a large city (Dallas). The curve for the noise amplitude as a function of depth for the day series of observations in the Grapevine Well constructed with respect to the 50% probability level (the heavy line with circles in Fig 8, a) lies in the region of the "night series" of observations in the Alma-Ata Well.

From the graphs of the noise spectra at different depths (Fig 8, c) it is obvious that maximum noise amplitude both at the day surface and at greater depths correspond to the long-period components of the spectrum. In the frequency band from 0.2 to 0.8 hertz the nature of the decrease in noise with an increase in frequency at the day surface and at depth is identical. At a frequency of 0.8 hertz the noise level at the day surface will be 0.08 nm. The noise level at a depth of 550 meters in this frequency range is approximately an order lower than on the day surface. Beginning with 1 and up to 4 hertz, the nature of the decrease in noise varies sharply. At the day surface against a background of sharp peaks, some increase in noise level is observed at the same time as at a depth of H=550 meters the noise level decreases, but this decrease takes place appreciably more slowly than in the low-frequency range. In the 5-7 hertz band, the noise amplitude at a depth of 550 meters is 40 times less than at the day surface. For the entire investigated frequency range the ratio of the spectra at a depth of H=950 meters and at the surface (Fig 8, c) is less than one. The ratio becomes minimal in the 1.7-2.7 hertz band. The nature of the decrease in noise on frequencies in the range of 0.2 to 1.0 hertz permits the consideration that the basic modes of the Rayleigh waves predominate here. In the higher frequency band the noise can be represented by a combination of basic, first and sometimes second Rayleigh modes and the volumetric waves. Inasmuch as the well is located directly on the edge of such a large industrial city as Alma-Ata, the noise can be explained primarily by the "cultural" activity of the city.

Observations in Areas with Low Level Noise at Depths of 300 and 600 Meters. The observations in wells several hundreds of meters deep are of great interest. This is explained by the fact that the wells are also comparatively cheaper and can be drilled by portable drilling rigs. In addition, from the technical point of view the observations at these depths are appreciably easier and equipment is appreciably simpler. At the same time, as was demonstrated, the sharpest decrease in background occurs in the upper part of the section.

The possibilities of the observations are estimated by the materials obtained in the Chilik borehole. In contrast to the Tashkent and the Alma-Ata Wells, the Chilik Well is located at a significant distance from the large cities which causes appreciably smaller background of the aboveground interference and permits synchronous observations on the day surface and in the well.

The Chilik Well, the depth of which is 600 meters, is located on the edge of the rayon center of Alma-Ata Oblast with the same name approximately 100 km east of Alma-Ata. In geological respects this area differs from the previously investigated ones by less thickness of the sedimentary deposits which reach a total of 1350 meters here and are represented, just as in Alma-Ata, by terrigenic coarsely clastic rock. The vertical seismic profiling by individual series in the day and night with a step of 50 meters over the entire depth interval made it possible to obtain the curves for the variation of the noise amplitudes for two night and two day series (see Fig 8, a). In the daytime the noise level quickly decreases with depth, and at 100 meters it is an order lower than on the surface, and at 300 meters, 20 times lower. In the range from 300 to 600 meters the noise amplitudes are cut approximately in half. At night the noise background on the day surface is essentially lower than in the daytime, and it decreases with depth more slowly than in the daytime. Thus, at a depth of 300 meters the noise background is 3 to 4 times less than on the day surface.

The predominant noise frequency on the recordings obtained on the surface is about 3 hertz; at a depth of 600 meters it decreases to 2.5 hertz.

The spectral analysis shows (Fig 8, c) that the nature of the spectral curves for the Chilik Well is analogous to the same curves for the Alma-Ata Well.

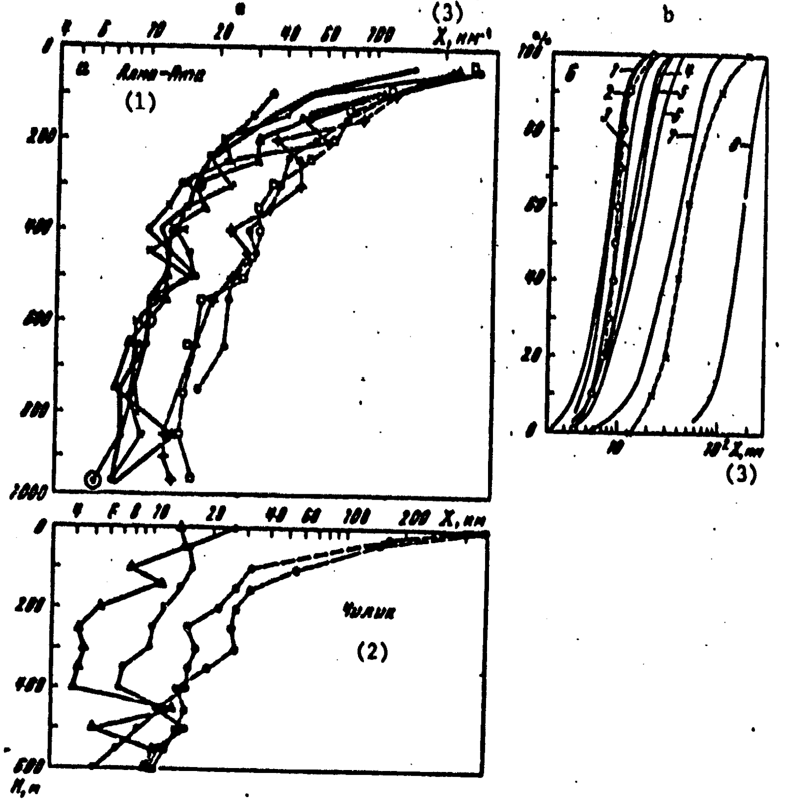

Figure 8. Noise background at night (solid line) and in the daytime (dotted line) in the wells of Alma-Ata and Chilik

a -- noise amplitude as a function of depth for the Alma-Ata and Chilik Wells; b -- probability curves of the occurrence of noise of the given or lower amplitude at depths of 1 -- 850 meters, 2 -- 750 meters, 3 -- 650 meters, 4 -- 500 meters, 5 -- 450 m, 6 -- 300 meters, 7 -- 150 meters and 8 -- 50 meters in the Alma-Ata Well. The dotted curves are the data on the Grapevine Well (Texas) for a depth of 650 meters (the circle) and the surface (crosses);

Key:

1. Alma-Ata
2. Chilik
3. X, nm

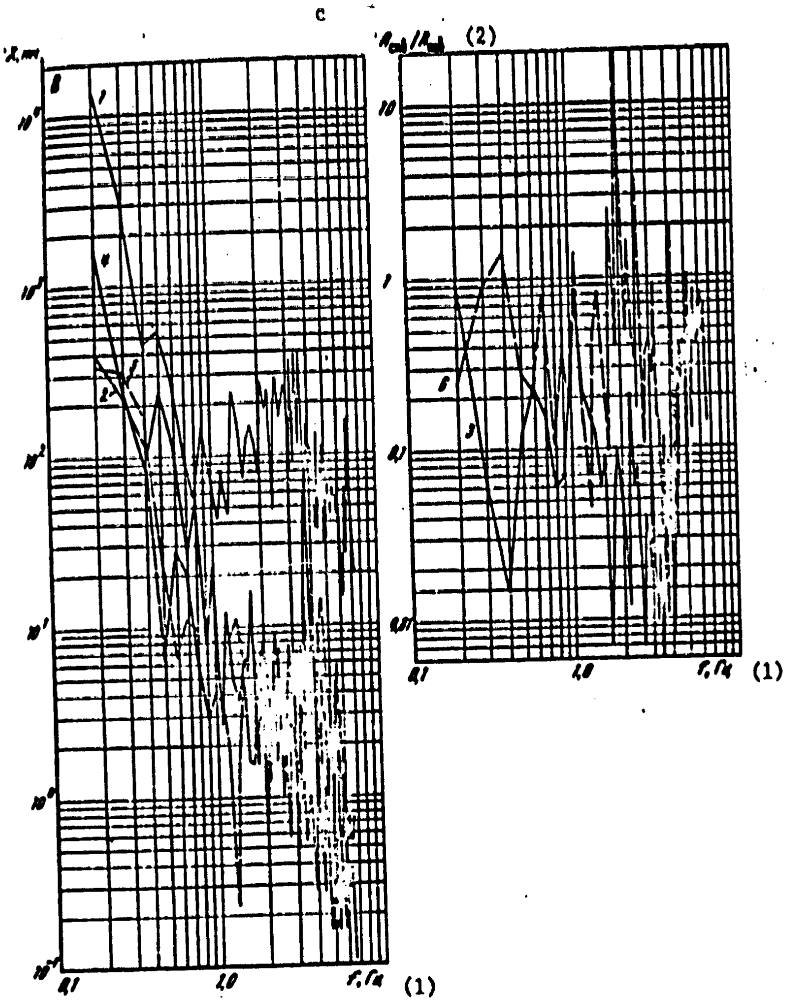

Figure 8 (continued)

c -- spectra and spectral ratio at depths of 1 -- 50, 2 -- 550, 3 -- 950 meters for the Alma-Ata Well and 4 -- surface, 5, 6 -- 600 meters for the Chilik Well.

Key:

1. f, hertz
2. $A_{well}/A_{surface}$

The maximum noise amplitudes are observed in the low-frequency part of the spectrum, and the differences in levels on the surface and at depth are minimal here. With an increase in frequency by approximately up to 1 hertz the noise level decreases sharply. At frequencies of more than 1 hertz, the decrease becomes less sharp. On the day surface the noise level decreases very little with frequency, and a relative maximum of the noise is observed at a frequency of 2.5-3 hertz. At a depth of 600 m the noise level reaches values of 4-6 nm on a frequency of 6-7 hertz. For the Chilik Well, the minimum ratio of the spectra at a depth of 600 m and on the surface is 0.02 on frequencies of 3.5-4.5 hertz (Fig 8, c).

Laws of Variation of Noise Background in Three Wells. For the day series, the background level in the Chilik Well is approximately half the background level in the Alma-Ata Well and four times less than the background level in the Tashkent Well. Let us remember that the general background level in the Tashkent Well is greater than in the Alma-Ata Well by approximately two times [2]. At a depth of 900 meters, the noise amplitude in the Alma-Ata Well is 12-13 nm in the daytime and it is close with respect to value to the noise level in the Tashkent Well at night. The different noise levels in the wells can be explained by the fact that the Tashkent Well is in the center of the city, near large industrial enterprises and other sources of noise, and the Alma-Ata Well is on the edge of the city and is comparatively remote from the basic explicit sources of interference. At a depth of 600 meters in the daytime the noise amplitudes in the three wells reach 10 (Chilik), 20 (Alma-Ata) and 40 nm (Tashkent).

The nature of variation of the background in the Chilik Well for the day series coincides with the variation of the day background in the other two wells.

At night the decrease in background in the Chilik Well is appreciably weaker than in the Alma-Ata and the Tashkent Wells. Whereas for the last two wells the ratio of the background on the surface to the background at a depth of 600 meters is 30-40, for Chilik it is 4 to 6.

Some increase in amplitude of the background on the surface in the frequency band from 2 to 4 hertz is observed for the Alma-Ata Well. It is possible to think that this increase is connected with the "cultural" activity. The nature of the peak in the spectrum of the surface noise in Chilik at 3.7 hertz is still unclear. Possibly, it is caused by a local source which has its effect only when recording on the surface.

§3. Background Stability at Different Depths

The noise stability has important significance in estimating the sensitivity. The noise stability has been specially investigated. Stationary and semi-stationary observations have been set up in two wells -- Alma-Ata which is characterized by a high level of ground noise, and Chilik, where the ground noise level is low.

Observations in an Area with High Ground Noise Level. The noise background in the presence of stationary observations in the Alma-Ata Well was investigated at depths of 1950, 950, 700, 500 and 300 meters.

Noise Level at a Depth of 1950 meters. Stationary observations at a depth of 1950 meters were performed in the first phase of the operation, and they were recorded by the seismograph without a borehole preamplifier. Under these conditions the basic source of the noise limiting the useful sensitivity of the equipment was electrical interference. The microseismic oscillations caused by storms on Lake Issyk-Kul' constitute an exception.

Electrical interference is unstable with respect to intensity and frequency, and it varies both during the course of the day and on different days and in different months. Frequently this type of interference is associated with one time of day. Among the electrical interference it is possible to isolate several types which are noted during various time periods. If we do not consider the individual pulses, then the low frequency intense irregular oscillations with a frequency of 0.4-0.8 hertz were observed for the longest time. For noise of this type a strict time coordination is characteristic. This type of noise appears in the evening from 2100 hours to 0200 hours local time. Sometimes comparatively high frequency (2-4 hertz) oscillations are recorded which form long arcs on the seismographs. Observation experience has demonstrated that the basic electrical interference is connected with leaks. Usually after starting the seismograph for the first time the interference level is comparatively low. However, later leaks appear in the lines and the intensity of the inductions increases significantly. The following law has been noted. In the daytime there is basically comparatively weak and high-frequency noise. In the evening and at the beginning of night, the long-period noise predominates. At night, as a rule, the noise stops, and this time is characterized by a comparatively quiet background.

Seismic interference has been investigated only in the periods when the electrical interference level was comparatively low, which has made it possible to raise the gain of the channel. However, it has not been possible to determine the quantitative amplitude of the seismic interference. With respect to nature of variation of the amplitude with depth which is typical of the majority of wells (including in Tashkent), it is possible to consider that the amplitudes of the background are included in the range of values from 2 to 5 nm. Even at depths of about 2000 meters the "cultural" noise is felt. In the daytime the interference background usually is one or two times higher than at night. This increase in amplitude of the day background is characteristic approximately for 65-70% of the total observation time with the exception of the night hours and holidays when the industry of the city is not operating and the noise level is the same in the daytime and at night.

Out of the seismic interference during observations at a depth of 1950 m, the most intense is the interference caused by storms on Lake Issyk-Kul', but the level of this interference is appreciably lower than on the day surface. Frequently even intense storm microseisms recorded at the Talgar station by the KSE channels (T_0=1 hertz) and the SKM channels (T_0=0.6 hertz) with a recording amplitude of 5-10 nm have not been noted in the well or at all, or were very weak although the useful signals (the earthquake recordings) in this case were commensurate with respect to intensity (Fig 9, a). In these cases the signal/noise ratio in the well turns out to be almost an order higher than at the Talgar station. This difference in interference amplitude is explained not only by the depth of the observation point but obviously by the fact that at the Talgar station the frequency characteristics of the KSE channel and, especially, the SKM channel, are somewhat shifted in the low-frequency direction (Fig 9, c). The storms are observed on Lake Issyk-Kul' most frequently in the winter when there can be 15 to 16 stormy days per month.

Noise Level at a Depth of 950 Meters. At a depth of 950 meters the stationary observations are performed with a well type preamplifier placed directly in the seismograph. This has made it possible significantly to reduce the noise background of electrical origin. The electric interference remains only in the form of individual, comparatively rare pulses. As a result, the useful sensitivity is limited only to the seismic interference, the amplitudes of which amount to from 4 to 15 nm. However, for the greater part of the recording time (75-80%) the values of the amplitudes are 7-14 nm. These data agree with the results of studying the interference background by the method of vertical profiling. At a depth of 950 meters the effect of the vital activity of the city is felt to a higher degree than at a depth of 1950 meters -- in the daytime the noise background increases by approximately 2-2.5 times by comparison with night, reaching values of 12-15 nm.

Noise Level at Depths of 700, 500, and 300 Meters. The increase in noise amplitude with a decrease in depth in this interval is comparatively small. The values of the minimum and maximum background amplitudes of depths of 700, 500 and 300 meters amount to 5-20, 6-30 and 7-50 nm respectively, but in the greater part of the recording time these intervals are appreciably less broad.

The changes in the noise with depth in the range of 950-300 meters were estimated by the variation in amplitude of the storm microseisms of Issyk-Kul'. For this purpose, the amplitude ratio of the microseisms was determined at each depth on the SKM channel located in a drift and acting both as the standard and as the well channel. The magnitude of this ratio varies within the limits of 3 to 5, that is, no clear dependence of the ratio on depth was observed in a range of 950-300 meters. An example of recording the storm microseisms in the well at a depth of 700 meters and on the SKM channel in the drift is presented in Fig 9, b. On the SKM channel the useful signal cannot be isolated against the noise background in general. A comparison of the recordings of the storm microseisms at depths of 700 and 1950 m indicates that their level has increased significantly at 700 meters.

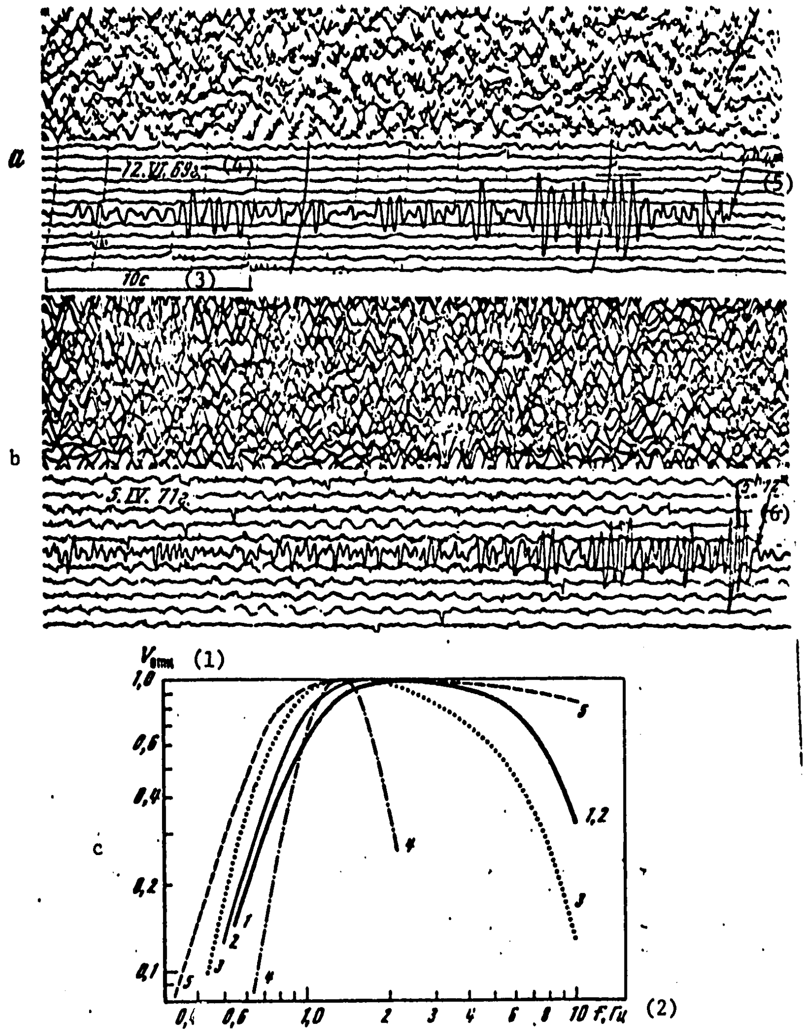

Figure 9. Recordings of storm microseisms and distant earthquakes at the Talgar station (SKM channel, upper recordings) and in the Alma-Ata borehole at depths of 1950 meters (a) and 700 meters (b); c -- frequency characteristics of the equipment: 1 -- well channel, 1969 (H=1950 m), 2-- the same, 1971 (H=960 m), 3 -- KSE channel of the Talgar station, 1969, 4 -- the same, 1971, 5 -- SKM channel of the Talgar station

Key: 1. V_{rem}; 2. f, hertz; 3. 10 seconds; 4. 12 June 1969; 5. 0448 hours; 6. 0512 hours

Observations in an Area with low Ground Noise Level. The low noise level in the vicinity of Chilik has made it possible to perform synchronous observations using identical equipment in the well at depths of 600 and 300 meters and on the surface. Unfortunately, the results of studying the noise in time do not claim to high accuracy. This is explained by the fact that the recording of low amplitudes depends strongly on the clamping of the pen. Observation experience indicates that quantitative processing is meaningful for amplitudes exceeding 2.5-3 mm, and the estimates obtained for the variation of the noise level are, in our opinion, of defined interest.

Depth of 300 Meters. The total recording time at a depth of 300 meters was 50 days. During this time the noise level varied with respect to amplitude from 6 to 50 nm. The noise amplitude distribution with respect to the recording time is illustrated below:

A, nm	4.0	8.3	12.5	17.0	33.0
t, %	1.0	40.4	5.5	52.7	0.5

Thus, during 98% of the total recording time the noise level at a depth of 300 meters was included in the range of amplitudes from 8 to 17 nm, and it varied by no more than 2 times.

Depth 600 Meters. When making the transition from a depth of 300 to 600 m the noise amplitudes decrease by approximately 2 times. The amplitudes and the range of their variations (see Fig 8, a) agree qualitatively with the vertical profiling data. At both depths (300 and 600 m) a stable difference in noise level is observed between night and day. At night time (from 2100 hours to 0600 hours local time) the noise level decreases by almost 2 times, which confirms the "cultural" nature of the noise. On holidays (Saturday and Sunday) the noise level in the Chilik Well, in contrast to Tashkent and Alma-Ata, does not decrease, which is obviously connected with the absence of industrial enterprises in the vicinity which are the basic sources of interference.

The noise level on the day surface varies with time within significantly greater limits than in the well -- from 15 to 500 nm, that is, by more than 30 times. Since the observations were performed during the quietest summer months, it is possible to consider that this range will increase significantly in the fall and winter as a result of wind interference which is not recorded in general at a depth of 300 and 600 meters.

For illustration of the variation of the noise level from the day surface and in the well let us present several seismograms. With equal channel gains (k=2) the ground noise level is appreciably greater than at a depth of 300 meters, but on increasing the ground channel, it is half that in the well (k=1), the noise amplitudes are comparable (Fig 10, a, see the insert). At a depth of 600 meters (Fig 10, b) for k=2 the noise level is comparable to the ground channel -- the upper part of the seismogram --

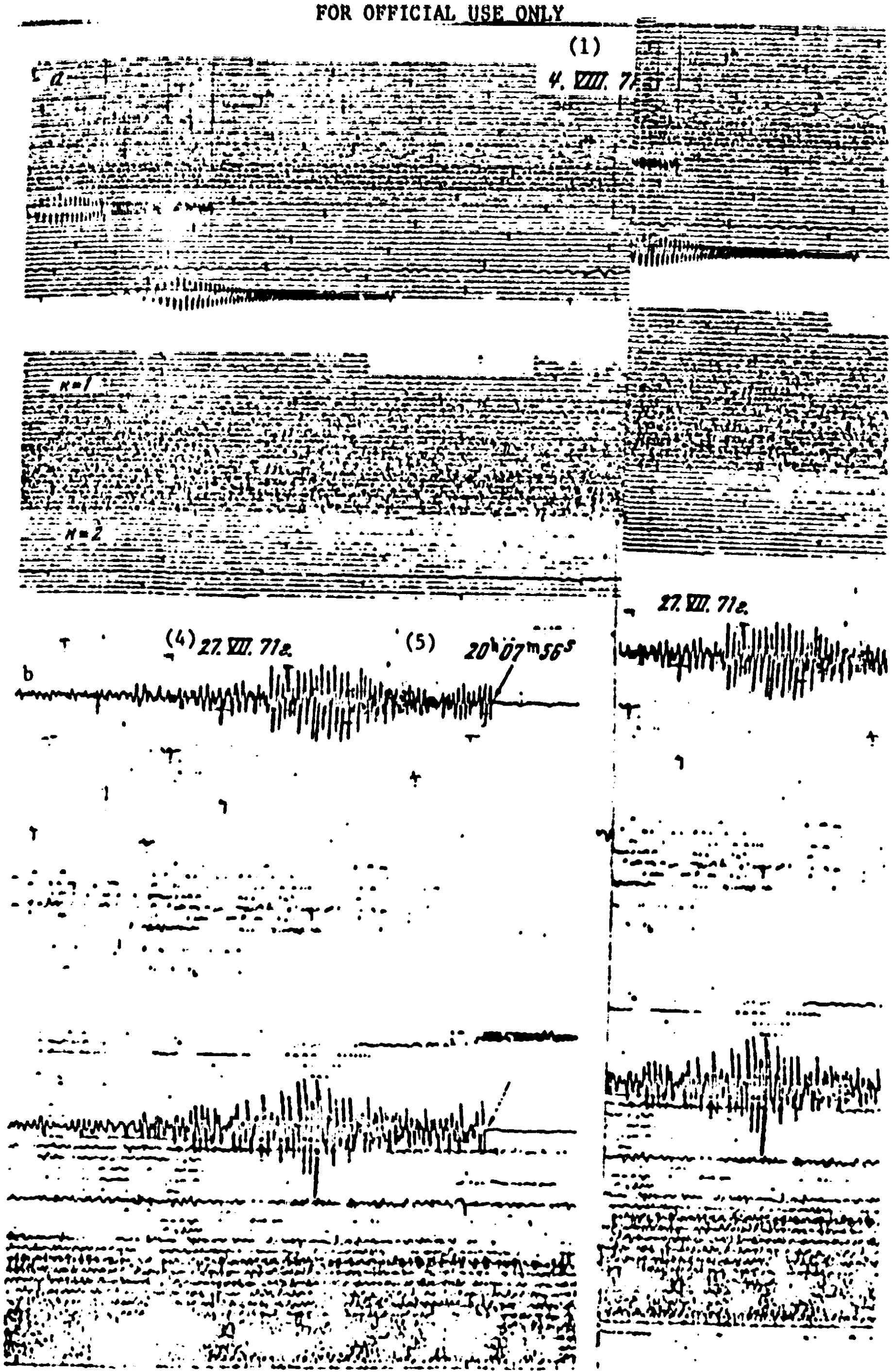

Figure 10 [See following pp]

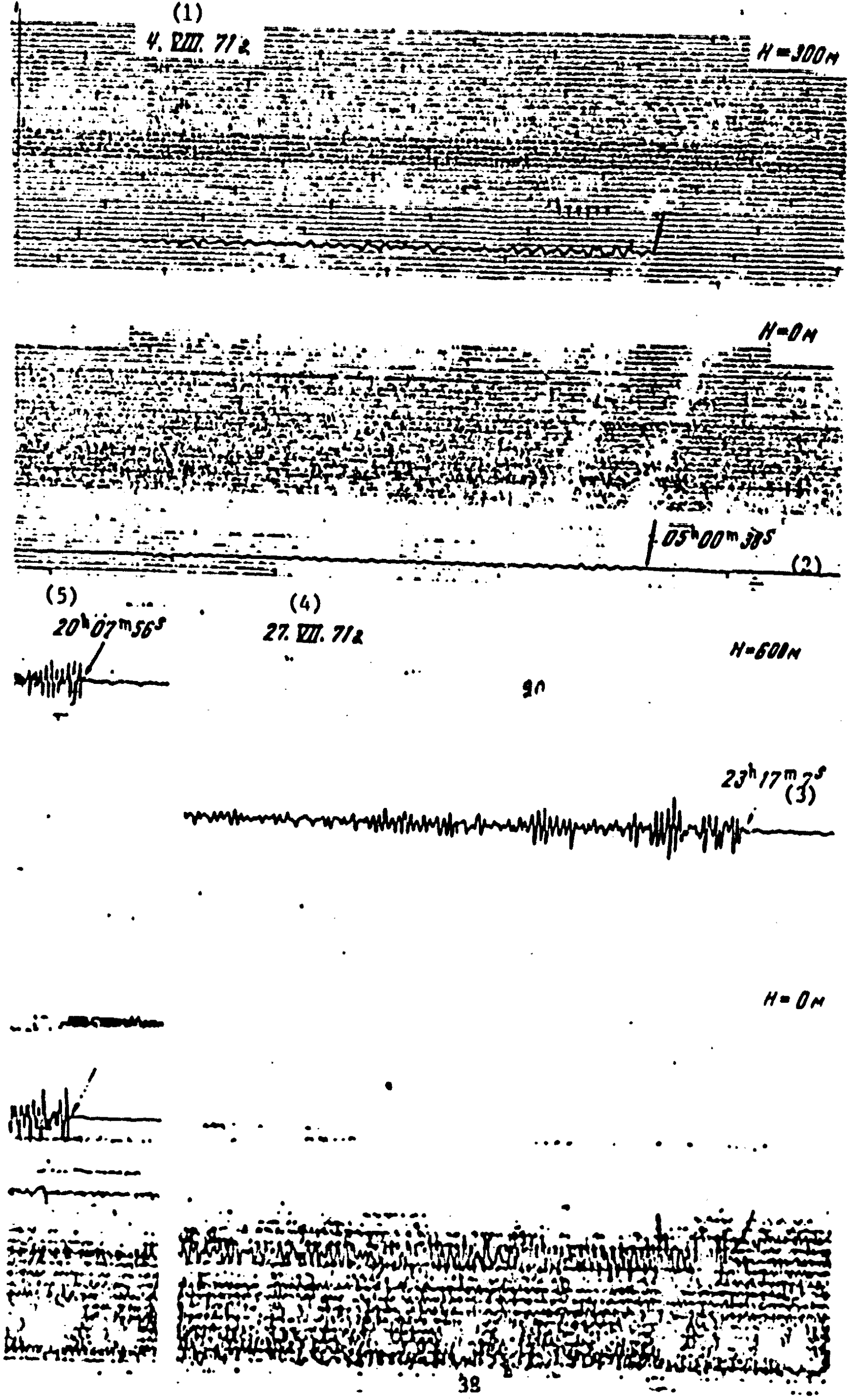
(1)
4. VIII. 71 г
H=300м
H=0м
05h00m38s
(2)
(5)
20h07m56s
(4)
27. VII. 71 г
H=600м
20
23h17m7s
(3)
H=0м

Figure 10. [see preceding page] Noise background on the day surface and in the Chilik Well at depths of 300 (a) and 600 meters (b).

Key:
1. 4 August 1971
2. 0500 hours and 38 seconds
3. 2317 hours and 7 seconds
4. 27 July 1971
5. 2007 hours and 56 seconds

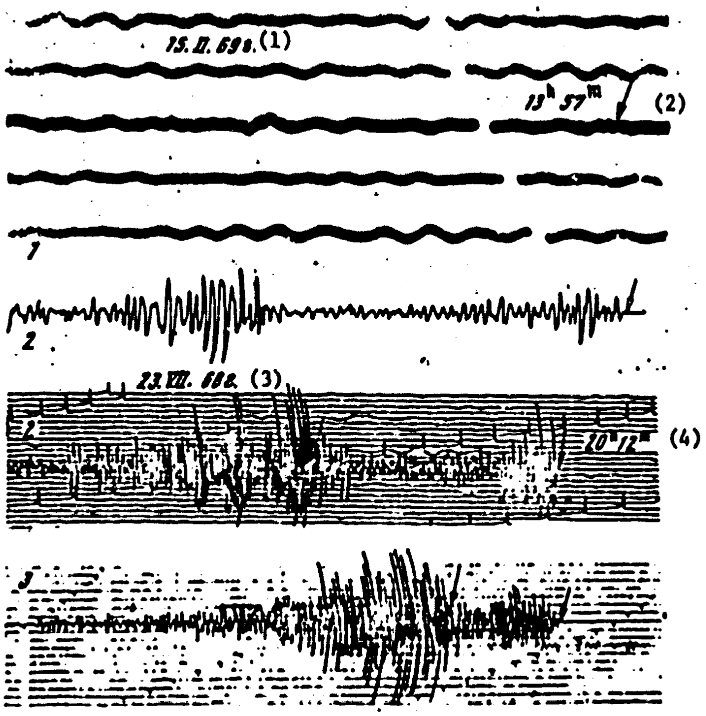

Figure 11. Recordings of earthquakes by the ground station (1) and deep-well station at a depth of 1950 meters (2) in the city of Alma-Ata and the KSE channel (3) of the Talgar station. The arrows indicate the arrival of the P and S waves.

Key:
1. 15 February 1969; 2. 1357 hours; 3. 23 July 1968; 4. 2012 hours

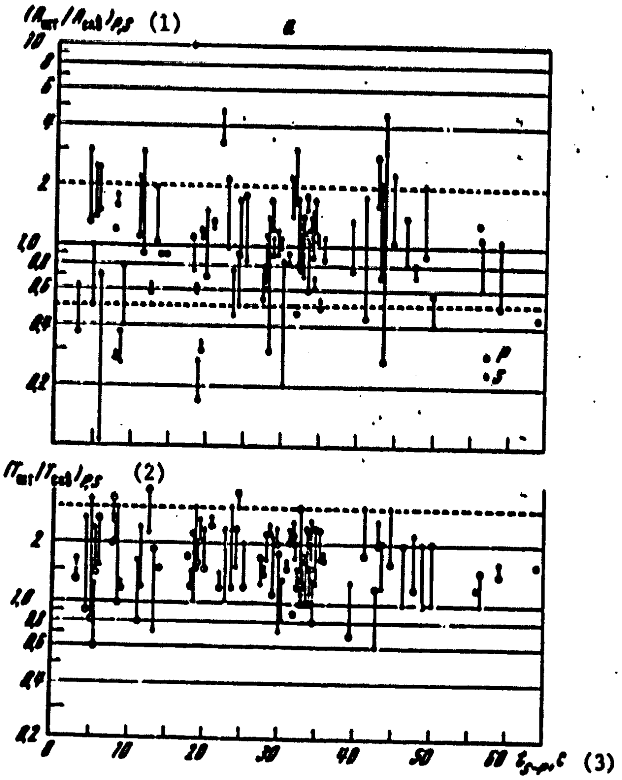

Figure 12. Amplitudes and periods of near (a, b) and distant (c) earthquakes by the deep station (1950 meters) and the Talgar station (KSE channel, drift, June-July 1969)
Histograms of the values of T_P and T_S in the well and the drift are also presented. The figures at the points on the graphs are the number of coinciding values.

Key:
1. $(A_{drift}/A_{well})_{P,S}$
2. $(T_{drift}/T_{well})_{P,S}$
3. t_{S-P}, sec
4. $T_{P,S(drift)}$, sec
5. $T_{P(drift)}$, sec
6. $T_{P(well)}$
7. $T_{P,S(well)}$
8. well
9. T_S, sec
10. T_P, sec

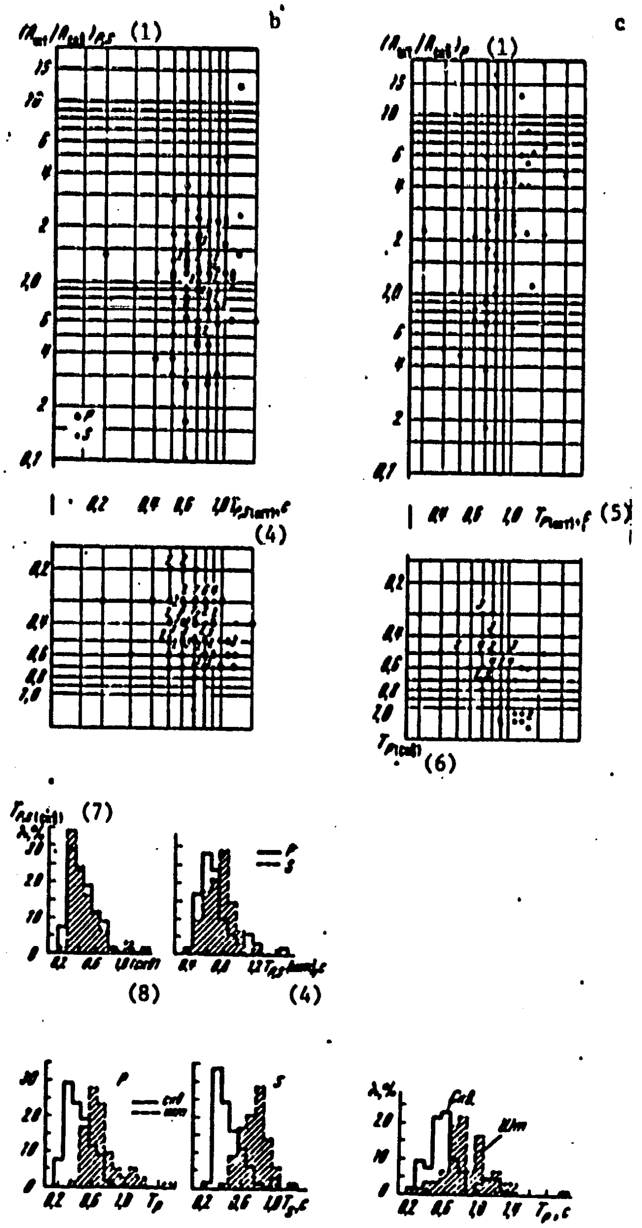

Figure 12 (End) [see key, preceding page]

but then the noise level on the surface is sharply amplified, and the signal (2317 hours) on the ground seismogram became typical. At the same time, at a depth of 600 meters no increase in noise occurred, and the signals were reliably separated during the entire recording time.

Thus, for observations in wells not only does the noise level decrease, but its stability increases sharply.

§4. Useful Signal and Sensitivity of Well Observations

The study of the useful signal in the wells was made in areas with high ground noise level (Alma-Ata) and low ground noise level (Chilik). In order to estimate the gain in sensitivity the observation materials in the Alma-Ata Well were compared with the recordings of the two ground stations, one of which (Alma-Ata) was located within the city with high ground noise level, and the other (Talgar), under favorable seismogeological conditions with low noise level. The seismometers of the second station were placed in a deep drift [mine tunnel].

Observations under High Ground Noise Level Conditions. Stationary observations in the Alma-Ata Well were performed at different fixed depths.

Depth 1950 Meters. A comparison of the observation materials of the well station with the ground station in Alma-Ata demonstrated that the sensitivity of the latter is 20 to 40 times lower. The recordings of these stations are in practice incomparable. Earthquakes (distant or near) which are isolated on the seismograms of the deep-well station either are not recorded at all by the ground station equipped with standard equipment or they have a very low amplitude (Fig 11, see the insert).

It is expedient to carry out the comparison with the Talgar ground station separately by the recordings of distant ($t_{S-P}>1$ minute) and near ($t_{S-P}<1$ min) earthquakes including local earthquakes ($t_{S-P}<10$ seconds). As a result of comparing the periods and the amplitudes of 130 earthquakes (Fig 12) it is possible to formulate the following conclusions.

For near earthquakes the predominant periods of the P-waves in the well are 0.3-0.5 seconds; on the KSE channel of the Talgar station they are 0.5-0.7 seconds. The periods of the S-waves are 0.3-0.5 and 0.6-0.9 sec respectively. The predominant values of the ratio of the periods in the drift and in the well T_{drift}/T_{well} for the P and S waves are included within the limits of 1 to 3. The difference in periods of the S-waves is somewhat greater than for the P-waves which is manifested especially clearly on recordings of local earthquakes.

The amplitudes of the recordings of the KSE channel and the well recording in general are similar; out of all of the investigated earthquakes in 80% of the cases the values of the ratios A_{drift}/A_{well} for the P and S waves are included within the limits of 0.5-2.0, that is, the amplitudes differ by no more than 2 times (Fig 12, b). The local earthquakes are almost always more intense on the deep-well seismograms than on the KSE channel, and especially the SKM channel. Some of the local earthquakes have not been recorded in general by the Talgar station or they are hardly isolated although the recordings of the more remote earthquakes are commensurate or more intense on the KSE channel (Fig 13, a, earthquakes 0118 hours).

The difference in amplitudes of the S waves on the recordings of the KSE channels and the deep-well channel are more significant than for the P-waves, for for S-waves the difference in periods is greater. The ratio A_S/A_P for the Talgar station and the deep-well station can be different.

Cases have been observed where the ratio A_S/A_P in the well is greater than in the drift and vice versa. This is explained by the fact that in addition to the difference in frequencies of the waves recorded in the well and on the surface (in the drift), the difference in directions of approach of these waves also influence the magnitude of the ratio. For observations in a borehole, the low-speed sedimentary rock determines the direction of approach of the waves close to vertical. Therefore the ratio A_S/A_P in the well can be less than in the drift where there are no such rocks. On the other hand, the thick series of sediments in the well under the instrument which reaches 2200 meters on submerging the instrument to 2000 meters causes a stronger absorption of the high frequencies in the longitudinal wave spectrum of local earthquakes than in the drift, and it has less effect on the absorption of the lower frequency S waves as a result of which the A_S/A_P ratio can be larger in the well than in the drift.

Depending on which of the factors predominates, one ratio or another occurs.

A comparison of the recordings of the channels of the deep-well and the SKM stations of Talgar indicates that the predominant periods of the P-waves of near earthquakes diverge significantly on both channels and amount to 0.3-0.5 seconds. The amplitude of the near earthquakes on the well channel usually is 2-4 times greater than on the SKM channel (Fig 13, b).

For distant earthquakes, the predominant periods of the P-waves on the recordings of the well channel are 0.5-0.6 seconds; on the KSE channel, 0.7-1.0 seconds, the oscillation amplitudes in this case on both channels are either close to or greater than on the KSE channel (see Fig 12, c). There are, however, recordings that are more intense on the well channel (Fig 13, c). The clear dependence of the amplitude ratio A_{drift}/A_{well} on the period is detected: beginning with T=0.8 seconds this ratio becomes greater than one and with an increase in T, it increases (Fig 12, b), which is caused basically by the difference of the frequency characteristics of the channels and periods greater than 0.8 seconds.

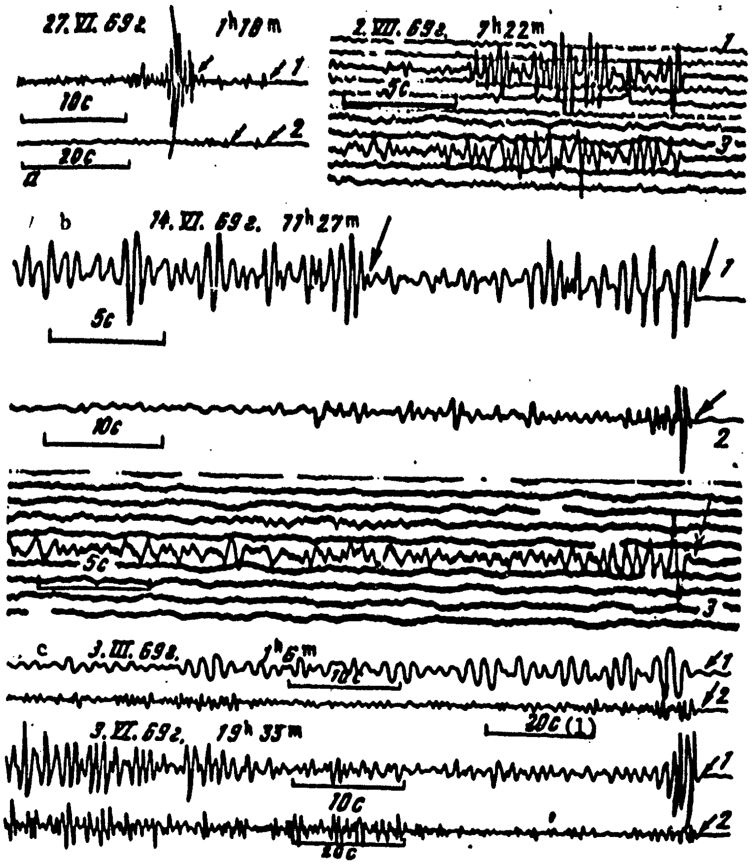

Figure 13. Recordings of local (a), near (b), and distant (c) earthquakes by a well station at a depth of 1950 meters (1) and by the KSE channel (2) and SKM channel (3) of the Talgar station. The arrows indicate the arrivals of P and S waves.

Key:
1. seconds

The predominant periods of the P-waves on the recordings of the SKM channel are 0.8-1.0 sec, and although on these frequencies the gain of the SKM channel is 1.5-2 times greater than the gain of the well channel, the recording amplitudes on the two channels are approximately identical, and sometimes they are even more intense in the well.

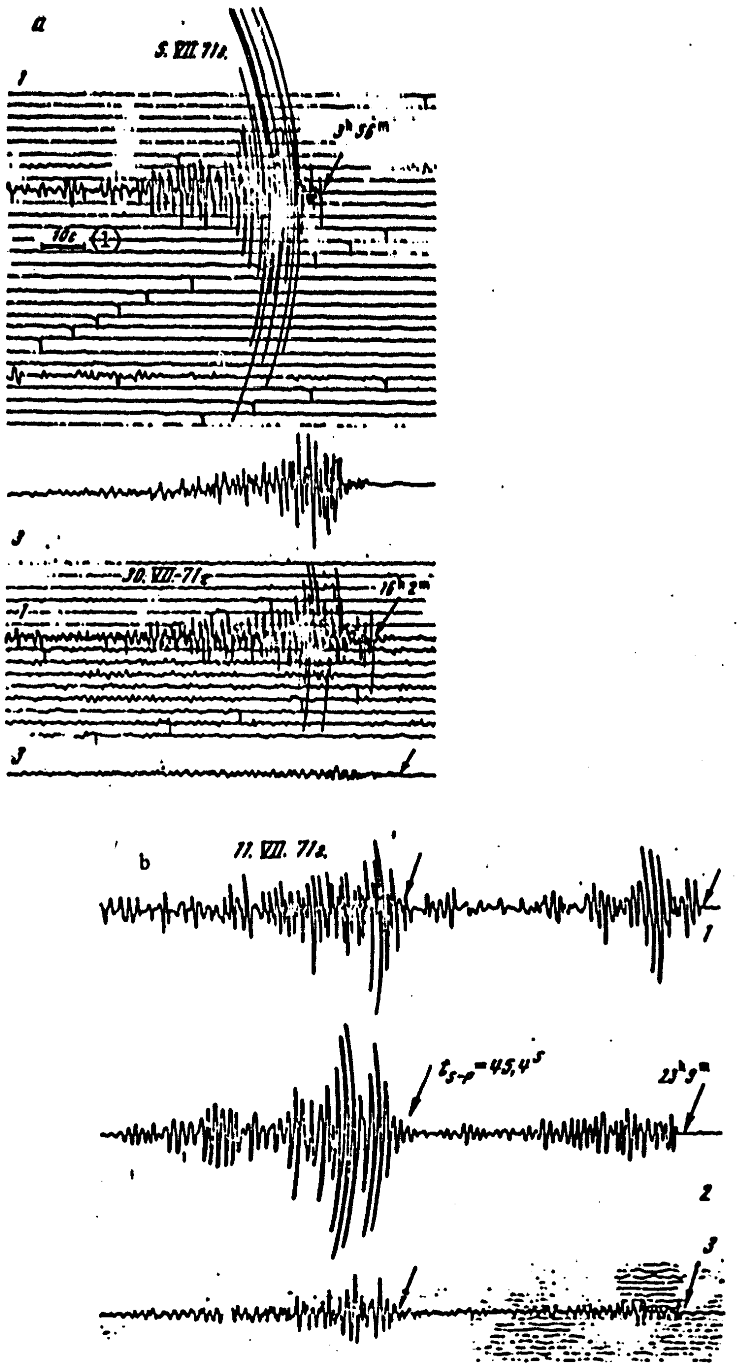

Figure 14 [see following page]

Figure 14 [see preceding page]. Recordings of local (a), near (b) and distant (c) earthquakes by the well channel at a depth of 960 meters (1) and the KSE channel (2) and SKM channel (3) of the Talgar station. Key:

1. seconds

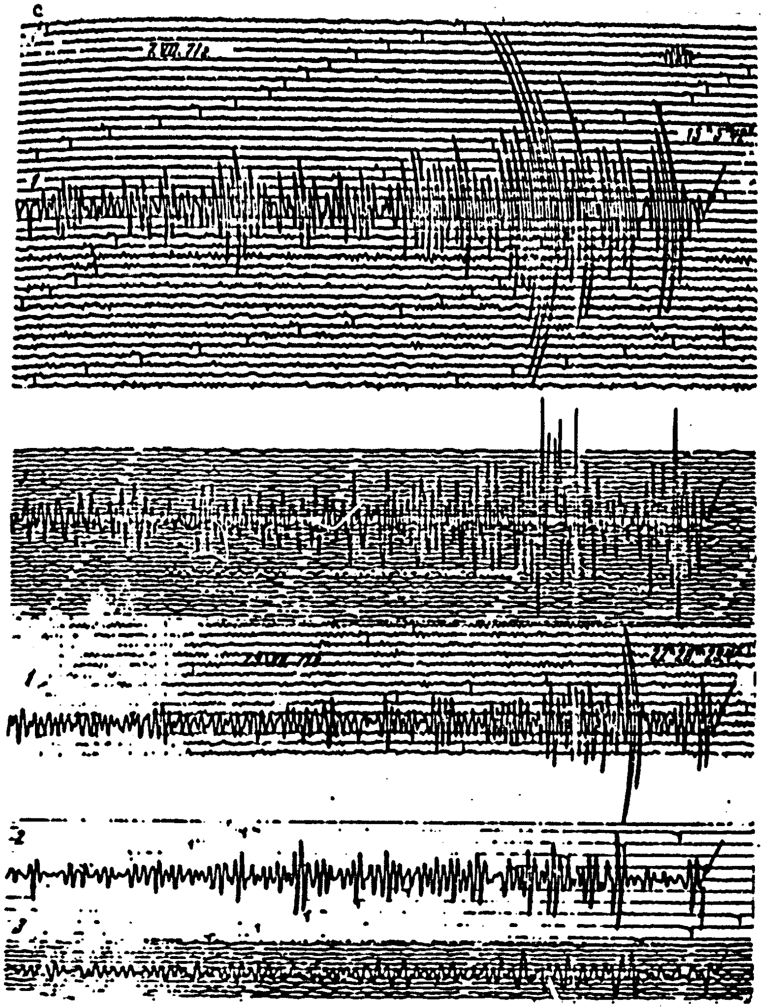

Figure 14 (Continued)

In the case of stationary observations in a well, in addition to the earthquakes, explosions were also recorded (Δ=50-100 km), the recordings of which differ from the recordings of the ground stations at Talgar and Alma-Ata by the absence of intense surface waves.

Depth 960 Meters. The useful sensitivity of the deep-well station, just as in the case of a depth of 1950 meters is in practice incomparable with the sensitivity of the ground station at Alma-Ata.

A comparison of the deep-well station was made with the Talgar station basically with respect to the SKM channel, the frequency characteristic of which was the closest to the well channel (see Fig 9, c). For this purpose an analysis was made of more than 130 recordings of earthquakes obtained in July 1971. For the near earthquakes, the predominant periods of the [letter missing] waves in the well are 0.8-1.0 seconds, and in the SKV channel, 0.3-0.5 seconds, that is, almost 2 times less.

The amplitudes of the recordings of the well channel are similar or exceed by 1.5-2 times the amplitudes of the recordings of the SKM channel; on the given KSE channel the amplitudes are usually larger (see Fig 14, a,b).

For the distant earthquakes, the predominance of periods of the P-waves on the two channels are approximately identical and amount to 0.8-1.0 seconds. Since the recordings of remote earthquakes are lower frequency, the effect of the sedimentary series is less felt in this spectrum.

The amplitudes of the recordings of the distant earthquakes and the well and the SKM channels are commensurate (Fig 14, c). With an increase in the period, the amplitudes on the SKM channel predominate, for a difference is felt in the frequency characteristics of the compared channels. On the KSE channel which is 1.5-2.0 times more sensitive than the SKM channel, the recordings of the distant earthquakes are, as a rule, more intense.

Depth Interval of 960-300 Meters. In order to estimate the useful sensitivity in this interval let us consider the recordings of aftershocks of near earthquakes obtained in the well at different depths (Fig 15, b). The recordings which are similar with respect to shape were compared, and the SKM channel recordings were used as the source control (Fig 15, a).

The growth of the noise background as the depth decreases can easily be seen in the figure (all of the recordings were obtained in the daytime). At a depth of 300 meters the increase in the well channel has diminished by 2 times by comparison with the remaining depths.

The variation of the useful sensitivity of the recording with depth was estimated by the recordings of aftershocks and earthquakes with t_{S-P}=32 sec. A study was made of the distribution of the ratio A_{well}/A_{SKM} (Fig 15, c) with respect to depth by the recordings of the aftershocks of near earthquakes.

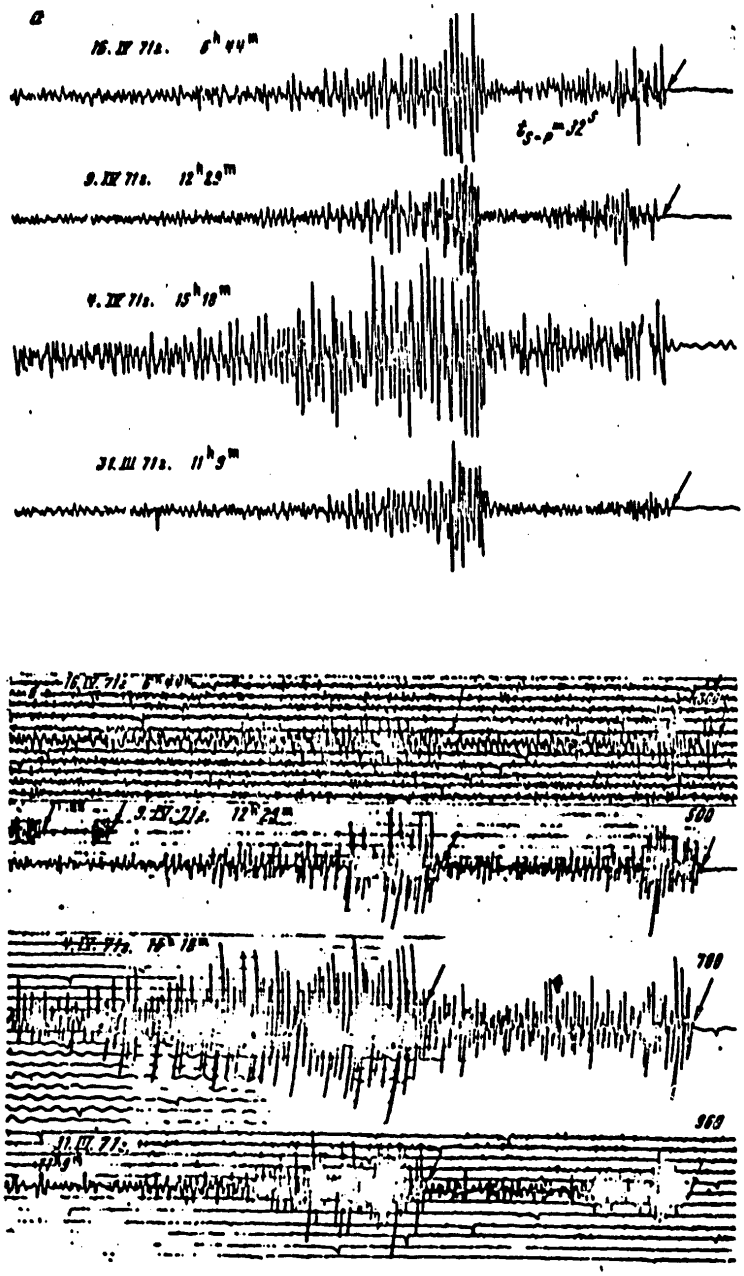
a
16.IV 71г. 5h44m
ts-p=32s
9.IV 71г. 12h23m
4.IV 71г. 15h18m
31.III 71г. 11h9m
16.IV.71г. 5h44m
300
9.IV.71г. 12h23m
500
4.IV.71г. 15h18m
700
960
31.III.71г. 11h9m

Figure 15

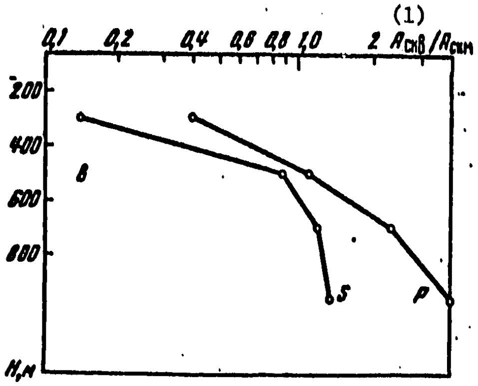

Figure 15. Recordings of aftershocks by SKM channel (a) and well channels at different depths (b) and with the graphs of A_{well}/A_{SKM} (c)

Key:

1. A_{well}/A_{SKM}

The results obtained indicate that on submerging the seismometer from 300 to 960 meters, the signal/noise ratio increases by 5-6 times.

Comparison of Recordings in a Well at Depths of 1 and 2 km. From investigation of the histograms (Fig 16) obtained by the results of processing the recordings of distant and near earthquakes at depths of 960 and 1950 m, it follows that with a decrease in depth from 2 to 1 km:

1) The recording periods of the distant earthquakes increase from 0.5-0.7 to 0.8-1.0 seconds (Fig 16, I). In the SKM channel the periods of the recordings are identical in this case both for 1969 and 1971, and they amount to 0.8-1.0 seconds (Fig 16, II);

2) The periods of the recordings of the near earthquakes increase still more (by twice as much) from 0.3-0.5 to 0.8-1.0 seconds (Fig 16, III). In the SKM channel, the same periods predominate -- 0.3-0.5 seconds (Fig 16, IV);

3) The amplitude ratio A_{well}/A_{SKM} of the distant earthquakes decreases: at a depth of 2 km the recording amplitudes on the well channel and the SKM channel as a whole are commensurate, and at a depth of 1 km they are either similar or on the SKM channel 1.5-2.0 times more intense (Fig 16, V);

4) The amplitude ratio A_{well}/A_{SKM} of close earthquakes also decreases, but it does not disappear (Fig 16, VI).

On the whole the recordings of the near earthquakes at depths of 1950 and 960 meters and in a drift either are close or on the average 2 times more intense in the well.

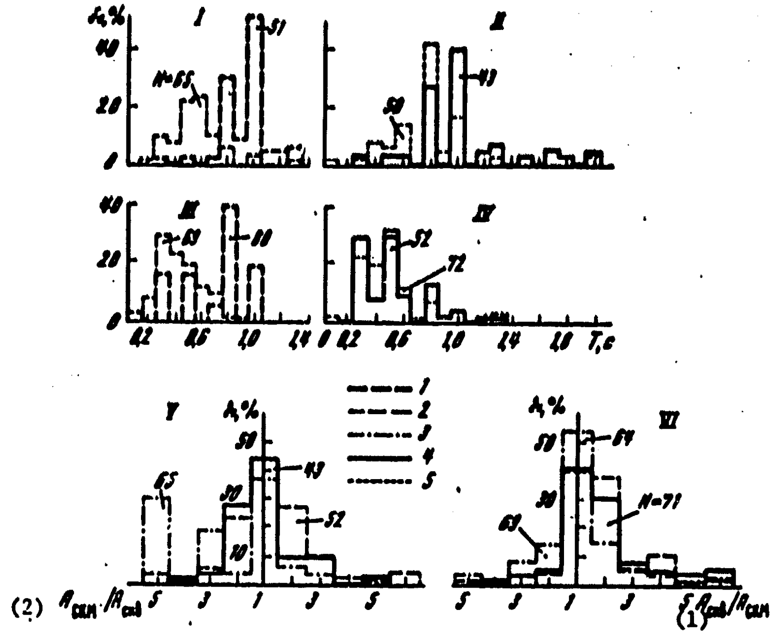

Figure 16. Histograms of the values of periods and the amplitude ratios A_{well}/A_{SKM} for longitudinal waves by the recordings of distant (I, II, V) and near (III, IV, VI) earthquakes. 1, 2 -- in a well at depths of 960 meters, 1971, and 1950 meters, 1969, correspondingly, 3 -- A_{well}/A_{KSE}, 1969; 4,5 -- by the recordings of the SKM channel in July 1971 and in June-July 1969, respectively

Key:

1. A_{well}/A_{SKM}
2. A_{SKM}/A_{well}

Thus, making the transition from a depth of 1950 meters to 960 meters, the increase in thickness of the sedimentary rock under the well tool leads to significant reduction of the frequencies in the investigated oscillations and some decrease in sensitivity of the equipment.

Observations under the Conditions of Low-Level Ground Noise in Small Groups. In order to estimate the sensitivity of the equipment at depths of 300 and 600 meters, let us compare the distant and near, including local earthquakes recorded during synchronous observations using identical equipment on the day surface at the mouth of the well and in the well itself.

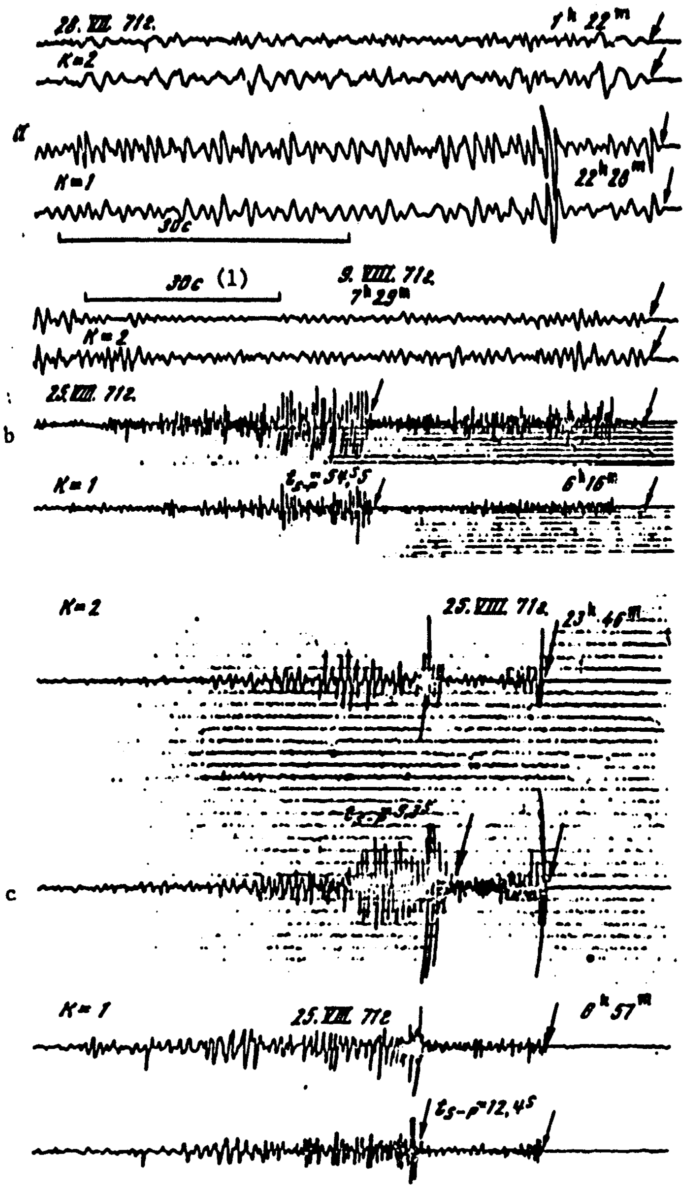

Figure 17. Recordings of distant (a), near (b) and local (c) earthquakes by the ground channel (upper) and the well channel at a depth of 300 meters (lower trace) at values of k=1 and 2 in the Chilik Well.

Key:
1. seconds

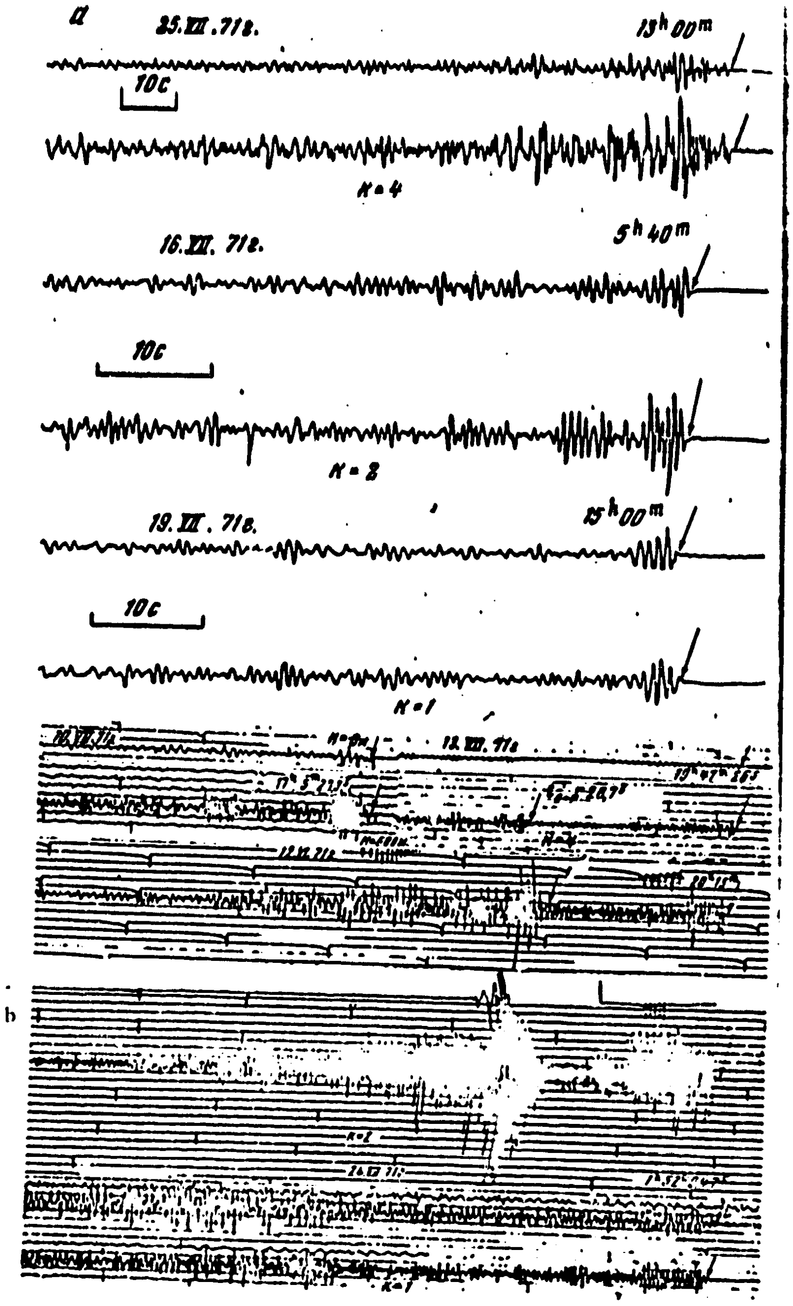
a
25.XII.71г.
13ʰ00ᵐ
10с
K=4
16.XII.71г.
5ʰ40ᵐ
10с
K=2
19.XII.71г.
15ʰ00ᵐ
10с
K=1
b

Figure 18

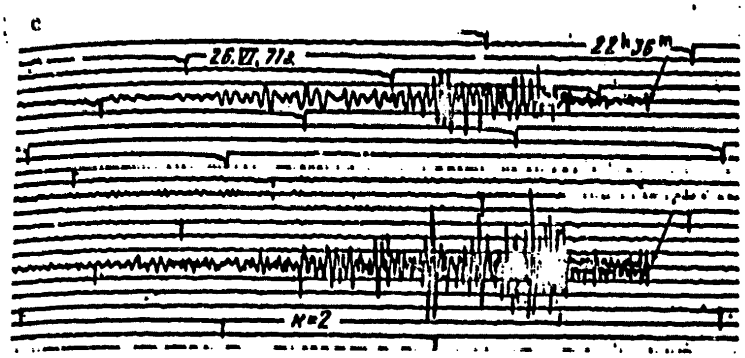

Figure 18. Recordings of distant (a), near (b) and local (c) earthquakes by a ground channel (upper) and a well channel at a depth of 600 meters (lower trace) by channels with values of k-4, 2 and 1 in the Chilik Well.

The gain in sensitivity is determined primarily by the signal/noise ratio. The greater the difference in amplification V the noise level on the surface and in the well makes it possible to realize, the greater the gain in sensitivity at depth by comparison with the day surface.

Depth 300 Meters. For observations at a depth of 300 meters it turned out to be possible to make a recording for k=4-10, k=2-68 and k=1-22% of the total recording time ($k=V_{well}/V_{surface}$). The basic conclusions obtained as a result of comparing the ground and well seismograms are the following.

For distant earthquakes at k=4 the recording amplitudes in the well are twice as great as on the surface. However, too few such recordings were obtained in order to make a reliable estimate of the gain in the useful sensitivity.

For k=2, which is predominant with respect to recording time at a depth of 300 meters, the intensity of the recordings of the distant earthquakes in the well usually is 1.5-2 times higher than on the surface, and more rarely it coincides. For k=1 the amplitudes of the well and ground recordings are commensurate or the ground recordings are 1.5-2 times greater (see Fig 17, a).

For near earthquakes, the material obtained will make it possible to estimate the useful sensitivity at a depth of 300 meters only for k=2 and 1. However, on individual available recordings when k=4 it is obvious that when the signal at the surface is comparable with the background and it is separated with difficulty, at a depth of 300 meters the signal amplitudes exceed the background by approximately 5 times.

In the case where k=2 the recordings of near earthquakes on the surface and in the well either are comparable with respect to intensity or they are 1.5-2 times more intense in the well. For k=1, the ground recordings usually are 1.5-2 times more intense than in the well (Fig 17, b).

Table 2

Глубина, м (1)	k	Землетрясения (2)		
		(3) далекие	(4) близкие	местные (5)
300	4	2	5	-
	2	1 - 1,5	1 - 2	1,5 - 2
	1	0,5	0,5	1
600	4	2	2 - 4	-
	2	1 - 1,5	1,5-2,5	2
	1	1	1	-

Key:

1. depth, meters
2. earthquake
3. distant
4. near
5. local

Table 3

Землетрясения (1)	T_0	T_{300}
(2) Далекие	0,6 - 1,0	0,5 - 1,0
(3) Близкие	0,5 - 0,7	0,6 - 0,7
(4) Местные	0,5 - 0,7	0,2 - 0,3

Key:

1. earthquake
2. distant
3. near
4. local

Table 4

Землетрясения (1)	T_0	T_{600}
(2) Далекие	0,6 - 1,0	0,5 - 0,6
(3) Близкие	0,5 - 0,7	0,4 - 0,5
(4) Местные	0,5 - 0,7	0,4 - 0,6

Key:

1. earthquake
2. distant
3. near
4. local

When recording local earthquakes, the gain in sensitivity in the well turns out to be greater than for the distant and near ones. For k=2 the recordings at a depth of 300 meters are always on the average 1.5-2 times more intense than on the surface (Fig 17, c), and with an identical channel amplification, the recording amplitudes are usually close.

Depths 600 Meters. At a depth of 600 meters, the noise level is half that at a depth of 300 meters, which has made it possible to make a recording for k=4 during 35% of the entire recording time, for k=2, for 45% of the time, and k=4, 20% of the time.

The distant earthquakes at k=4 on the recordings in the well are on the average 1.5-2 times more intense than on the surface. For k=2 the recordings in the well are either close with respect to intensity to the recordings on the surface or they are 1 to 1-1/2 times more intense. For k=1 (few such recordings were obtained at a depth of 600 meters) the recordings on the surface and in the well are usually equivalent (Fig 18, a).

For k=4 the near earthquakes are recorded in the well 2-4 times more intensely than on the surface; for k=2, 1.5-2 times. For k=1 the recordings are close or approximately 1.5 times more intense than on the surface (Fig 18, b).

The majority of the recordings of local earthquakes at a depth of 600 m were obtained for k=2. The gain in sensitivity in this case is the same as for near earthquakes, and it is on the average 2 times (see, for example, Fig 18, c).

The ratios of the amplitudes of the earthquakes recorded by surface and deep well seismometers $A_{well}/A_{surface}$ at different depths are presented in Table 2.

Form of the Recording and Structure of the Seismograms. In addition to estimating the useful sensitivity, the synchronous observations by identical equipment in the well and on the surface make it possible to compare the form of the recording of the individual waves and the structure of the seismograms. In this respect the observations in the Chilik Well differ advantageously from the observations in Alma-Ata, where, as a result of the very high ground noise background the recording on the day surface is impossible.

A comparison of the form of the earthquake recordings leads to the following conclusions.

The recordings of all of the earthquakes -- distant, near and local -- usually are more high frequency at a depth of 300 meters than on the surface. The difference in frequency composition is more noticeable for the high-frequency earthquakes, it is smaller for the near ones and still less for the distant ones, the periods of which at H=0 and 300 meters are close. The predominant values of the periods (in seconds) of the longitudinal waves on the surface and in the well for equally removed earthquakes are presented in Table 3.

The low-frequency signals at a depth of 300 meters are frequently more intense than on the surface for commensurate high-frequency signals.

The shape of the low-frequency signals on the surface and at a depth of 300 meters in practice is identical at the same time as the shape of the high-frequency recordings in the well usually is more complex and less regular. Here the basic factor influencing the form of the recording of the individual wave is the superposition of the wave pulse reflected from the day surface on the incident wave pulse. The form of the recording of each individual wave in the well is determined by the conditions of interference of these waves which, in turn, depends on the depth of the observation point, wave length and velocity section.

Fig 19, a shows the results of calculating the shape of the pulse in the well for two of the simplest pulses taken from the seismogram. The pulses were calculated considering the velocity characteristic of the section with respect to the Chilik Well. The periods of the initial pulses varied within the range of 0.1 to 1.6 seconds, which covers the range of variation of the periods of the recorded signals. It is obvious that in the upper part of the section there is superposition of the pulses, and the pulses are separated only from some depth. This depth is inversely proportional to the frequency. Thus, whereas for a period of T=0.1 seconds the waves are separated at a depth of 300 meters, for T=1.6 seconds this depth is 1500 m. The shape of the high-frequency signals with a period of 0.2 seconds at a depth of 300 meters is complex. Additional extrema appear at the same time as for the lower frequency pulses (T=0.4 to 1.6 seconds) only the amplitude ratio of the first extrema varies. In Fig 19, a the last two examples correspond to superposition of several more complex pulses.

At a depth of 600 meters the recordings are still more high frequency by comparison with the surface than at a depth of 300 meters, which is connected with an increase in thickness of the sediment over the seismometer (Fig 19, b, c). The values of the predominant periods (in seconds) of the P-waves on the surface and at a depth of 600 meters are presented in Table 4.

For the low-frequency recording the difference in shape decreases, which also agrees well with the calculation data. The dependence of the ratio A_{600}/A_0 on the frequency is expressed not so clearly as at a depth of 300 meters.

Thus, for close and local earthquakes at a depth of 600 meters the gain in sensitivity is 1.5-2.0 times greater than at a depth of 300 meters. For the recordings of the distant earthquakes this gain is identical at both depths.

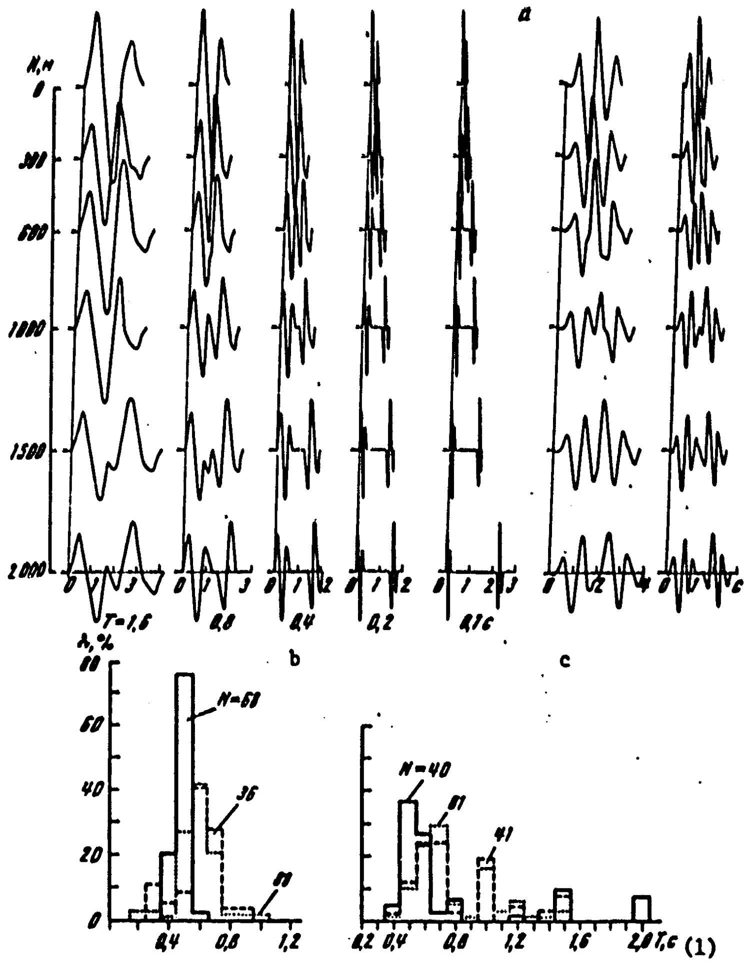

Figure 19. Theoretical seismograms calculated for two forms of pulses in different periods (a) and histograms of the values of the periods of the longitudinal waves for near (b) and distant (c) earthquakes with respect to the Chilik Well at a depth of 600 meters (the solid line), 300 meters (the dotted line) and on the surface (the points).

Key:
1. seconds

However, the lower noise level and its stability at 600 meters permit us to realize the maximum possible sensitivity for 3 times longer time than at a depth of 300 meters.

§5. Noise Background in the Case of Stationary Noise Sources

In the preceding items a study was made of the results of the observations in the areas characterized by high and low ground noise level. In both cases, no noise source was concentrated in the vicinity of the well. The background was the result of superposition of the interference waves caused by a large number of distributed sources. The Novo-Alekseyevskaya Well is distinguished from the investigated ones with respect to its conditions. It is located far from large populated places (at the edge of a small village), and the noise level here is very low, but the presence of a large building materials combine near the well (approximately 3-4 km to the east) and a rock crushing plant (about 4 km to the south) has led to a sharp increase in noise level and specific variation with depth. The basic source of the interference waves is the crushers operating at these enterprises. With respect to the nature of their operation they are similar to stationary vibrators, and the study of the waves excited by sources of this type is of interest not only from the point of view of estimating the possible gain in sensitivity of the equipment but also from the point of view of the possibility of using such sources for seismological studies.

The Novo-Alekseyevskaya Well is located between the Alma-Ata and Chilik Wells 22 km east of the Alma-Ata Well. The thickness of the coarsely clastic sedimentary rock is 2960 meters here. Let us remember that in the Alma-Ata and Chilik Wells this thickness was 4200 and 1350 meters respectively.

Observations in the Novo-Alekseyevskaya Well were used to study the laws of variation of noise with depth along the well stem, the stability of the noise on the day surface and at certain fixed depths, the frequency composition of the noise on the surface and at fixed depths, and the gain in sensitivity of the well observations.

The noise background was measured synchronously on the surface and at the well by the method of vertical seismic profiling (the variation of the noise with depth) and stationary observations (the stability of the noise) when the well seismograph was located at one fixed depth.

During the stationary observations, the set of equipment did not differ from that described in Chapter I. For observations by the VSP method, the noise was recorded on the magnetic tape using a 4-channel R-351F type tape recorder built by the TEAC Company. On one of the recording channels the ground seismograph recording was made, and on the other, the well seismograph recording was made with constant increase, on the third channel the well seismograph recording was made with approximately constant amplitude, but with enhancement from point to point. On the fourth channel a recording was made of the second and minute time marks. In parallel with the recording on the magnetic tape, a visible control recording was made of the same channels using the RV3-T recorder. The SD-1F seismometer was used as the seismic signal converter. A preamplifier was mounted directly in it. For commutation of the seismograph with a preamplifier, a special control panel was built.

The control panel was used to perform such operations as locking and unlocking the seismograph, adjusting the period of the pendulum, control of the operating voltages and also various types of commutations.

Eight vertical profiles (series of observations) were worked out, of which the first seven were on working days, and the eighth was on Sunday when the noise sources were not in operation. The depth of the observations was limited by the high temperatures at which the preamplifier placed in the well seismograph failed. The observations points during VSP were every 50 meters from the head of the well to a depth of 400 meters, and below that, every 100 meters. The recording time at each point was 3 minutes.

In order to study the variation of the noise level with depth recording, photooscillograms were made from the magnetic tape. In order to study the frequency composition of the noise, the spectral seismograms of the frequency selection seismographic station were obtained from the magnetic tape. During the processing, basically the recordings from two other channels were used -- the ground channel and the well channel with approximately a constant recording amplitude.

Study of the Laws of Variation of Noise with Depth. The results of the processing indicate that with respect to noise level and nature of its variation with depth there are two noise regimes differing sharply from each other. The first is "quiet" or "nonoperating." It is characterized by a comparatively low noise level and coincides with respect to time with the period when the crushers of the construction combines were not in operation (Sunday and short breaks for eating and preventive maintenance). For the second regime -- the noise or operating regime -- which takes up the main part of the time, a high noise level is characteristic which is connected with the operation of the crushers.

Before proceeding to an investigation of the relations obtained, let us briefly characterize the noise background on the surface for the two regimes. The average value of the noise amplitudes on the surface for the "quiet" regime represented by the Sunday series of observations fluctuates within the limits from 30 to 70 nm. The value of the noise with respect to the 50% probability level corresponds to 45 nm. The maximum values reach 120-140 nm of shift.

A characteristic feature of the nonoperating background is its sharp instability and great variability with respect to magnitude, from 12 to 140 nm, that is, by more than 10 times.

The second regime is characterized by the average value of the amplitudes equal to about 250 nm with respect to the 50% probability level. The maximum values of the amplitudes reach 550-600 nm.

A distinguishing feature of the "operating" background by comparison with the "nonoperating" one is its significantly greater stability; the noise level varies from 90 to 600 nm (by less than 7 times). The great stability of the "operating" background is explained by the stationary operation of the crushers.

An example of recording the background noise at different depths is shown in Fig 20, a. The magnitude of the noise level of the two regimes is sharply different, which is obvious by the graphs for the variation with depth of the mean noise amplitudes and also by the probability curves for the occurrence of the noise of given or lower amplitudes (Fig 20, b).

For the "quiet" regime there is a comparatively weak decrease in the noise with depth which is characteristic in general for the "quiet" regions (in particular, Chilik). At a depth of 1250 meters the noise amplitude is about 8 nm, that is, the decrease with respect to the surface is 8 times. The sharpest decrease, however, takes place in the first 300-400 meters where the noise level decreases by 5.5-6 times. Then the decrease proceeds much more slowly, and at a depth of 1200 meters, by comparison with 400 m the background decreases by only 1.5 times.

For the "noise" regime the nature of variation of the noise with depth differs not only from the "quiet" regime but also from all of the previously investigated cases (Tashkent, Alma-Ata, Chilik). Basically this refers to depths of more than 400-500 meters. In the upper part there is a sharp decrease in noise analogous to the areas with their high ground level (Tashkent, Alma-Ata). Thus, already at a depth of 5 meters the background level decreases by comparison with the surface (with respect to 50% probability level) by more than 2 times, at a depth of 2h0 meters by 7 times. The maximum decrease in background level is observed at a depth of 500 m -- approximately by 13 times (from 200 to 18 nm with respect to 50% probability level). Below 500 meters, with an increase in depth not only is a decrease in background amplitude observed, but, on the contrary, there is a trend toward some increase in the noise level. Thus, at a depth of 1000 meters the background amplitude is 20 nm, that is, 1.2 times greater than at 500 meters, and at a depth of 1700 meters the background level is larger by 1.3 times.

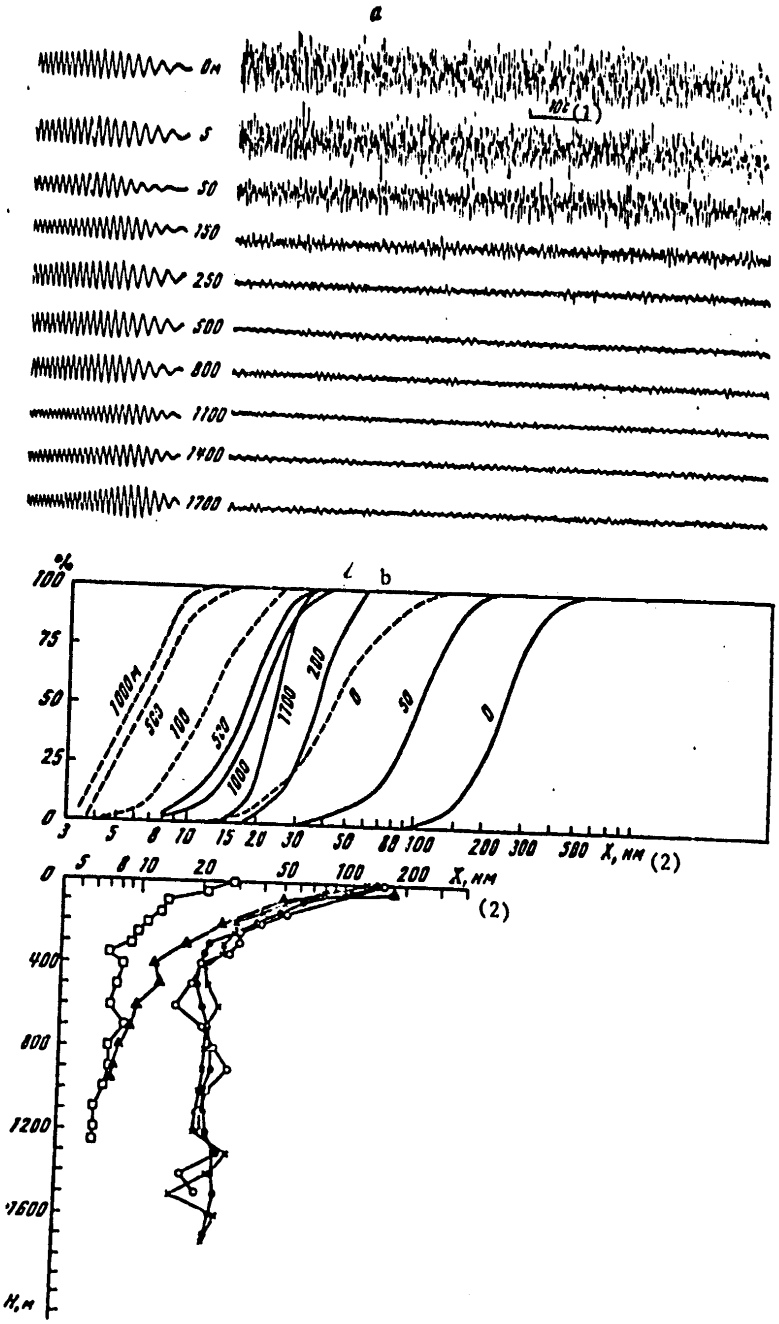

Figure 20 [continued on following page]

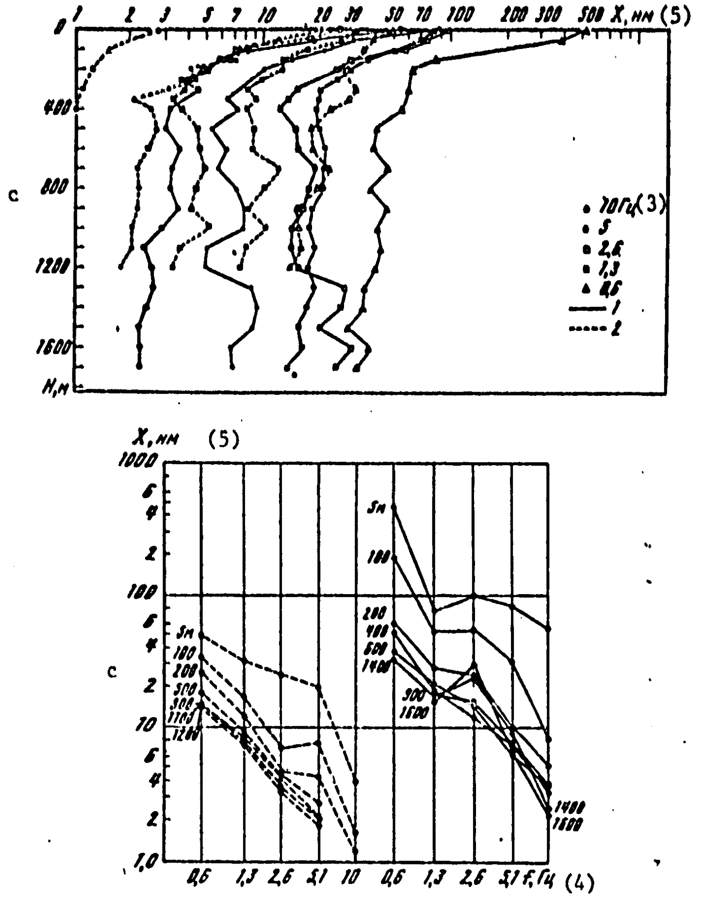

Figure 20. Noise in the Novo-Alekseyevskaya Well
a -- recording by the ground channel and the well channel at different depths. The increases in the ground channel are 80,000, and in the well channel, 140,000 at all depths. On the left we see the calibration signal of the constant amplitude magnetic generator (MGPA).
b -- Probability of occurrence of noise of given or slower amplitude on work days (solid line) and Sundays (dashed lines) at different depths (the numbers on the curves) and the mean amplitudes of the noise as a function of depth for the different series of observations (the triangles indicate data for the Alma-Ata Well).
c -- The frequency components of the noise as a function of depth (at the top) and its average spectra in the frequency range of 0.6-10 hertz for Sunday and working series of observations at different depths.
Key: 1. seconds; 2. X, nm; 3. hertz; 4. f, hertz; 5. X, nm

For comparison, Fig 20, b shows the graph of the variation of the noise amplitudes in the Alma-Ata Well constructed by 50% probability level for the first series when the majority of industrial enterprises are at work. The Alma-Ata chart differs sharply from the curves of the Novo-Alekseyevskaya Well. Whereas in the upper part it approaches the "noise" picture and above 100 meters it is shifted still more to the right in the direction of large amplitudes, below 400-500 meters, the graph is similar to the "quiet" regime and decreases smoothly with further increase in depth. For the "noise" regime of Novo-Alekseyevka, a smooth increase in noise level with an increase in depth is characteristic below 500 meters.

Variation of Noise with Time. Inasmuch as for Novo-Alekseyevka the primary source of interference is the operation of the crushers, they also determine the variation in noise background time both on the surface and in the well.

When the enterprises are not in operation, the background noise level is low although it varies within quite broad limits. The maximum noise amplitudes are determined on the day surface basically by the motor transportation and they are represented on the recording by individual comparatively high-frequency (10-15 hertz) blips. In this case, on the ground channel during stationary observations it is possible to realize amplification of about 20,000, and in the well channel, at a depth of 1200 meters, about 200,000. The amplitude of the background noise recording on both channels does not exceed 1 mm. However, it is necessary to note that on the ground channel at this time the background noise can periodically increase by 2-3 times which is connected primarily with transportation.

In the case where the combines are in operation, the background noise level increases sharply both on the surface and in the well. The realized increase in the ground channel is a total of about 5,000, and in the well channel about 50,000, that is, on the day surface and in the well the sensitivity decreases by 4 times. However, the background on the ground channel can periodically increase, complicating the isolation and analysis of the useful signals.

Since the enterprises operate almost continuously with the exception of one Sunday a week, lunch breaks and brief shutdowns for preventive maintenance of 1 to 1.5 hours, the conditions for seismological observations in the well, and the more so on the surface, are highly unfavorable. The Novo-Alekseyevskaya Well is similar with respect to observation conditions to the Alma-Ata Well located in the large industrial center.

Variation of the Frequency Components of Noise with Depth. Let us consider how the intensity of the frequency components 10, 5, 2.6, 1.3 and 0.6 hertz in noise varies for the "quiet" and "noisy" conditions (see Fig 20, c). When constructing the graphs for the "noise" regime the results of averaging the working series were used, and the Sunday series was obtained on a single day; therefore the representativeness of the graphs is not identical.

The strong dependence of the noise level on frequency both on the day surface and in the well is a common law: the curves for the higher frequency components are left shifted.

Let us consider the variation with depth of the frequency components of the Sunday series. Let us note that all of the curves in the series are shifted in the direction of lower amplitudes by comparison with the corresponding frequency components of the operating series which is caused by a different noise level for the "quiet" and "noisy" regimes. In addition, the laws of decrease in the components with depth are distinguished. Thus, the 10 hertz component of the Sunday series has a very small value (3 nm) at the day surface (at a depth of 5 meters), and it decreases sharply with depth -- at 400 meters it is not recorded. The decrease with depth is also observed for the components at 5, 2.6 and 1.3 hertz. However, the gradient of the decrease falls off with a decrease in frequency. If we compare the background level at depths of 50 and 300-400 meters, then the decrease takes place by more than 6 times for the 5 hertz components, 6 times for the 2.6 hertz component and only 3 times for the 1.3 hertz component. The still slower decrease takes place for the 0.6 hertz component -- the amplitude ratio of depths of 500 and 50 m is two. Below 400-500 meters, the decrease in noise for all of the components is quite insignificant.

The analogous picture is observed when investigating the spectra of the Sunday series constructed for different depths (see Fig 20, c). A comparison of the spectra indicates that all of the frequency components decrease with depth. The 10 hertz component is recorded only in the upper part of the section. The 0.6, 1.3, and 2.6 hertz components decrease more slowly. The 5.1 hertz component decreases still less sharply, for which at depths of 100 and, to a lesser degree, 200 meters, even some relative increase in spectral amplitude is noticeable by comparison with the 2.6 hertz frequency. Deeper than 200 meters the decrease of the 5.1 hertz component is analogous to the other components. Thus, all of the components of the Sunday series are characterized by quite monotonic decrease in amplitude with depth.

An essentially different variation is observed for the components of the working series (Fig 20, c). In the upper part of the section to 400-500 m, a sharp decrease in noise takes place at all frequencies -- the greater, the higher the frequency. For 10 hertz the level ratio at depths of 500 and 5 meters is 20; for 5.1 hertz it is about 18, for 2.6 hertz, it is less than 10, for 1.3 hertz it is 4. The anomalously sharp decreases are observed only for the 0.6 hertz component -- by more than 10 times. At a depth about 500 meters the variation of the noise level for the different components also is not identical. Whereas for 10 and 0.6 hertz, a decrease in noise with depth is observed even though it is a slow one (approximately 1.5 times at a depth of 1700 meters by comparison with 500 meters) and a still slower decrease takes place for 1.3 hertz, for 5 and 2.6 hertz the picture is quite different. Beginning with a depth of 400-500 meters the background level increases slowly, and at 1700 meters this increase is equal to 1.5 and 2 for 5 and 2.6 hertz respectively.

For the working series the same picture is observed when analyzing the spectra. The spectra in the upper part of the section (5, 100 and 200 m) are characterized by the relative predominance of the 1.3 znd 2.6 hertz components and a quite sharp decrease in the remaining ones, especially 10 hertz. Below 200 meters the 0.6, 1.3 and 10 hertz components decrease with the same gradient, and 2.6 and 1.5 hertz decrease more sharply than at depths of 100 and 200. Beginning with 600 meters the gradient of the decrease at the 0.6 hertz component decreases. The noise amplitudes decrease still more slowly at frequencies of 1.3 and 10 hertz. For a frequency of 5.1 and especially 2.6 hertz, both relative and absolute increases in spectral amplitudes with an increase in depth are characteristic (see 1400 and 1600 meters in Fig 20, c). Whereas the spectral amplitude of 2.6 hertz for a depth of 900 meters is 16 nm with respect to shift, for a depth of 1400 and 1600 meters it is 25 and 30 nm respectively, that is, the total increase in amplitudes of the noise with depth below 400-500 meters basically take place as a result of the 2.6 hertz component and to a lesser degree as a result of 5.1 hertz.

Thus, the results of studying the noise in the Novo-Alekseyevskaya Well indicate that in the "quiet" regime the nature of the decrease of the noise with depth corresponds on the whole to the results of the observations in other wells.

The working days are of special interest when the noise is formed by concentrated sources. The curves for the variations of the noise amplitudes can be provisionally broken down into two parts: with high negative gradient in the upper layers of the section to a depth of 400-500 meters and low positive at depths of more than 500 meters. It is possible to consider that two opposite laws of variation of the noise level correspond to different types of waves which predominate in the noise at different depths. In the upper part of the profile the noise is formed primarily by surface waves, and this determines the sharp decrease in noise amplitudes with depths. However, beginning with depths of 400-500 meters when the surface wave level has dropped sharply, obviously the volumetric waves acquire special significance, and their intensity increases smoothly with depth. The observed, sharpest increase in spectral amplitudes of the 5.1 and 2.6 hertz components obviously is to a great extent determined by the vibration source.

Useful Sensitivity. In order to estimate the sensitivity of the well observations it is necessary to study the useful signals at the surface and at depths in addition to the variation of the noise background with depth and in time. For this purpose let us consider the earthquake and explosion recordings in the Medeo area recorded on the day surface and in a well.

The studies in Novo-Alekseyevka demonstrated that the sensitivity of the well observations when recording local earthquakes ($t_{S-P} \leq 10$ seconds) at a depth of 1200 meters is 8 to 10 times higher than the ground observations.

In Fig 21, a, recordings of local earthquakes are presented which were taken both by well and ground seismographs.

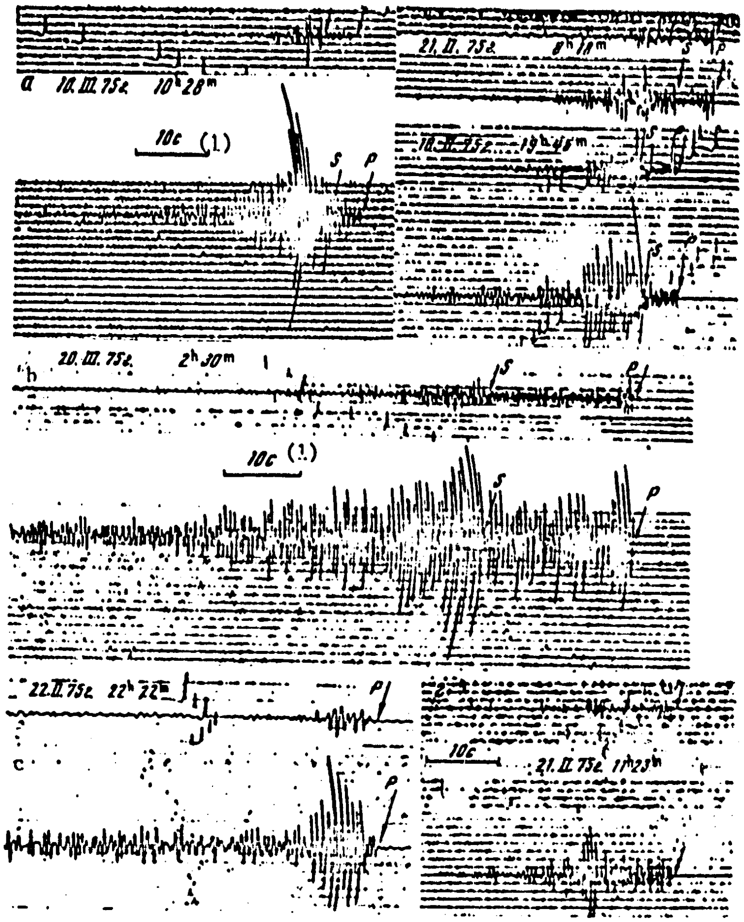

Figure 21. Recordings of local (a), near (b) and distant (c) earthquakes and explosions in Medeo (i) by ground (the upper recording) and well channels at the Novo-Alekseyevskaya station

Key:

1. seconds

The earthquake on 10 February 1975 at 1945 hours was recorded by a ground channel with amplification of 10,000, and by the well channel with amplification of 50,000. If we consider the background noise on both channels and the ratio of the useful signals, then it turns out that the sensitivity of the well channel is 9-11 times more than the ground channel.

For the earthquake at 0818 hours on 21 February 1975, the analogous value is approximately 7 times, and for the earthquake at 1028 hours on 10 March 1975, about 7-10 times. Let us note that on the ground channel the noise can increase periodically, complicating the isolation of the useful signal. For example, the earthquake at 0818 hours on 21 February 1975 was difficult to isolate on the ground channel in connection with the sharp increase in background. On the well channel, the increase in noise background does not take place, and the signal is clearly separated.

Comparing the recordings of local earthquakes by the Novo-Alekseyevskaya station with the recordings of other stations in the test area (see, for example, Fig 48, a; 56, c), it is possible to state that its sensitivity is somewhat less or commensurate with such stations as Alma-Ata or Ali.

The sensitivity of the Novo-Alekseyevskaya station when recording close earthquakes (these include earthquakes with $t_{S-P}>10$ seconds) is approximately 6-8 times higher in the well than for ground observations (Fig 21, b).

For distant earthquakes the gain in sensitivity of the well channel is less than for near and local earthquakes, and it is 5-6 times (Fig 21, c).

The sensitivity of the well channel when recording industrial explosions in the Medeo (Fig 21, i) is approximately the same as when recording near earthquakes, that is, 6 to 8 times higher than the ground channel.

Thus, in spite of the high interference level caused by the operation of the combines, the sensitivity of the well observations in Novo-Alekseyevka is essentially higher than the ground observations both in recording earthquakes and when recording industrial explosions.

§6. Observations in Shallow Wells Opening Up the Crystalline Basement

The investigated results indicate that under the conditions of great thickness of the sedimentary series, for a significant increase in useful sensitivity it is necessary to bury the seismometers to significant depths.

It was possible to expect significantly better results when submerging seismographs in the wells opening up the crystalline basement at shallow depths. In order to estimate the gain in sensitivity for the well observations under such conditions on the Ukrainian shield, studies were made in shallow wells (several tens of meters) opening up the crystalline basement. The observations were made in three wells located at distances of about 20-25 km from each other.

Inasmuch as the results of the observations in all of the wells are analogous, we shall limit ourselves to a description of the results in one of them located several kilometers from the rayon center and distinguished by the highest level of ground noise. The depth of the well is 86 meters. The thickness of the sediments represented by alluvium of the Neogenic age (sand, clay, loam) is 54 meters. From 54 to 71 meters is weathered granite, below 71 meters to the bottom is fresh, hard, massive, fine-grained granite in which the SBU-V deep-well seismometer was installed. The ground seismometer was installed in the alluvium directly at the head of the well.

The study of the laws of variation of noise with time and the useful signal was performed by the semistationary observations in the frequency range of 1-5 hertz. In order to obtain average statistical estimates of the noise at different times (the hours of the day, days, weeks), brief recording sessions were held with large increases of the equipment with a pass band of 1-20 hertz.

Noise Sources. For observations in a well, the primary noise source is the crushers of several rock crushing plants located approximately 4 km to the northeast of the well. If we do not consider the lunch breaks and short-term preventive maintenance shutdowns, the crushers operate continuously, in the steady state mode. The noise level is determined by the number of rock crushing plants operating simultaneously. Another source of interference is the industrial explosions in the open pit mines, but they are very short-lived, they are produced in the majority of cases at one and the same time (usually about 1800 hours local time), they are easily recognized on the recordings and do not limit the sensitivity of the observations.

On the day surface the basic sources of interference are transportation (automobiles, tractors, and so on), farm machinery operating in the surrounding fields and various machinery in the lumbering section in direct proximity to the well (beginning with 200 meters and more). The rayon center located at 6 km and several villages near the well are also sources of noise. In addition, interference can be connected with the reservoirs located 200 meters from the well and the dam over which the water is discharged into the river flowing out of it.

Observation Data. The semistationary observations were performed in April 1976. The amplification of the ground channel was given depending on the noise level, 16,500 or 33,000, and the well channel, 140,000 or 280,000. The stability of the equipment was controlled by systematic recording of the calibration signal. An example of seismograms from a visible recording is shown in Fig 22, a. By the seismogram obtained in the daytime (from 0900 to 2100 hours local time) it is obvious that on the ground channel with amplification of 16,500, the recording was broken by transport noise with an amplitude of 25-30 mm. At the same time at a depth of 86 meters, with channel amplification of 140,000, the amplitude of the background noise does not exceed 1 mm. At night (from 2100 hours in the

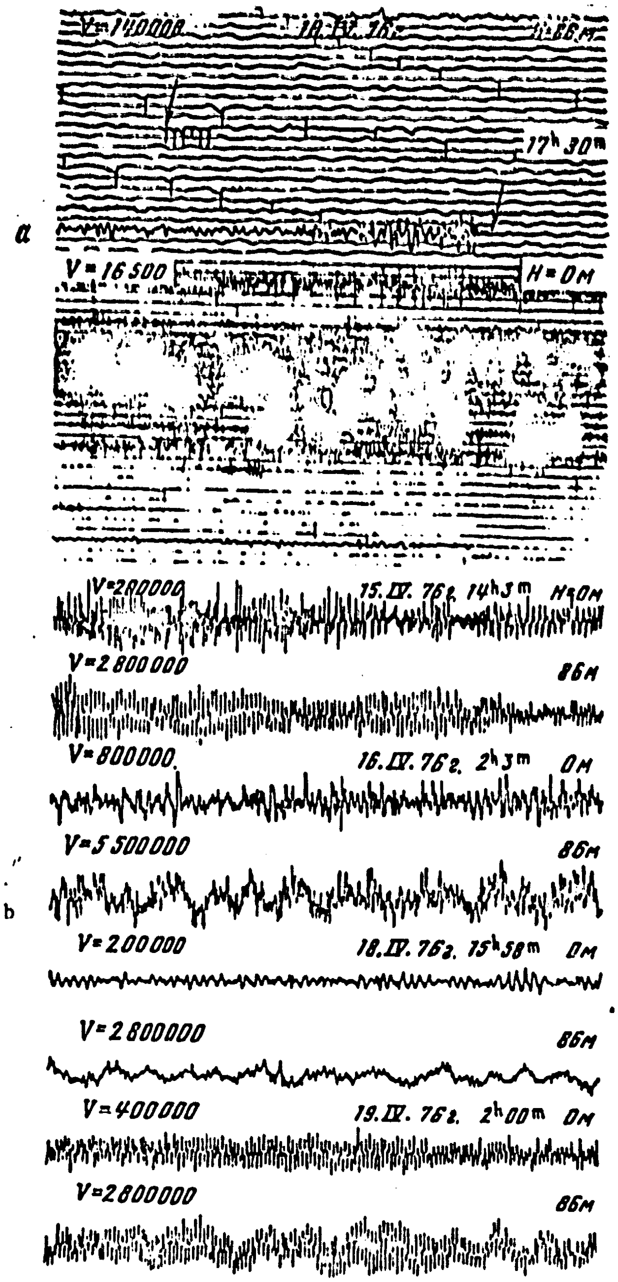

Figure 22. Seismogram of the noise and a distant earthquake recorded by the well and ground channels during semistationary recordings (a) and photooscillograms of the noise with high amplification (b).

evening to 0900 hours in the morning local time) the transport noise makes up 50% of the total observation time.

During continuous observations, the well channel was used to record more than 70 different signals, including 15 distant earthquakes. Out of the 55 near signals the majority are industrial explosions from various distances. The ground channel was used to record a total of about 20 signals, and of them none was a distant earthquake. This is explained by insufficient sensitivity of the ground observations limited by the high interference level.

The highly sensitive recording of noise was carried out in three minute sessions every 2 hours for 4 days (Thursday, Friday, Saturday and Sunday) from 15 to 18 April 1976. Examples of seismograms are shown in Fig 22, b. The seismogram at 1430 hours was obtained in the daytime, and at 0200 hours at night, but the basic interference in both cases was the noise of the crushers recorded both by the well and by the ground channels. The noise from motor vehicles was also superimposed on the ground channel recording of the seismogram at 1430 hours. The seismogram at 0203 hours illustrates noise under conditions where not all of the crushers of the rock crushing plants were in operation, and the seismogram at 1558 hours, when all of the crushers were not in operation. On the recordings of the well channel, the low-frequency interference is quite visible with a period of about 3.5 sec which is hardly noticeable on the ground channel recordings in connection with the small realized amplification and the high amplitude of the high-frequency noise of the motor vehicles and the crushers.

Observation Results. Analysis of the materials shows that in the wells three noise levels are observed which differ significantly with respect to amplitude and duration. The highest level with displacement amplitudes of about 10 nm occupies about 70% of the total observation time and is determined by the operation of the crushers of the rock crushing plants. The frequency of this interference is about 4 hertz.

The minimum interference level with displacement amplitudes of about 2.5 nm occupies a total of 10% of the time out of the total duration of the observations, and it is tied to the periods when the crushers of the rock crushing plants are not in operation. The intermediate noise level of about 5 nm is obviously associated with times when part of the crushers are operating. With respect to duration, this level takes up about 20% of the total observation time. The minimum background level corresponds predominantly to the period between 0200 and 0600 hours at night local time, occupying short intervals of 1-1.5 hours. The noise level of 5 nm is observed basically from 1600-1700 to 2100-2200 hours in intervals lasting 1-2 to 4-5 hours.

The statistical processing of the data was carried out to estimate the noise from the various sources. The average noise level from the rock crushing plants in the well is 6 nm (line 2 on Fig 23, a), it is constant and does not depend on the time of day. The transport noise (region 3 in Fig 23, a) does not exceed the plant noise with respect to level, that is, it is no more than 6 nm. They are observed on recording only in the case where the crushers are not in operation and the motor transportation moves directly at the head of the well (10-20 meters). When motor transportation moves at distances closer than 20 meters from the head, the noise from it is not isolated on the well channel recording.

In the well low-frequency noise is also recorded with a period of about 3-4 seconds, the arithmetic mean level of which fluctuates around a value of 300 nm. During the observations in the well, the low-frequency interference was continuously observed. The interference level in Fig 23, a is provisionally illustrated without a time scale. Inasmuch as this noise is outside the pass band of the equipment, its amplitude does not exceed 2 mm on the recording.

On the day surface at the head of the well, the noise level reaches 2000 nm (region 3 on Fig 23, a), and it is determined basically by the transport interference. With respect to time it occupies 75% of the daytime recording, attenuating only at night. The transport noise level on the surface depends on the distance at which the moving transportation is located, and to a lesser degree on its form (mass). For example, during movement of a motor transport at a distance of about 150-200 meters from the observation point the noise level reaches 400-600 nm, and with a decrease in distance to 15-20 m, this value increases to 2000 nm or more, that is, 300 times higher than in the well. In the absence of transport interference, the noise amplitude on the surface reaches 50 nm in the daytime and 30 nm at night (line 1 on Fig 23, a). The decrease in noise at night indicates that some part of the total noise level is determined by the "cultural" noise connected with the vital activity of nearby populated places. On the surface, just as in the well, a low-frequency interference is recorded with a period of 3-4 characteristic in general for the given area. The interference level on the surface is somewhat greater than in the well, and it reaches about 400 nm (region 4 on Fig 23, a).

As a result of the statistical processing of the data for the surface and the well, curves were constructed for the probability of occurrence of noise of the given or lower amplitude (Fig 23, b). In the absence of transport interference the noise in the well is determined by the crushers (curve 1), the mean amplitude of the noise with respect to 50% probability level is 6 nm; the noise amplitude varies from 2.5-3 to 12 nm. On the surface under analogous conditions the noise reaches values of 45 nm (curve 2). The variation of the noise amplitudes on the surface is 15-90 nm.

In the case where only part of the crushers are in operation, the probability curves are shifted in the direction of smaller values of the noise amplitude (for example, curve 3 for the well and 4 for the surface). When the crushers are not in operation, the average noise level in the well is 1.5 nm, varying within the limits of 0.7-4 nm (curve 5 in Fig 23, b). In this case on the surface (curve 6) the amplitude varies from 8-10 to 50 nm, and the mean value is 25 nm.

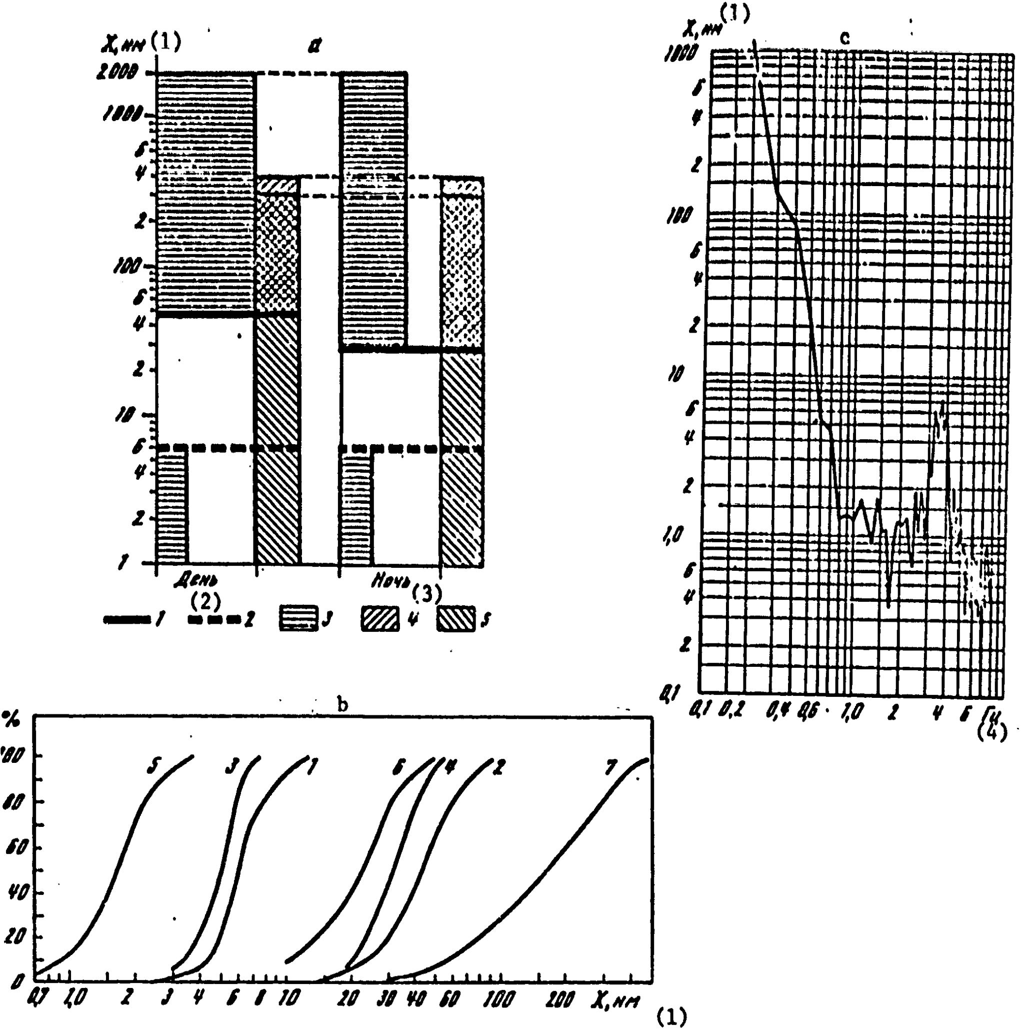

Figure 23. Characteristics of noise during observations in a shallow well opening up the basement.

a -- noise level in the daytime and at night on the day surface and a depth of 86 meters: 1 -- noise level on the surface without considering transport interference, 2 -- the same in the well, 3 -- transport noise on the surface and in the well, 4 -- low-frequency noise on the surface, 5 -- the same in the well;

b -- probability curves for the occurrence of noise of given or lower amplitude at a depth of 86 m (1,3,5) and on the surface (2,4,6,7) under various conditions;

c -- average noise spectrum at a depth of 86 meters.

Key: 1. X, nm; 2. day; 3. night; 4. hertz

For observations on the surface 35% of the time is characterized by the presence of transport interference. Curve 7 (Fig 23, b) is constructed in accordance with the noise recording in the presence of transportation moving at a distance of about 200 meters from the observation point. A large range of variation of the noise amplitudes (from 30 to 500 nm) is characteristic, and the mean value with respect to the 50% probability level is 150-170 nm.

The spectral analysis of the noise in the well at a depth of 86 meters indicates that the maximum amplitudes correspond to the low-frequency part of the spectrum (Fig 23,c). With an increase in the frequency, the noise level decreases sharply. For example, with an increase in frequency from 0.2 to 0.8 hertz the noise level decreases by more than two orders. With further increase in frequency, the noise amplitudes decrease significantly more slowly. In the 3-4 hertz range, the relative maximum connected with the operation of the crushers is observed. The nature of decrease in the noise with increase in frequency in the 0.2-1 hertz range will permit us to propose that the basic mode of the Rayleigh wave predominates here.

Sensitivity of Well Observations. In connection with the presence of a high level of ground noise the recording on the surface under the condition of recording on the seismogram of normal background with an amplitude of more than 1-2 mm is realizable only for amplifications not exceeding 500-1000. Inasmuch as the high level of ground interference is characteristic for 75% of the observation time, the stationary high-frequency observations are in practice impossible.

The sensitivity of the well observations is more than 2 orders higher than that of the ground observations. Distant earthquakes considered as useful signals which are clearly recorded by the well channel are not separated in the ground channel under these conditions.

In the absence of transport interference (about 25% of the total observation time) the sensitivity of the well channel is approximately 5-6 times higher than the ground channel. For example, if the earthquake at 1730 hours (see Fig 22, a) is recorded by the well channel with an amplitude which exceeds by 10 times the background level, the amplitude of the signal on the ground channel recording will only exceed the background level by a slight amount.

A comparison with the ground seismic station, the seismometers of which are installed on outcrops of bedrock approximately 10 km from the well indicates that the sensitivity of the two stations is comparable (Fig 24). The higher low-frequency noise (T=3-4 seconds) on the ground station is explained by the fact that the natural period of its seismometers is 1.5 seconds (the natural period of the well seismometer is 1 second).

Let us identify the results of the well research.

For a high level of ground noise

1. Under the conditions of the large industrial cities the noise level on the day surface is very high and unstable. The range of variation of the noise amplitudes with time exceeds 2 orders. However, approximately to 300-400 meters the noise level is stabilized and basically varies from day to night by 2-3 times.

2. The sharpest variation of the background takes place in the upper part of the section (the first hundreds of meters). With further increase in depth the gradient of the amplitude variation of the noise decreases rapidly. Thus, whereas on going from the day surface to a depth of 600 meters the noise amplitudes decrease by 30-40 times, on making the transition from 1000 to 2000 meters the noise amplitude decreases by a total of 2-3 times.

3. The maximum noise amplitudes both on the day surface and at great depths correspond to the low-period components of the spectrum. With an increase in frequency the noise level decreases significantly faster in the well than on the day surface.

4. The recordings of the ground and deep-well stations located in Alma-Ata are in practice not comparable. The earthquakes, the recordings of which are readable at the deep stations are not recorded by the ground station and, vice versa, the earthquakes recorded by the ground station are completely washed out on the recording by the deep station.

A comparison of the recordings of earthquakes obtained under city conditions in a well at a depth of 2 km with the recordings of the Talgar station located far from the city in a drift in crystalline rock indicates approximately identical useful sensitivity of the stations.

5. The results obtained make it possible to recommend the creation of highly sensitive stations with seismographs buried in deep wells to study the seismic characteristics of large cities located in seismically active zones.

For a low ground noise level

1. The noise amplitudes decrease with depth significantly less sharply than in areas with a high noise level. The nature of variation in the Chilik Well for the day series coincides with the variation of the day noise in the Tashkent and Alma-Ata Wells. At night the noise level in the Chilik Well decreases significantly more weakly than in the daytime. Whereas for the Tashkent and Alma-Ata Wells the ratio of the noise level at the surface and at a depth of 600 meters is 30-40, for the Chilik Well it is 4-6.

2. On the day surface the noise amplitudes can vary by several tens of times with time. At a depth of several hundreds of meters (300-600 meters)

the noise level varies, as a rule, by no more than 2-3 times. These differences are stably connected with an increase in noise in the daytime. The gain in useful sensitivity is appreciably lower than in the areas with a high level of ground noise. However the high stability of the noise even at shallow depths increases the effectiveness and the value of the well observations sharply.

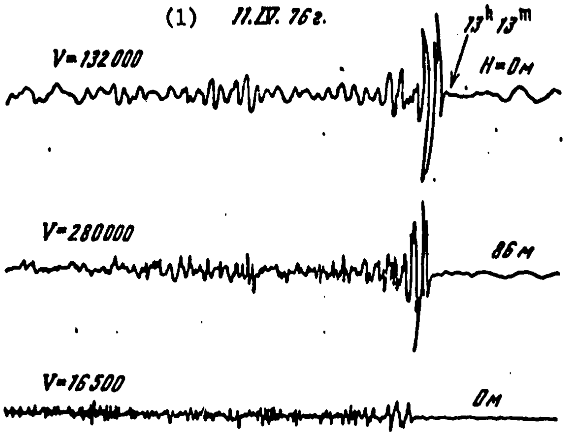

Figure 24. Recordings of a distant earthquake by the well and ground stations, the seismographs of which are installed on outcrops of bedrock (upper trace) and on sedimentary rock at the head of the well (lower trace)

Key:
1. 11 April 1976

3. In the well the shape of the recording of each individual wave is determined primarily by the superposition of the pulses of the incident wave and the wave reflected from the day surface. In the section of the well adjacent to the day surface, the shape of the recording of the individual wave can be more complex than on the day surface. The length of this section depends on the shape of the pulse of the incident wave, its predominant frequency and the high speed section. At depths where the pulses of the incident and reflected waves are resolved, the shape of the individual wave is newly simplified, but in this case the number of waves recorded on the seismogram increases, and the structure of the seismogram becomes significantly more complicated.

For noise from stationary sources

1. Under the conditions of the effect of stationary noise sources their level at the surface can be very high. However, the range of variation

of amplitudes with time is appreciably lower than from the standard sources. Thus, whereas in Alma-Ata and Tashkent the range of variation exceeds two orders, in Novo-Alekseyevka it is less than an order (7 times).

2. There are two "noise" conditions for stationary sources differing sharply between each other with respect to level and nature of variation of the noise -- "quiet" and "noisy." The former is characterized by a low noise level and a monotonic decrease in noise with depth. For the latter, a sharp decrease in amplitude in the upper part of the section (400-500 meters) and smooth increase in amplitudes with furrher increase in depth are characteristic. This decrease in noise indicates various types of waves predominant at different depths: in the upper part the surface waves predominate, and deeper than 500 meters the volumetric waves predominate.

The higher frequencies decrease more sharply from the surface to a depth of 500 meters. Below 500 meters the total increase in noise amplitudes with depth takes place primarily as a result of the 5.1 and especially the 2.6 hertz components.

4. The gain in useful sensitivity for well observations in Novo-Alekseyevka when recording at a depth of 1200 meters for local earthquakes is 8-10, for nearby earthquakes 6-8, and distant earthquakes 5-6 and industrial explosions, 6-8 times.

With respect to useful sensitivity the Novo-Alekseyevskaya station is comparable with the other well stations of the test area (Alma-Ata, Ali).

For shallow wells which open up the crystalline basement

1. Even under conditions of high ground noise level, completely excluding the possibility of high frequency ground observations, submersion of the seismograph in a well to the crystalline basement permits amplification of about 300,000, that is, it makes it possible to obtain the sensitivity which is commensurate with the useful sensitivity of the station located on the day surface directly on outcrops of bedrock under unfavorable conditions.

2. The gain in sensitivity obtained is connected primarily with the transition to the crystalline basement. It is possible to assume that this gain depends little on the thickness of the sedimentary series and will be observed in other regions of analogous structure.

3. Considering the high velocity gradient in the upper weathered zone of the basement, it is expedient to bury the seismograph 10-15 meters into stronger rock.

PART II. RADIOTELEMETRIC RECORDING

The centralized radiotelemetric recording with a unit time service permitting the accuracy of the constructions to be increased is one of the basic features of the developed procedure. A more detailed description is presented of the Alma-Ata radiotelemetric test area and the equipment of the automated well and ground stations and also the radiotelemetric recording system. Special attention has been given to a description of the experiment and the observation results.

CHAPTER III. ALMA-ATA SEISMOLOGICAL RADIOTELEMETRIC TEST AREA

The observation conditions in the vicinity of Alma-Ata are characterized by the presence of a very high level of seismic noise caused by the vital activity of the city and its high variability in time.

At the same time the seismogeological situation near Alma-Ata which is located in a force-10 zone requires a detailed study of the seismic characteristics of both the city itself and its environs. The necessity for highly sensitive observations arises also from the fact that at the present time the basic characteristic of the seismic regime is "calmness" of seismic activity. In order to discover and trace the seismically active zones it is necessary to increase the accuracy of determining the coordinates of the earthquake centers.

Thus, the basic specific requirements on the observations in large industrial centers are, first of all, high sensitivity of the equipment and, secondly, high accuracy of determining the coordinates of the earthquake centers. The satisfaction of these requirements has led, on the one hand, to the creation of highly sensitive deep-well seismic stations and, on the other hand, to the organization of centralized multichannel radiotelemetric recording of the signals of all stationary observation points. Both of these areas were basic to the creation of the Alma-Ata test area.

§1. Geological-Geophysical Characteristics of the Region

In administrative respects, the observation region belongs to Alma-Ata Oblast and includes the city of Alma-Ata directly, The region includes areas that are different with respect to their geomorphological appearance -- from plains and mildly hilly areas in the north to the mountainous area in the south. The Iliyskaya[1] basin is located in the north. It runs in a sublatitudinal direction along the Zailiyskiy Alatau Ridge which is located in the southern part and is separated from the Kyungey Ala-Too Ridge located farther south by the Chon-Kemin River valley. In the west, the Zailiyskiy Alatau is split into two branches -- the Kastekskiy and the Chon-Keminskiy Ridges. The highest altitude of the Zailiyskiy Alatau reaches 5000 meters. Strong dismemberment of the ridges is a characteristic feature.

Tectonics. On the regional level the district is in an area of joining of the Caledonian structures of Northern Tyan'-Shan' with the Hercinian structures of the Dzhungaro-Balkhash Province which is complicated by alpine discontinuous tectonics. The Kungeyskiy, Zailiyskiy and Chu-Iliyskiy anticlinoriya and Iliyskiy synclinorium are large structures.

The Kungeyskiy anticlinorium is made up of metamorphic series of the Proterozoic with inclusions of large masses of intrusions of Silurian and Ordovician age. In the north the anticlinorium joins the Zailiyskiy anticlinorium along the deep Chilik-Keminskiy fault of ancient occurrence. In the core of the Zailiyskiy anticlinorium, on a modern section Proterozoic deposits are noted which are highly intensely dislocated and form small isoclinal folds. The lower Paleozoic series are represented by a system of narrow folds of the sublatitudinal direction. Together with the Proterozoic, they are the only Lower Paleozoic structural state.

The surface effusive-sedimentary series of the Devonian and Lower Carboniferous occur unconformably on the Caledonian folded base in the form of a number of comparatively gently sloping synclinal folds, forming the Middle Paleozoic structural stage.

In the north the Zailiyskiy anticlinorium borders with the Iliyskiy synclinorium through the Zailiyskiy zone of faults of sublatitudinal strike which is a structural element of the Upper Paleozoic stage. There are no Devonian deposits here, and the Carboniferous and Upper Paleozoic deposits of basically effusive-tufogenic origin occur unconformably on the dislocated rocks of the Silurian, forming gently sloping brachysynclinal and anticlinal folds. The gently sloping bell-shaped poles are made up of Mesozoic formations, and the Iliyskiy intermontane trough with a flat bottom and several uplifted limbs is made up of Cenozoic deposits which maintain almost undisturbed horizontal bedding or their depth corresponds to the slope of the Paleozoic base.

In Quaternary time the most intense vertical displacements of the blocks took place both with respect to the renewed ancient tectonic futures and with respect to the newly occurring faults which has created a stepped relief system so characteristic of the region. The systems of deep faults are illustrated in Fig 25, a.

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[1] [Ili River Basin]

Geophysical Study. The first large-scale seismic studies in Northern Tyan'-Shan' are connected with the names of G. A, Gamburtsev, K. I. Satpayev and D. I. Kazanli. They were started immediately after the disastrous Ashkhabad earthquake. The first studies were made of the deep structure of the region by the deep seismic sounding technique in 1949 [22, 24], and the basis was laid down for the regional network of seismological stations (Alma-Ata, Ili, Chilik, Kurmenty, Rybach'ye, Przheval'sk, Krasnogorka, Naryn). These stations made it possible to record earthquakes beginning with the eighth energy class.

Here, in the vicinity of Alma-Ata in 1951 G. A. Gamburtsev began the first highly sensitive observations to study the weak local earthquakes in the high-frequency range (5-30 hertz) by the correlation method of studying earthquakes (KMIZ) [20, 21]. It is necessary to note that the application of this method at the present time is the basic trend in the development of seismology.

During the period from 1965 to 1967, in connection with the designing of a number of hydroengineering structures in the Ili, Charyn and Chilik River basins, a set of operations were performed to study the degree of seismic danger of this region. In addition to the regional network of stations in the Chilik and Charyn interfluve, a group of four temporary stations were organized which made it possible to record weak shocks and more precisely to define the parameters of the earthquake centers.

Since 1966, the complex regional geophysical studies, including seismological studies with the Zemlya [earth] stations have been performed by the Kazakh Geophysical Trust and the regional network of seismic stations of the Institute of Geological Sciences of the Kazakh SSR Academy of Sciences. However, these observations have insufficient detail to study the seismic characteristics of the city of Alma-Ata and its environs.

Deep Structure. The earth's crust in this area is characterized by subhorizontal layering and it is separated into individual blocks by vertical or steeply dipping fractures [3]. The thickness of the earth's crust is from 40 to 60 km. According to the geophysical data, the roofs of the basement, the Conrad and Mohorovichich boundaries are isolated (see Fig 25, b). The Conrad surface is submerged from west to east to a depth from 20 to 35 km and it is characterized by a complex structure. It is cut by the Kurtinskiy, Altyn-Emel'skiy, Kemin-Ushkonurskiy and the Chilik-Keminskiy deep fractures in the northeasterly direction coinciding with the strike of the structures of the Kungey-Zailiyskiy anticlinorium. The Kemin-Ushkonurskiy and Altyn-Emel'skiy faults are traced in the entire series of the earth's crust to the Mohorovichich interface.

The "basaltic" layer bounded by the Conrad and Mohorovichich surfaces has a thickness from 20 to 35 km, increasing toward the east in the direction of the submersion of the Mohorovichich surface.

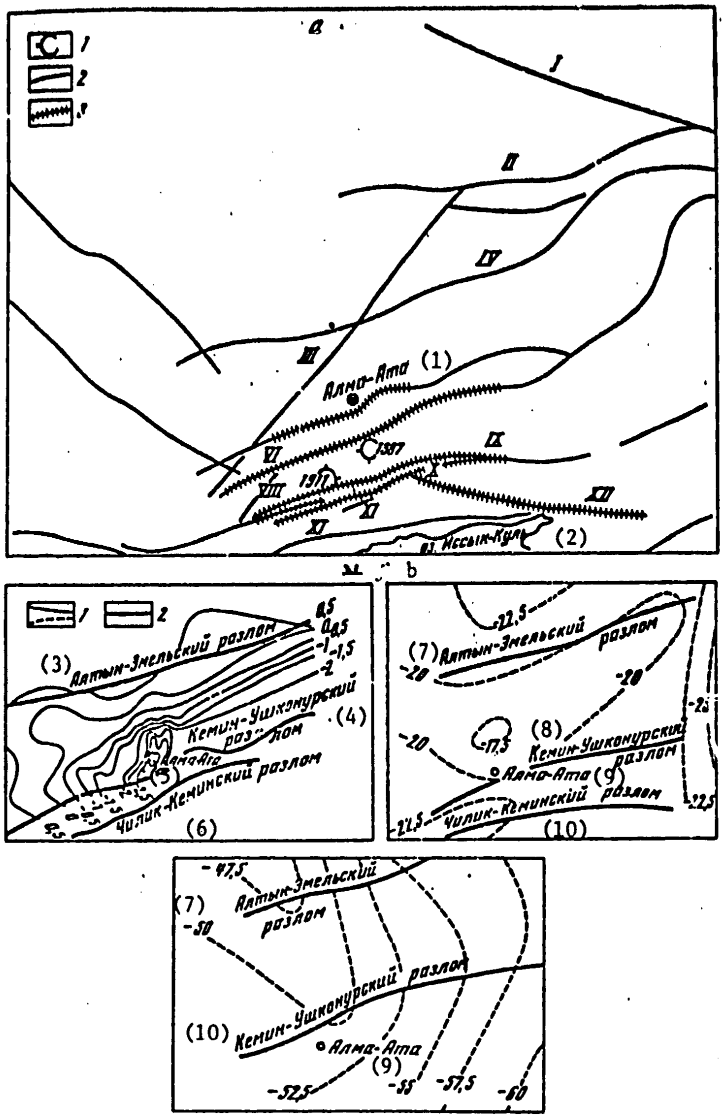

Figure 25. Schematic of deep faults (a) and structural diagrams (b) with respect to the basement roof (on the left), the Conrad boundary (on the right), the Mohorovichich surface (at the bottom) and according to the data of [3].

[See following page for legend and key]

[Legend and key to Fig 25, preceding page]:

a: 1 -- epicenters of destructive earthquakes in the past, 2 -- deep faults (I -- Yuzhno-Dzhungarskiy, II -- Malay-Sarayskiy, III -- Kaskelenskiy, IV -- Altyn-Emel'skiy, V -- Karakastekskiy, VI -- Karagayly-Bulakskiy, VII -- Kemin-Ushkonurskiy, VIII -- Aktyuzskiy, IX -- Severo-Keminskiy, X -- Chilik-Kemkiskiy, XI -- Severo-Kungeyskiy, XII -- Tyupskiy); 3 -- active deep faults;
b: 1 -- isohypses of the interfaces, 2 -- deep faults.
Key:

1. Alma-Ata
2. Lake Issyk-Kul'
3. Altyn-Emel'skiy fault
4. Kemin-Ushkonurskiy fault
5. Alma-Ata
6. Chilik-Keminskiy fault
7. Altyn-Emel'skiy fault
8. Kemin-Ushkonurskiy fault
9. Alma-Ata
10. Chilik-Keminskiy fault

The "granite" layer which includes the series bounded by the roofs of the Lower Paleozoic basement and the Conrad surface has a thickness of 14-22 km. The Paleozoic basement is distinguished by a block structure and it is cut by a series of differently oriented tectonic fractures with amplitudes reaching 500 meters. The depth of occurrence of the basement is different in different parts of the area. In the south and southeast the Paleozoic formations emerge at the surface. The Paleozoic series in the north and northwest are also close to the surface. In the central part the depth of occurrence of the basement is maximal. The series of tectonic dislocations with a break in continuity -- deep fractures -- roofs of the Paleozoic basement in the vicinity of Alma-Ata -- are broken down into three blocks: southern, central and northwestern. The southern block is a monoclinal which dips steeply to the north to a depth of up to 3000 meters. The central block is separated from the southern and northwestern blocks by faults complicated by a series of small discontinuities of latitudinal and northeasterly direction, and it is the most submerged. The thickness of the sedimentary deposits here fluctuates from 2.5 to 3 km in the west and to 4 km in the center. The northwestern block is also separated from the adjacent fractures and is characterized by uniform (quiet) bulging of the basement in the northwesterly direction.

According to the data of geophysical research, the propagation rates of the longitudinal waves in the earth's crust have the following values: the sedimentary layer is 2500-2700 m/sec, the "granite" layer is 5700-6600 m/sec, the "basaltic" layer is 6600-7300 m/sec, the subcrustal layer (the Mohorovichich surface) has a velocity discontinuity to 8100 m/sec. The velocity on the surface of the Paleozoic basement does not depend on the depth of its occurrence within the limits of accuracy of the determinations.

Seismicity of the Region.[1] A characteristic feature of Northern Tyan'-Shan' is the fact that in a short interval four disastrous earthquakes have occurred here: Vernenskoye (1887, M=7-7.25), Chilik (1889, M=7.5-8), Kebinskoye (1911, M=8.7) and Kemino-Chuyskoye (1938, M=6.5). B. Gutenberg assigned a maximum possible magnitude of 8.7 to the strongest of them, the Kebinskoye earthquake. Stronger earthquakes did not occur later, and the seismicity is connected with the appearance of weak and medium earthquakes. For the area nonuniform distribution of the earthquake epicenters is characteristic (see Figures 73, 74). The basic number of them is concentrated in the central and eastern parts. A separate group of earthquakes is located in the Chilik and Charyn interfluve in the epicentral zone of the 1889 earthquake. A clearcut law is observed in the mutual arrangement of the epicenters of the weak ($K \leq 10$) and stronger ($K \geq 11$) earthquakes. The stronger earthquakes are systematically located at some distance from the accumulations of epicenters of earthquakes. They outline the zones of increased activity formed by the weak earthquakes.

A characteristic feature is the almost complete absence of earthquake centers beyond the limits of the crust and coordination of the majority of them with the "granite" layer. The basic number of centers with $K \geq 9$ have a depth of 5-12 km; the earthquakes with $K<9$ have a depth basically within the limits of the first 5 km from the earth's surface. Considering the accuracy of determining the centers (± 5 km) it is possible to state that the majority of the earthquakes have a depth of 5-15 km; the deeper centers are a rare phenomenon. The majority of strong earthquakes of the past were also located in the earth's crust at shallow depths.

It is indicative that migration of the maximum density of epicenters is observed over the area for the observation period of 1956-1967. In 1956 the maximum density of the centers was observed in the eastern part; subsequently in 1958-1959, the maximum shifted to the west, and in 1960 the central and eastern (the Charyn and Chilik interfluve) parts of the region were active. From 1961 to 1964 basically only the eastern part was active; certain sections were active at different times. In 1965 the central part begins to become active, in 1966 the activity spreads farther to the west, and in 1967 a general decrease is observed. However, whatever changes took place in the seismic situation in the region its eastern part turned out to be consistently more active, and the western part, including the city of Alma-Ata and its environs was characterized by significantly weaker activity, especially in recent years.

The presented brief characteristic of the region gave rise to the necessity for using a theoretically new approach in studying the seismic characteristics of Alma-Ata and the creation of the Alma-Ata radiotelemetric test area of automatic stations with central multichannel recording of the signals.

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[1] Seismicity of Zailiyskiy Alatau is described in detail in §1 of Chapter VI.

§2. Structure and Technical Indexes of the Test Area

Alma-Ata and its environs are located in the foothills of Zailiyskiy Alatau. The southern part of the city approaches directly to the north slopes of the ridge, in individual cases being located even on the slopes themselves. The northern part of the city is located in the foothills of the Iliyskiy basin made up of a thick series (more than 4000 meters) of sedimentary deposits.

The geological situation and the level of seismic noise require the creation of a test area of stations of two types: deep well stations located in the sedimentary rock (in the north) and ground (southern) stations located in the mountains on the bedrock outcrops (Fig 26).

Deep-Well Stations. The northern stations are located in the Iliyskiy basin in a thick series of sediments, and they are characterized by a very high level of noise connected basically with the vital activity of Alma-Ata. In order to insure maximum sensitivity for the given conditions at all of the stations, the seismometers of its northern stations must be placed in the deep wells. For this purpose, random wells were used which were drilled in their own time for one purpose or another. The location of these wells cannot be considered optimal; indeed with respect to technical condition and structural design they are not suitable at all for stationary seismological observations.

Alma-Ata. The station was built on the basis of a deep hydrogeological borehole located within the city, at its eastern edge, in the central, most submerged part of the Iliyskaya basin. The total thickness of the terrigenic deposits is according to the geophysical data about 4200 meters here. The well was drilled in 1962 to a depth of 3238 meters, but at the present time it has been drilled only to a depth of 2000 meters where a cement plug is set. The geological section of the well and a graph of the temperature variation with depth appear in Fig 27. The five-inch casing is cemented only in the 2030 to 3230 meter range. Water comes out of the well with a discharge rate of about 1 liter/minute. This fact and also the fact that the casing has not been cemented throughout reduces the value of the well for observations somewhat.

Novo-Alekseyevskaya. The station is located 25 km to the east of Alma-Ata and it is organized on the basis of the well drilled to find thermal water. The depth of the well is 2985 meters, the Paleozoic basement is discovered at a depth of 2960 meters. The well has been cased with a 5-inch casing along its entire extent, and it is cemented in practice to its entire depth. In this regard it differs advantageously from the Alma-Ata Well, but the building materials combine located several kilometers from the station where the powerful crushers are in operation causes a high interference level. The geological section through the well and the temperature curve are also shown in Fig 27. The seismologists of both stations, Novo-Alekseyevskaya and Alma-Ata, were lowered to a depth of 1200 meters. The central recording station is located on the first of them.

Ali. The station is the northernmost station of the test area located 30 km to the north of Alma-Ata. A well drilled to find the structures under the gas storage is used for observations. The Paleozoic basement is revealed at a depth of 850 meters, but the well has been opened up only to a depth of 800 meters where a cement plug has been installed. The casing has been cemented to the head of the well, but the quality of the cement is low. Between the 8 and 12 inch casings there is an artesian flow of water from the upper horizon with a high discharge rate. By comparison with Alma-Ata and the Novo-Alekseyevskaya stations, the conditions for the observations here are comparatively favorable which is explained basically by the closeness of the basement and also significant removal from the city of Alma-Ata.

Ground Stations. The southern stations are located on the slopes of Zailiyskiy Alatau directly on the outcrops of the crystalline bedrock and they are characterized by a low noise level which makes it possible to realize high amplifications of the equipment. The location of the stations under conditions of sharply broken relief creates definite difficulties transmitting information to the central recording station by radio in the ultrashort wave band, and it has a significant effect on the structure of the seismograms (see §5, Chapter IV).

Talgar. This station is located 7 km south of the city of Talgar in the foothills of Zailiyskiy Alatau. The seismomometers were installed in a deep 120-meter drift drilled directly in the crystalline rock of the Paleozoic basement which emerges at the surface. The elevation above sea level is about 1200 meters.

The station is removed from various sources of noise of artificial origin; therefore the conditions for the seismological observations are highly favorable here. The only disadvantage is the closeness of the mountain river of Talgar which lowers the sensitivity of the station somewhat.

Ozero. The station is located in the mountains at an altitude of about 3000 meters above sea level, 25 km south of the city of Alma-Ata and 5 km from the Bolshoye Alma-Ata Lake in the territory of the observatory of the State Astronomical Institute imeni P. K. Shternberg. The seismometers are installed in a prospecting hole. The noise level at the Ozero station is very low, which is highly favorable for seismological observations.

Portable stations. In addition to the described stationary installations, portable stations have been used which are periodically located in the most interesting places. In particular, one of the temporary stations (Plato) conducted observations in Malaya Alma-Atinka Canyon near the center of the local earthquake at 0046 hours on 6 June 1972 in order to locate it, and the other temporary station (Kurty) was set up on outcrops of bedrock approximately 100 km northwest of the central recording station near the village of Kurty. Some of the information about the stations in the test area is presented in Table 5.

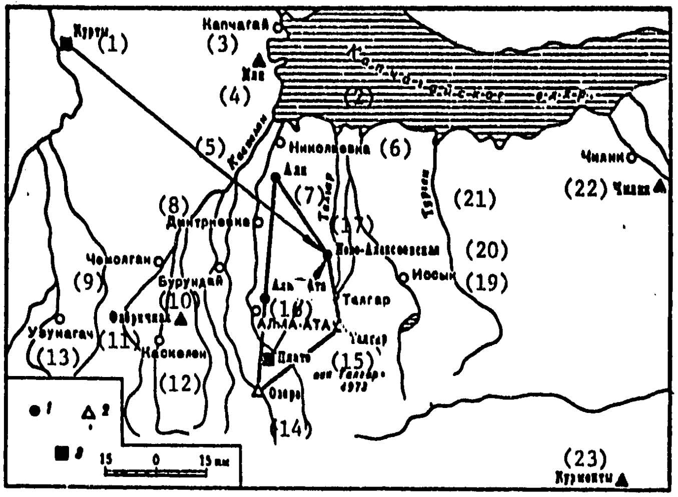

Figure 26. Diagram of the arrangement of the deep-well (1), the ground surface (2) and portable automatic stations of the Alma-Ata radiotelemetric test area. The black triangles are the stations of the regional network.

Key:

1. Kurty
2. Kapchagayskoye Reservoir
3. Kapchagay
4. Ili
5. Kaskelen
6. Nikolayevka
7. Ali
8. Dmitriyevka
9. Chemolgan
10. Burunday
11. Fabrichnaya
12. Kaskelen
13. Uzunagach
14. Ozero
15. Talgar
16. Plato
17. Talgar
18. Alma-Ata
19. Issyk
20. Novo-Alekseyevskaya
21. Turgen
22. Chilik
23. Kurmenty

Let us note that when selecting the locations of the stations, the conditions of insurance of stable round the clock radio communications in the ultrashort wave range and also the presence of stable electric power lines for the system transmitters had decisive significance.

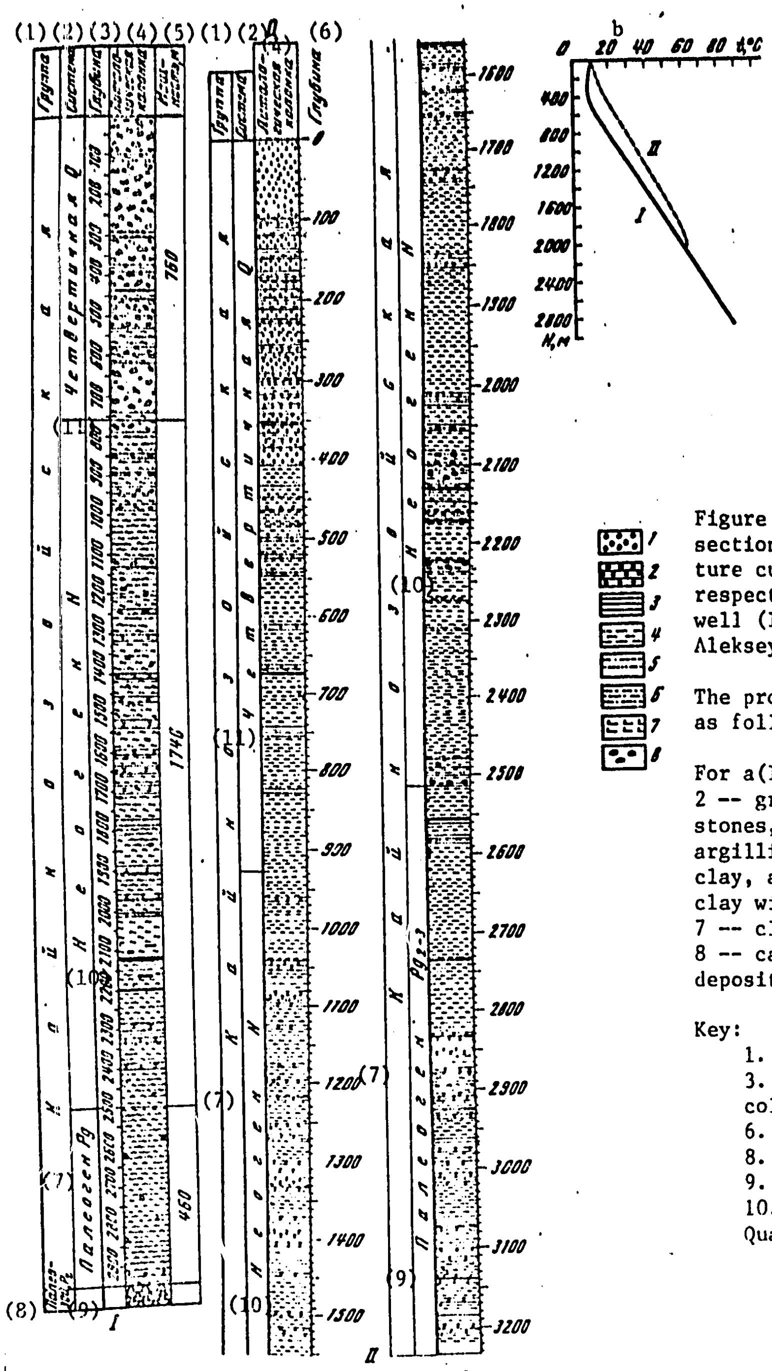

Figure 27. Geological sections (a) and temperature curves (b) with respect to the Alma-Ata well (I) and the Novo-Alekseyevskaya well (II).

The provisional notation is as follows

For a(II): 1 -- shingle, 2 -- gravelites, 3 -- sandstones, 4 -- clay, argillites, 5 -- silty clay, aleurolites, 6 -- clay with sand admixture, 7 -- clay, lime argillites, 8 -- carbonaceous-clay deposits

Key:

1. group; 2. system; 3. depth; 4. lithologic column; 5. thickness, m; 6. depth; 7. Cenozoic; 8. Paleozoic, Pz; 9. Paleogene, Pg; 10. Neogene N; 11. Quaternary Q

Table 5

Станция (1)	Обозначение (2)	(3) Координаты				(4) Расстояние между станциями, км						
		φ	λ	h, м	H, м	T	O	A–A	A	H–A	K	П
(5) Талгар	T	43°14,25′	77°13,55′	1200	–	–	27	20	40	17	110	17
(6) Озеро	O	43 04,25	76 59,25	2960	–	27	–	24	55	41	108	9
(7) Алма-Ата	A–A	43 17,23	76 59,55	800	1000, 2000	20	24	–	31	23	94	15
(8) Али	A	43 33,92	77 02,13	550	800	40	55	31	–	25	72	45
(9) Ново-Алексеевская	H–A	43 23,58	77 13,64	700	1200	17	41	23	25	–	98	38
(10) Курты	K	43 53,6	76 20	550	–	110	108	94	72	98	–	105
(11) Плато	П	–	–	1700	–	17	9	15	45	38	105	–

(12) Примечание. h – высота над уровнем моря, H – глубина прибора в скважине.

Key:

1. Station
2. Notation
3. Coordinates
4. Distance between stations, km
5. Talgar
6. Ozero
7. Alma-Ata
8. Ali
9. Novo-Alekseyevskaya
10. Kurty
11. Plato

12. Note. h is the elevation above sea level, II -- depth of instrument in the well.

§3. Radiotelemetric Channel

In 1971 the laboratory of deep well observations began work on the development of the equipment and the process for centralized recording of signals. In 1972 V. G. Katrenko took the radio channel in Tashkent as the initial one. The development ended with the construction of the radiotelemetric test area of highly sensitive automated stations in 1972. Later the equipment was improved significantly and a great deal of experience was accumulated in its operation. Let us consider the individual assemblies and units of equipment which are not series manufactured by industry. For this purpose we shall use the materials of reference [37] in part.

The radiotelemetric channel includes the equipment at the transmitting and receiving stations. The equipment makes it possible to input seismic data to the communications channel for which the series radio relay RRS-1M stations are used.

Basic technical specifications of radiotelemetric equipment (without a communications channel) are as follows:

Frequency band of transmitted seismic data, hertz	0.5-10
Dynamic range (without the communications channel), decibels	60
Nonlinearity, %	≤0.5
Operating temperature range, °C	from -15 to +40
Feed voltage (from storage battery), volts	12

The functional diagram of the telemetric channel is presented in Fig 28, a. The basic links of the channel are as follows: a seismograph with preamplifier, an amplifier-modulator, transmitter, receiving radio station, demodulator, low-frequency amplifier and recording device.

The SBU-V seismometers are used as the seismic converters in the deep-well stations, and the SM-2M at the ground surface stations.

Amplifier-Modulator (UM). The UM module (Fig 28, b) is made up of the amplifier, modulator and feed voltage stabilizer. The low-frequency amplifier, to the input of which the seismic signal is fed after being picked up on the preamplifier is a low-noise five-stage amplifier with direct couplings between stations. It is encompassed by two loops of common negative feedback which rigidly stabilize its parameters and shape the frequency characteristic. For compensation of the characteristic of the pendulum conversion, the transmission coefficient of the UM in the frequency range of 1-10 hertz is inversely proportional to the first power of the frequency.

Basic parameters of the amplifier:

Input impedance, kilohms	8.2
Output impedance, ohms	≤600
Natural noise fed to the input, microvolts	≤ 1
Transmission coefficient with respect to voltage (on a frequency of 1 hertz)	1000
Dynamic range, decibels	≥ 70

From the amplifier output the signal goes to the frequency modulator which transfers the seismic signal spectrum of 0.5-10 hertz to the frequency range of 300-3400 hertz, that is, it modulates the telephone channel frequencies of the radio station by the seismograph signals.

The frequency modulator is a tunable multivibrator with separate functional circuits which permits us to obtain a linear conversion characteristic in a wide frequency band. The T_8-T_9 input circuits assembled by the system with a common base are the capacitor charge current generators. The circuits with a common collector T_{10}, T_{12}, T_{13}, T_{14} (the multivibrator

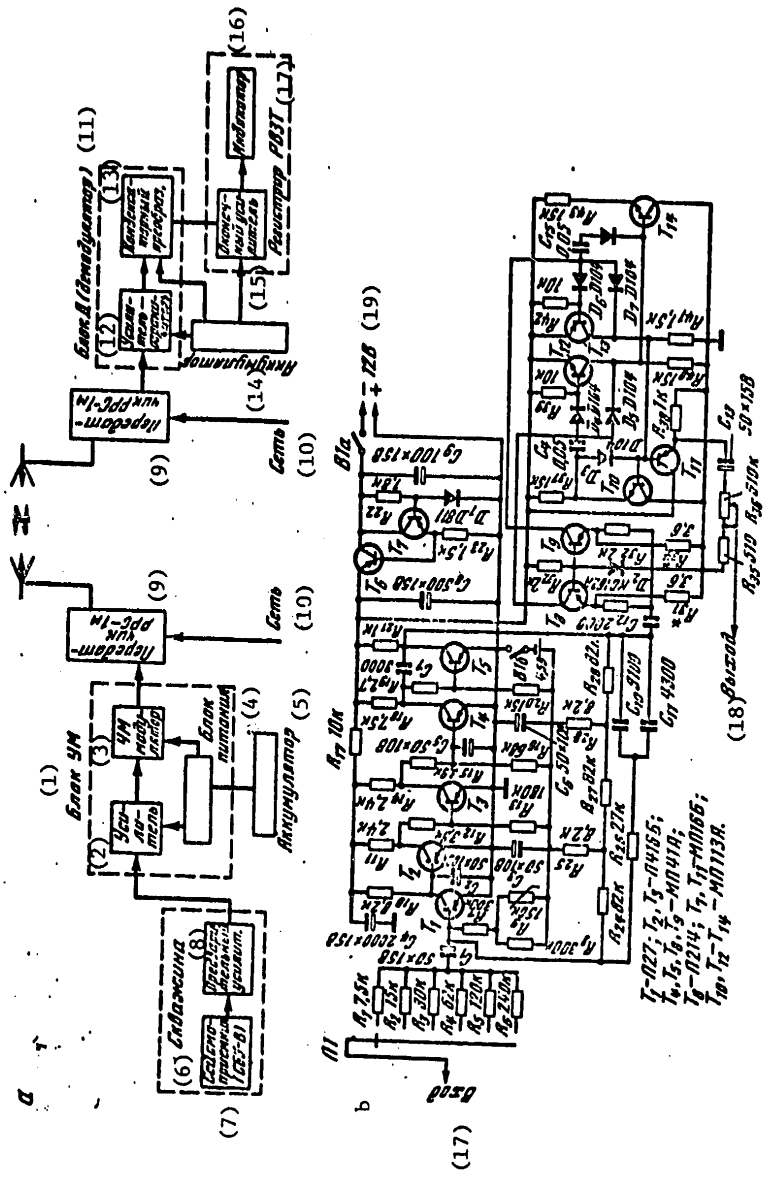
a
b
(1) Блок ЧМ
(2) Уси-ли-тель
(3) ЧМ генератор
(4) Блок питания
(5) Аккумулятор
(6) Скважина
(7)
(8)
(9) Передатчик РРС-1М
(10) Сеть
(11) Блок Д (Демодулятор)
(12)
(13)
(14) Аккумулятор
(15)
(16) Индикатор
(17) Регистр РВЗТ
(17) Вход
(18) Выход
(19) +12В
T1-П27; T2,T3-П415Б;
T4,T5,T6,T9-МП41А;
T8-П214; T7,T13-МП16Б;
T10,T12-T14-МП113А.

Figure 28

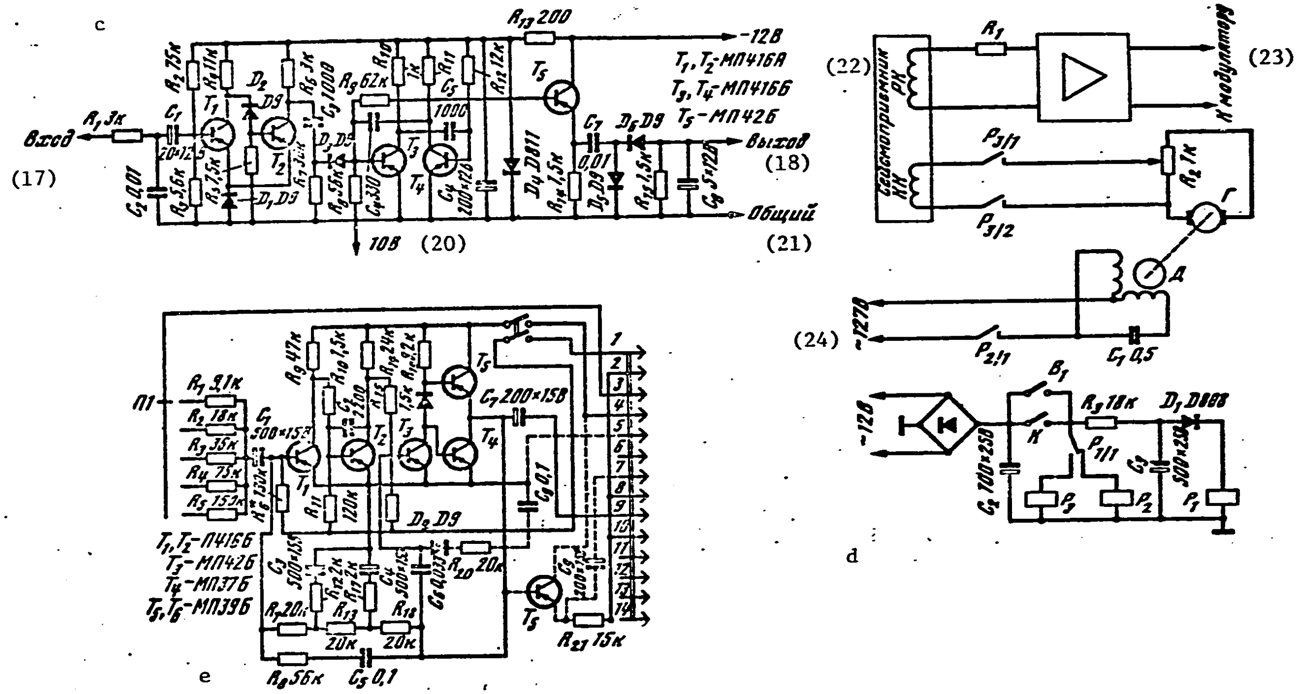

Figure 28. Functional diagram of the radiotelemetric channel (a) and schematic diagrams of the amplifier-modulator (b), demodulator (c), the control signal feed (d) and the power amplifier (e)

Key:

1. Amplifier-modulator unit; 2. amplifier; 3. FM modulator; 4. feed unit; 5. storage battery; 6. well; 7. SBU-V seismograph; 8. preamplifier; 9. RRS-1M transmitter; 10. network; 11. block D (demodulator); 12, amplifier-limiter; 13. capacitive converter; 14. storage battery; 15. end amplifier; 16. display; 17. RVZT recorder; 17. input; 18, output; 19. ± 12 volts; 20. 10 volts; 21. common; 22. seismograph; 23. to the modulator; 24. 127 volts.

itself) play the role of the controlling switches. The multivibrator frequency depends on the charge current developed by the input circuits, and it is controlled by the output current of the amplifier.

Basic parameters of the frequency modulator;

Central frequency, hertz	1850 ± 15
Frequency deviation, hertz	≤ 1600
Frequency stability, hertz	$1 \cdot 10^{-4}$
Output impedance, ohms	600

The frequency modulator signal of the amplifier modulator unit is fed to the radio station modulator which takes the signal to the ultrashort wave band.

The ultrashort wave signal goes through the air to the receiving radio station, from the output of the receiver of which the frequency-modulator signal is picked up in the 300-3400 hertz band and it is fed to the modulator-amplifier unit.

Demodulator (D). The basic purpose of the demodulator is conversion of the frequency spectrum obtained in the receiving radio station (300-3400 hertz) to the low-frequency spectrum of seismic information. Let us briefly discuss its operation (see Fig 28, c).

The demodulator is executed from five triodes and five diodes. The output signal of the subcarrier frequency with an amplitude of 5-8 volts, similar with respect to shape to sinusoidal, goes from the radio to the demodulator input where a threshold unit of the Schmidt trigger type (T_1, T_2) converts it to square pulses.

The shaped square pulses are differentiated; then they go through the C_3, R_7 circuit to the slaved multivibrator (the triodes T_3, T_4) which shapes the pulses of constant duration and amplitude independent of the input signal parameters. Only the frequency of shaping of the pulses determined by the input signal frequency is a variable. Then the pulses go through the emitter repeater T_5 directly to the demodulator D_5, D_6, R_{15}, C_8.

The advantages of the described demodulator circuit are the following:

a) Economy -- the demodulator does not require a separate feed and is connected to one power supply (a 12 volt storage battery) jointly with other units of the channel;

b) Absence of mutual effects between the channels and, as a consequence, quite high noiseproofness;

c) Resistance overload, simplicity, reliability, a small number of parts.

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The low-frequency signal is fed from the demodulator output to the recording equipment.

Channel Calibration. The problems of calibrating the seismic equipment, that is, determination of the frequency-amplitude and phase characteristics of the seismic channel and also amplification of it have been investigated in many papers, for example, in [45] and other papers. The calibration of the radiotelemetric channel has its own specific characteristics.

Actually, on an ordinary seismic station all of the channel elements are located in direct proximity to each other. In the radiotelemetric channel the individual elements are located at great distances, in particular, the receiving and transmitting parts are several tens of kilometers apart. Inasmuch as the transmitting radio station is rigidly "tied" to the AC network power supply, in the search for a "quiet" place it is necessary to remove the seismometers to significant (up to 300-400 meters) distances. Simultaneously, in order to avoid induction from the transmitter itself, the preamplifier and the amplifier-modulator are moved there.

Additional difficulties occur when calibrating well channels, the seismometers of which are located in the wells at great depths and are connected to the ground equipment by long lines (the construction length of the series-produced armored logging tables is about 3500 meters). The influence of such long lines on the parameters of the entire channel must be taken into account. In addition, at great depths (to 3000 meters) under high temperature conditions reaching 100°C, the seismometers change parameters. This is taken into account by introducing the corresponding directions or approaching the actual operating conditions to the maximum when calibrating the channel. Inasmuch as the radiotelemetric channel is made up of seismic and radio communications channels, the latter must be individually tuned and adjusted before calibration in order to avoid its influence on the seismic channel parameters.

Frequency Characteristic of the Channel. According to Fig 4, b, the characteristic on the 0.7 level has a pass band of 0.8-7 hertz. In order to compensate for the amplification of the seismograph emf with an increase in frequency, an integrating cell is provided in the amplifying-recording equipment (see curve 2, Fig 4).

When preparing the radiotelemetric channel for operation when all of its assemblies are located on the central recording station, the frequency characteristic of both the entire channel and its individual elements can be picked up by any of the known procedures. When part of the equipment is installed at the seismic and data transmission point, the most convenient for determination of the frequency characteristic of the entire channel as a whole is the procedure for which the signal is fed from the generator on various frequencies directly to the input of the control coil whether it is a ground seismometer or a deep well seismometer. This procedure is convenient for daily monitoring -- feeding the signal of a constant amplitude magnetic generator (MGPA) to the auxiliary coil, it is possible to control both the shape and level of the frequency characteristic of the channel operatively.

It is also possible to pick up the frequency characteristic of the amplifying and recording channel, feeding the signal from the generator to its input. Then multiplying it by the frequency characteristic of the seismometer and introducing a correction for the seismometer converter, we obtain the frequency characteristic of the entire channel.

Channel Amplification. Under laboratory conditions, before setting up the channel for operation, the amplification, just as the frequency characteristic, can be determined by various methods (for example, electrodynamically or by the method based on direct measurement of the displacement of the pendulum by a microscope [32]). Usually the recording of the frequency characteristic and determination of the amplification both in the laboratory and in operation are handled in the same way. For determination of the amplification by the procedure most convenient for an operating radiotelemetric channel, first it is necessary to determine the sensitivity of the amplifying and recording channel as a function of frequency, feeding the signal from the generator to the input of the preamplifier. Here we simultaneously obtain the frequency characteristic of the amplifying and recording channel.

The amplification of the channel is calculated by the formula

$$V=S\bar{U}2\pi GR_{\text{input amplifier}}/\ell(R_{\text{input amplifier}}+R_K),$$

where $S=A_{\text{record}}/U_{\text{input}}$, m/volt is the sensitivity of the amplifying and recording channel equal to the ratio of the recording amplitude on various frequencies to the voltage fed from the generator to the input of the preamplifier; $\bar{U}$ is the frequency characteristic of the seismometer for the adopted damping coefficient D which is taken from the standard curves; G is the electrodynamic constant of the seismograph coil; ℓ is the reduced length of the pendulum; $R_{\text{input amplifier}}$ is the input impedance of the amplifier; R_k is the resistance of the operating coil of the seismograph.

Let us note that the values of the amplification of the same channel taken by different procedures usually are quite close and do not differ by more than 5 to 10%. Therefore the choice of procedures is determined by the arguments of convenience under certain specific conditions.

Controlling the Identity of the Receiving Parts of Radiotelemetric Channels. This control can be realized by two procedures. The first consists in the fact that one transmitting station is organized at the central recording station to which all of the receiving stations are tuned. Feeding the voltage on various frequencies to the input of the modulator (or seismometer) from the generator, it is possible to construct the amplitude-frequency characteristics for each receiver ard then compare them.

A second, stricter and more objective procedure consists in tuning all of the receiving stations to any one transmitting station located at the seismic data transmission point and recording identical seismic information for some time from the same seismograph.

Channel Control. For operative control of the parameters of each channel on the transmitting station, automatic feed of the control signal of the MGPA to the control coil of the seismograph has been introduced. The control signal makes it possible to determine the parameters of the entire radiotelemetric channel and trace their stability. For this purpose the circuit has been developed (see Fig 28, d) for automatic feed of the control signal. The control signal from the MGPA is fed to the control coil of the seismograph through a potentiometer by means of which the required amplitude of the control signal is established. The circuit diagram of the MGPA [constant amplitude magnetic generator] contains a rectifier, a time relay P_1, servorelays P_2, P_3 and the electric motor D, the shaft of which is installed coaxially with the shaft of the MGPA, and both are connected to each other by a spring coupling.

On closure of the contact K of the alarm of the Slava electromechanical clock, the relay P_1 is connected through the normally closed contacts to the relay P_2, and the electric motor spins the MGPA. After 10 to 12 seconds -- during this time the frequency of the MGPA reaches 10-15 hertz -- the relay P_1 is switched on, and the power is disconnected from the electric motor, simultaneously connecting the output of the MGPA to the control coil of the seismometer through the contacts of the relay P_3. This relay remains connected until the contact K of the alarm on the clock is broken (approximately 2.5-3 minutes). The duration of the control signal is 1-1.5 minutes. The power supply for the circuit is realized from the power supply unit of the RRS-1M radio station (12 volts DC and 127 volts AC).

§4. Equipment of the Central Recording Station

At the Novo-Alekseyevskaya central recording station, after demodulation the seismic signals are recorded in two modes: continuous and slaved.

Continuous Recording. The recording is made by a pen recorder, and it is basically a display. It permits observation of the seismic regime, operative determination of the directions of the sources of distant earthquakes and the coordinates of the centers of nearby earthquakes. The direction of the source can be determined without interrupting the recording several minutes after recording the first wave of the earthquake. In addition, the display recording permits continuous control of the operation of the stations, the noise level, and so on.

For continuous recording, the RV3-T visible recorder is used in which power amplifiers have been utilized which were developed at the Earth Physics Institute of the USSR Academy of Sciences (Fig 28, e). The amplifiers are assembled from five triodes in a circuit with galvanic coupling and symmetric emitter repeaters at the output. In order to insure stability of the parameters, the amplifier is encompassed by two common and two internal negative feedbacks, and it has five positions for manual regulation of the gain (6 decibels each).

Basic parameters of the amplifier:

Maximum amplification coefficient with respect to voltage	800
Minimum input impedance, kilohms	9
Output impedance, ohms	50

Structurally the recorder contains four amplifier modules loaded on the pen recording heads with a resistance of 800 ohms and a resonance frequency of 8 hertz. Inorder to record the signals from the radiotelemetric system, each unit of the amplifier also has demodulators mounted in it. Instead of a collectorless DC motor, a DSM electric motor is used to wind the paper tape. It is fed from the 220 volt network. The power supply for the demodulators and the amplifiers comes from the same 12 volt storage battery.

Slaved Recording. The slave recording system organized at the central station makes it possible to record only the useful events, the recording of which is used for basic processing of the materials, analysis and comparison of them.

The four-channel slaved recording system was first organized on the basis of the device with magnetic memory developed and manufactured by the special design office of the Earth Physics Institute of the USSR Academy of Sciences. However, the significant deficiencies discovered when checking out and test operating the equipment led to the necessity for significant alteration and improvement of its assemblies and units. The specific peculiarities connected with the multichannel radiotelemetric recording led to the development and manufacture of a special analysis and switching unit. A description of the slaved recording system is presented.

The basic elements of the system are the analysis and switching unit and the magnetic recorder.

Analysis and Switching Unit. This unit switches on any of the recorders (one or several simultaneously) on appearance of a useful signal confirmed by three radiotelemetric channels and it disconnects the recorders when the signal intensity drops below the given level with respect to all three channels. The circuitry of the unit (Fig 29) includes a control panel, threshold circuits, logical filters, disconnect relay, connect relay, servorelays, selector circuits, and comparison circuit. Let us briefly consider the operation of the elements of this unit.

The threshold circuit is made up of matching stages executed from the T_1-T_3 triodes and the Tsh_1-Tsh_2 Schmidt triggers. It is used for shaping square pulses at the output in the presence of the seismic signal at the input exceeding the given level. The regulation of the response threshold is realized by the R_1-R_3 potentiometers.

The logical filters which generate the instruction to switch on are executed from triggers connected by the counting circuit in such a way that the triggers Tg_3, Tg_6, Tg_9 are set to the one condition when four start pulses arrive from the threshold circuit (which corresponds to four periods of the input signal). The -10 volt level is taken as the ones condition. Thus, the filters filter out ones noise.

The disconnect relays periodically clear the logical triggers of the filters in order to erase false information. This information is stored by the logical filters on random arrival at the threshold circuits of signals exceeding the given response threshold. The disconnected relay is made up of the trigger Tg_{10}, the time relay based on the triodes T_6 and T_7 and the P_1 relay. On appearance of the pulse from the threshold circuit of any channel and passage of it through the OR collecting circuit (T_5, D_{10}-D_{12}) the trigger Tg_{10} is set to the ones condition, it starts the time relay and after 10 seconds the P_1 relay is switched on, through the contacts of which the clear signal is fed on closure to all triggers of the circuit, including Tg_{10}. The signal light L_1 indicates the passage of a single or periodic signal the given level through one or several channels. On clearing, the entire system is initialized, and the light burns. With the arrival of a single signal the operating cycle repeats. This condition of the circuit is slaved even in the presence of a regular signal at two diodes simultaneously.

The switching on relay closes the circuit of the servorelay IR in the presence of a signal at the outputs of all of the logical filters simultaneously and it disconnects IR after diappearance of the control signals from the threshold circuits. The switching on relay is made up of the trigger Tg_{11}, the time relay T_8-T_{10} and the relay P_2. On arrival of a regular signal above the given level at all three inputs, the threshold devices develop the start pulses of the triggers of the logical circuits with frequencies equal to the frequencies of the incoming signals. After passage of four oscillation periods along each of the channels, the triggers Tg_3, Tg_6, Tg_9 flip to the ones condition and thus switch on the comparison circuit (T_4, D_{13}, D_{15}). The signal passing through the comparison circuit trips the trigger Tg_{11} which leads to response of the relay P_2 which by one of its contacts includes the servorelay IR, and the other, the preset input 2 of the trigger Tg_{11} to the output of the OR circuit.

In this mode the trigger Tg_{11} is periodically initialized by the clear signal from the disconnect relay and it is again set to the ones condition by the input signal of any other channels. The relay P_2 will stay in the on state until the input signal level falls below the threshold value on all channels. After disconnection of the relay P_2 the recorders are disconnected, and the connect relay again connects only to the output of the comparison circuit. The system goes into the slaved regime.

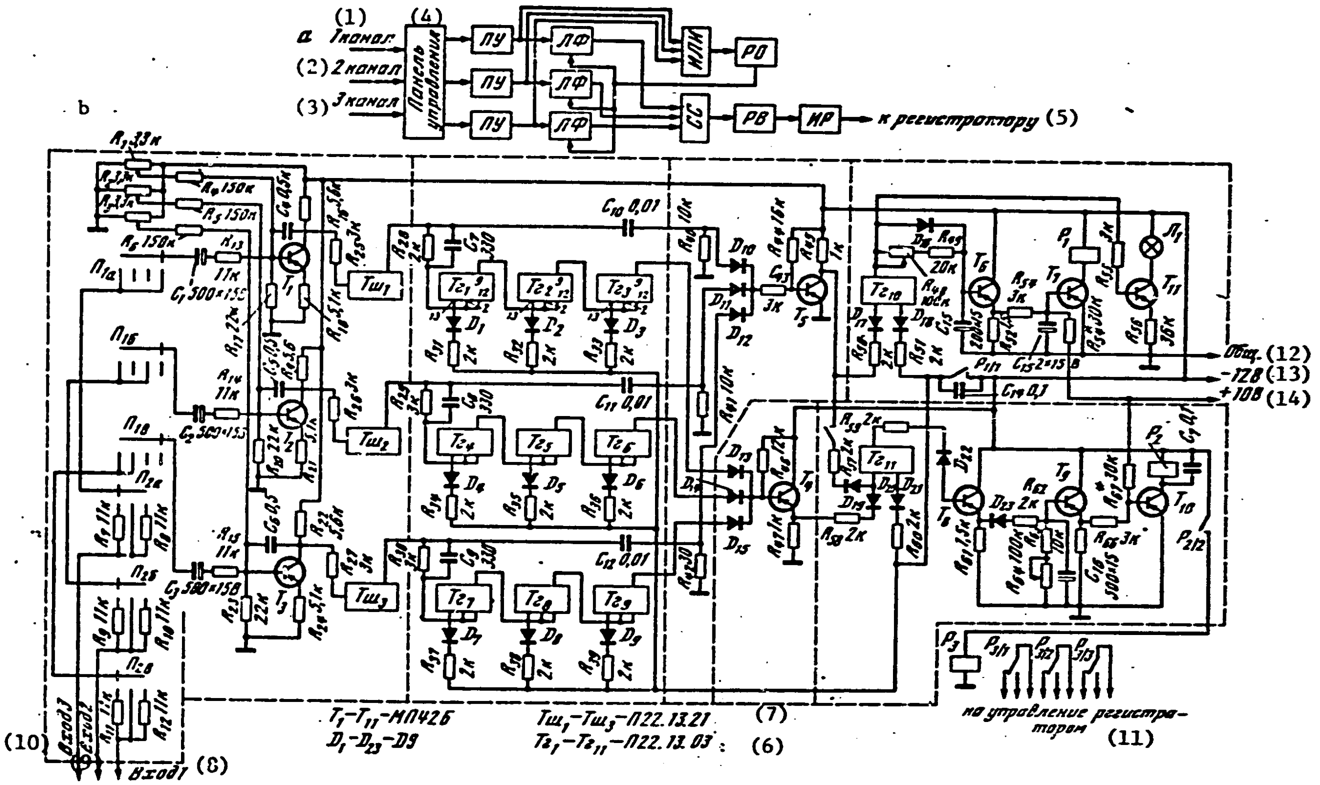

Figure 29. Functional (a) and schematic (b) diagrams of the module for analysis and switching on the slaved recording

ПУ -- threshold circuit; ЛФ -- logical filter; ИЛИ [OR circuit] -- collecting circuit; СС -- comparison circuit; РО -- disconnect relay; РВ -- connect relay; ИР -- servorelay [See key on following page]

[Key to Fig 29, preceding page]:

1. Channel 1
2. Channel 2
3. Channel 3
4. control panel
5. to the recorder
6. Tg...
7. Tsh ...
8. Input 1
9. Input 2
10. Input 3
11. to the recorder control
12. Common
13. -12 volts
14. +10 volts

The control panel contains the potentiometers regulating the connect level, a control light and the switches Π_1 and Π_2. The switch Π_1 is used for selective connection of the required channel when adjusting the connect level. In the fourth position, all three channels are connected to the module. The switch makes it possible to perform stepped variation of the amplification of the channels by two or four times.

The power supply for the unit comes from a DC voltage -12 volts source. In order to feed the circuits with a bias voltage of 12 volts an internal power supply is provided in the unit which is made up of a square pulse generator, rectifier and filters.

Magnetic Recording. The magnetic recording is organized on the basis of the four-channel station for recording surprise phenomena TEAC SR-2101C, operating in combination with the TEAC R-351F reproduction tape recorder (built by the Japanese Company TEAC).

Basic technical parameters of the TEAC station:

Magnetic memory time, sec	30
Number of operating channels	4
Amplitude of the input signal, volts	±1
Amplitude of output signals, volts	±1
Frequency band, hertz	0-25
Dynamic range, decibels	40
Tape speed during recording, cm/sec	4.75
Operating temperature range, °C	0-40
Intake power, watts	700
Feed voltage, volts	220
Recording principle	frequency modulation

Basic parameters of the TEAC R-351F reproduction unit:

Tape speed, cm/sec	9.5; 19 and 38
Output signal amplitude, volts	±1
Number of channels	4
Dynamic range, decibels	40

Output impedance, ohms	600
AC power supply, volts	100
Frequency band, hertz	0-300

One of the channels is used for recording and reproducing voice from a microphone. The starting and stopping of the tape drive mechanism to record data with continuously rotating drum for the magnetic memory on magnetic tape is accomplished by a starter which controls the analysis and slaved recording connected unit.

Let us discuss the operation of the station for recording surprise phenomena. The input signals with an amplitude of ±1 volt go from the RV3-T amplifiers through the emitter repeater to four recording amplifiers which convert the analog signal to a frequency modulating signal with a mean modulation frequency of 250 hertz. From the recording amplifiers the signals go to magnetic heads. The information is recorded on a continuously rotating magnetic drum. A stable frequency from a quartz oscillator is also recorded on the drum. A fifth signal is used for compensation of the knocking of the tape drive mechanism. After rotation of the magnetic drum by 330° (which is 30 seconds with respect to time) the information is read by the reproduction heads, it goes to the reproduction amplifiers, then it is demodulated, filtered, and fed to the four outputs of the magnetic memory unit with a time delay of 30 seconds from the time of arrival. Then the information that is delayed in time goes without transformation of amplitude and velocity to four recording amplifiers of the unit for automatic storage of the information where the analog voltage is again converted to a frequency modulated signal with a mean carrier frequency of 4 kilohertz. This signal is fed through the recording heads to the magnetic tape.

On arrival of the record instruction from the start-stop starting unit, the tape drive mechanism is switched on, and information about the event is recorded on the magnetic tape with the 30-second delay. In the information storage element there is one amplifier for reproduction of the signal from the magnetic tape which offers the possibility of channel by channel reproduction of the recorded information for monitoring or copying on other recorders.

The distinguishing feature of the magnetic memory module is the fact that the drum with the head is placed in an oil bath in which a constant temperature is maintained by using a thermostat, as a result of which constant viscosity of the oil is insured. Therefore the clearance between the magnetic drum and the heads formed as a result of the oil film is strictly constant. For recording, a type 10 magnetic tape 6.3 mm wide is used. The cassettesinstalled on the recorder hold 375 meters of magnetic tape (it is possible to install cassettes with a 1000-meter capacity). Depending on the seismic activity of Alma-Ata, during one period or another this amount of tape will be sufficient for from 4 to 8 days. The number of recorded useful events reached 30-40 on the average.

The R-351F reproduction tape recorder is analogous with respect to circuitry and parameters to the tape recorder which is part of the recording station for surprise phenomena with the exception of differences in the speeds at which the magnetic tape is driven.

The slaved recording system based on the station for recording surprise phenomena is reliable and will operate stably for several years.

Time Service. One of the basic advantages of the centralized recording system is the single time service permitting significant increase in precision of all of the instructions.

In order to feed the time signals to the central recording station, the PKCh-2 type electronic quartz clocks are used. In connection with the fact that the correction for the daily running of the clock does not exceed ±0.1 seconds, there is no necessity for introducing it. This has significantly reduced the primary processing time of the seismograms.

The circuit for forming the minute time marks with the application of a quartz clock differs from the analog circuit using chronometers, and it has a number of advantages. In particular, eliminating the electromechanical relays increases the amplitude and shape stability of the time marks. This is explained by the fact that the parameters of circuits with weak currents which are commuted by mechanical contacts depend sharply on the surface state of the contacts themselves. In addition, the given electronic circuit permits superposition of several second pulses on the display seismogram at the time of disconnection of the slaved recorder. The presence of such pulses indicates that an earthquake has been recorded on the magnetic tape, and it permits accurate establishment of the times it was switched on and off.

Let us describe the operation of the circuit for shaping the minute marks (Fig 30, a). The minute pulse signals from the PKCh-2 go through the switch B_1 to the time mark pulse shaper, from the output of which T_5 the pulses go to all of the RV3-T amplifiers. The transmission of the marks is controlled by the light L_1. For recording the exact time radio signals they must be fed from the radio receiver to the input of the shaper using the switch B_1.

In order to plot several second marks on the display seismogram, which are required for coordinating the recording on the slaved recording magnetic tape, the relay P_1 is used which controls the contacts of the servorelay of the analysis and slaved recording connect module through the T_7 transistor.

The minute marks are simultaneously plotted on the display seismograms and on the slaved recording magnetic tape. Each slaved recording seismogram contains at least one minute mark by which after reproduction on photographic paper it is coordinated with absolute time.

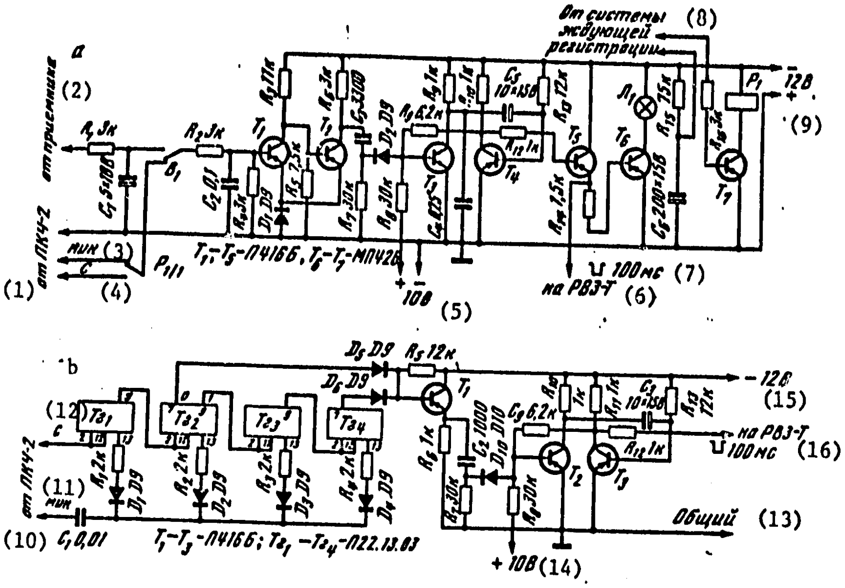

Figure 30. Schematic diagrams of the shaping of the minute (a) and 10 second (b) time marks

Key:

1. from PKCh-2
2. from the receiver
3. minutes
4. seconds
5. ±10 volts
6. to the RV3-T
7. 100 milliseconds
8. from the slaved recording system
9. +12 volts
10. from the PKCh-2
11. minutes
12. seconds
13. common
14. +10 volts
15. -12 volts
16. to the RV3-T, 100 milliseconds

The 10-second time marks from the quartz clock are plotted also on the magnetic tape with respect to one of the channels. The circuit (Fig 30, b) includes the decimal counter and the time mark shaper. The decimal counter is made up of four triggers of the two-input comparison circuit. It realizes division of the repetition frequency of the second pulses coming from the PKCh-2 by 10. In order to eliminate summation of the error when there is a failure of any of the triggers, a clear signal is induced on the preset input of all the triggers from the PKCh-2 minute output. Each tenth second pulse starts the slave multivibrator which generates the pulse lasting 100 milliseconds and amplitude of 12 volts, which is then fed to the corresponding RV3-T power amplifier.

Reproduction Equipment. The TEAC R-351F reproduction unit combined with two oscillographs and the ChISS [frequency selective seismic station] filter circuit is used to reproduct the recorded signals from the slaved recording magnetic tape.

Table 6

Станция (1)	Отсутствие электроэнергии для передачи (2)	Передатчик (3)	Приемник (4)	Кабели (5)	Модулятор (6)	Демодулятор-усилитель (7)	Предварительный усилитель (8)	Сейсмоприемник (9)	Антенны (10)	Радиопомехи (11)	Ме (12)
(13) ЦРС	17/28	-	7/11	-	-	9/14	-	-	2/3	25/40	2/
(14) Алма-Ата	4/15	8/31	-	-	6/23	-	2/8	3/11	2/8	-	1/
(15) Талгар	6/21	4/14	-	2/7	9/3	-	3/11	-	3/11	-	2/
(15) Озеро	8/47	6/35	-	1/6	1/6	-	-	-	-	-	1/
(17) Али	12/35	2/6	-	1/3	2/6	-	6/17	4/12	2/6	-	5/

Key:

1. Station
2. Absence of electric power for transmission
3. Transmitter
4. Receiver
5. Cables
6. Modulator
7. Demodulator-amplifier
8. Preamplifier
9. Seismograph
10. Antennas
11. Radio interference
12. Metrologic amplifier
13. Central recording station
14. Alma-Ata
15. Talgar
16. Ozero
17. Ali

Note. The number of failures is indicated in the numerator, the percentage failures for a given cause are indicated in the denominator. The shutdown of equipment for preventive maintenance operations, changing power supply, improvement of the equipment, and so on, were not taken into account in the table.

The cassettes with the magnetic recordings obtained on the recorder are reproduced on the R-351F module with copying on the oscillograph phototape.

The marking of the event consisted in recording the earthquake -- dates and times -- before each earthquake. The recording is made by the head through a microphone. Then the cassette is placed in a film holder for long-term storage and a label is attached to it with indication of the location of each event (meters), its duration and the number of the RV3-T display tapes where it was recorded.

The filter module of the frequency-selective station (ChISS) [33] is made up of a set of octave resonance filters with damping steepness on the order of 20 decibels per octave on the left and right slopes. The channel required for spectral analysis from the reproduction unit goes to the ChISS input, and the POB-12M oscillograph is connected to the output. Some of the frequency characteristics of the filters are depicted in Fig 4, b (the pass bands of the channels are plotted on the 0.7 level as a function of amplitude on the resonance frequency).

Analysis of the Operating Reliability of the Equipment. It appears significant to estimate the operating reliability of the equipment of the radiotelemetric system. For this purpose a study was made of the causes of failure of the equipment of the basic automated stations and the central recording station. The results of this analysis are presented in Table 6.

From the table it is obvious that for automatic stations the basic cause of equipment failure was loss of power supply at the transmitting stations. At the Ozero station located at an altitude of about 3000 meters, this loss of power occurred 8 times, which is 47% of all the failures. For the Alma-Ata and Talgar stations this figure is 15 and 21% respectively. The failures because of the transmitter at the Alma-Ata and Ozero stations occurred in 8 and 6 cases (31 and 35% of all the failures of the station). The next cause of equipment failures is failure of the modulators. It is true that their failures pertain to the initial phase of operations. The preamplifiers operate in practice fail-safe. During a 4-year recording period, the failures for this reason occurred twice at the Alma-Ata station and 3 times at the Talgar station. The Alma-Ata Well station failed 3 times because of the seismograph, but this also pertains to the initial stages of the operations. The Alma-Ata and Talgar stations failed 2-3 times each as a result of breaking of antennas -- basically in the winter under high wind conditions. The recording was disrupted once or twice each during powerful thunderstorms in the summer.

The failures of the central recording station are connected with the absence of electric power in 28% of the cases and radio interference in 40% of the cases. The latter were caused by the presence of transmitters near the central recording station operating on very low frequencies. The failure of the receivers accounted for 11% and as many demodulators also failed.

Analysis shows that in order to increase the operating reliability of the radiotelemetric system it is necessary first of all to insure reliability and provide a stationary power supply for the transmitters and the receivers.

§5. Equipment for Controlling the Tayga Recorder during Tricomponent Recording of Earthquakes in the Slaved Mode

The Tayga recording station is designed to record explosions in the slaved mode.

The joint use of explosions in earthquakes not only significantly lowers the cost of operations, but it also makes it possible to obtain a more complete idea about the environment. The majority of the recording stations designed to record earthquakes on magnetic tape (for example, Zemlya and Cherepakha) operate in the stationary regime. At the same time the recording of the earthquakes in the slaved modes significantly simplifies and reduces the cost of the observation equipment in the field and the processing of the materials. It also permits improvement of the quality of the material by using less economical equipment having the best parameters.

In order to study the polarization of seismic waves caused by earthquakes, materials were used which were obtained by the Tayga recording station installed at the Talgar seismic station.

In this section a description is presented of the control equipment. The possibilities of the application of analogous sets for profiled and area earthquake recording systems in the slaved mode are discussed.

The tape drive mechanism of the Tayga recorder was switched on by the radio channel by using a circuit specially developed for this purpose. The additionally manufactured devices noted the time the tape drive mechanism was shut down after recording the earthquake on the magnetic tape and its end by the signals on the visible recording tapes of the central recording system. Changes were introduced into the circuitry of the recorder and the Tayga station reproduction equipment, and the necessary changes were introduced for improvement of the quality of the received material.

Control Circuit for the Tayga Recorder. The Tayga recorder located at the Talgar automated transmitting station of the Alma-Ata radio temperature test area is connected over the radio channel to the Novo-Alekseyevskaya central recording station (see Fig 31, a).

The control circuit operates jointly with the circuits for analysis and switching on the slaved recording of the central recording station. The operating principle of the control circuit consists in logical summation over two channels of the Ali and Ozero stations. The control signals are the voltages from the terminal amplifiers of the RV3-T visible recorder operating in the continuous mode. The response of the circuit takes place on arrival of the first negative halfperiod over any of the two channels with an amplitude exceeding the given threshold which is regulated within the limits from 0.4 to 8 volts. The operating state of the circuit is maintained for the time necessary to analyze and switch the slaved recording in the case of a useful signal. If the module does not respond, the circuit returns to the initial position. In the case of a useful signal, the analysis and connect module keeps the circuit on to the end of the earthquake.

The recorder control circuit is made up of two threshold circuits (Schmidt triggers) T_1, T_2, T_3 and T_4, to which the input signal is fed from the connect level potentiometers R_1, R_7. The shaped square pulses fit the trigger Tg_1 through the OR circuit D_3, D_6, T_5. As a result, the relay R_1 i- included through the contacts of which the voltage is fed to the call circuit of the RRS-1M radio station where the transmitter generates the service signal and transmits it.

In the receiver of the radio located at the point of installation of the recorder, the service signal causes the appearance of a voltage in the call buzzer circuit. This voltage is fed to the recorder to feed the motor of the tape drive mechanism.

Simultaneously with inclusion of the relay P_1, fast charging of the capacitance C_4 takes place. In the case of a false inclusion caused by seismic or radio noise, a clear pulse goes from the analysis and slaved recordings connect module through R_{15}, D_7 to Tg_1, and the circuit returns to the initial state after a defined time given by the R_{13}, C_4 circuit. If there is a useful signal, the P_1 relay does not disconnected. In this case its contacts are also blocked by the contacts of the P_3 relay of the module for analysis and inclusion of the slaved recording of the central recording station.

Recorder Inclusion and End of Magnetic Tape Mark Circuits. Short (5-6 sec) sinusoidal signals are fed to the radiotelemetric channel with subsequent recording on the RV3-T continuous recording display tape to mark the inclusion of the recorder (just as to mark the end of the magnetic tape).

The schematic diagram of the marking of inclusion of the recorder is presented in Fig 31, b. A sinusoidal generator is assembled from the transistor T_1. The magnitude of the fed signal is adjusted by the potentiometer R_{10}. The time relays T_3, T_4 connect the output to the control coil of the seismograph for a defined time. In turn, the time relay connected to the recorder control circuit is controlled by the contacts P_1.

The end of magnetic tape marking circuit (see Fig 31, c) differs from the described inclusion mark circuit (Fig 31, b) only by the time relay control which realizes the photodiode autostop D_2, T_5.

Changes in the Tayga Equipment. During the operation of the Tayga equipment difficulties arose with the reproduction of the information. In accordance with the technical specifications, the reproduction level was 30-300 microvolts which with lowered quality of the tape is commensurate with its natural noise.

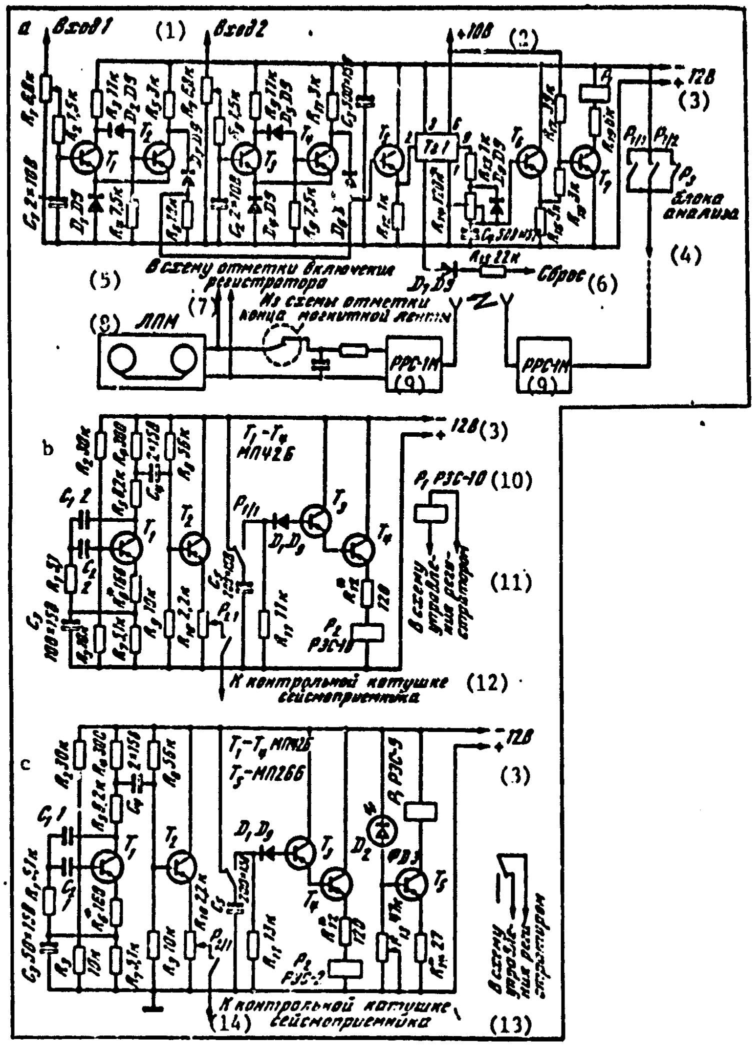

Figure 31. Schematic diagrams of the Tayga control stations: a -- recorder control; b -- recorder inclusion mark; c -- end of magnetic tape mark

Key:

1. Input 1, input 2; 2. +10 volts; 3. ±12 volts; 4. analysis module; 5. to the recorder inclusion mark circuit; 6. clear; 7. from the end of magnetic tape mark circuit; 8. LPM=tape drive mechanism; 9. RRS-1M; 10. RES-10; 11. to the recorder control circuit; 12. to the seismograph control coil; 13. to the recorder control circuit; 14. to the seismograph control coil

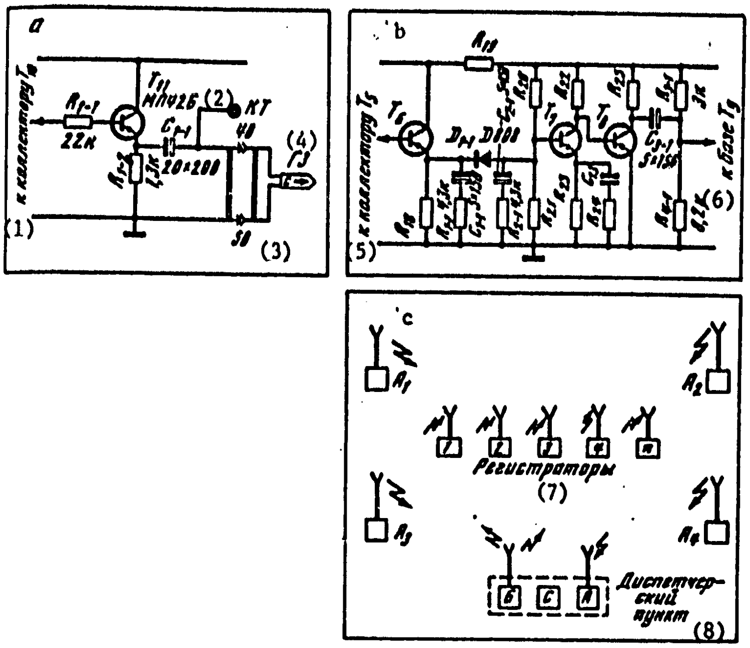

Figure 32. Variations in the recording amplifier circuit (a) and the reproduction amplifier circuit (b) and one of the versions of the control of the Tayga station complex (c)

Key:

1. to the collector T_{10}
2. MP42B
3. 5 volts
4. G3
5. to the collector T_5
6. to the base T_9
7. recorders
8. dispatch panel

The low level of the reproduction signal is explained by the unsuccessful selection of the recording method (pulse-frequency modulation) and the terminal stage circuit of the recording amplifier of the recorder. The short pulses recorded on the tape, especially on the low carrier frequency, give many harmonics on reproduction which greatly distort the shape of the signal. This leads to the appearance of false pulses. The constant component of the current flowing through the head during the recording time accompanies the high noise level of the film on reproduction. Finally, the single-pole- method of recording itself artificially lowers the efficiency of the output of the magnetic carrier by 50%.

The changes introduced into the record amplifier circuit (Fig 32, a) and the reproduction amplifier (Fig 32, b) made it possible: a) to replace the PFM method by the FM method (which significantly improves the shape of the reproduction signal); b) to exclude the permanent magnification c) to make a dipolar recording without returning to 0. As a result, the amplitude increased to 1.5 millivolts on reproduction (the recording current is the same). With quite good shape, excluding false pulses (noise), the tape noise was reduced by 2 times, and the signal/noise ratio increased by 6-8 times.

Theoretically the method of recording the seismic signals (earthquakes or explosions) by the Tayga recorders in the slaved mode can also be used during profile and area observations required to solve different problems, including the study of exchange transmission waves. In this respect the developed Tayga automatic recorder control system is the initial step.

The proposed control system for the set of Tayga recorders can be represented in the form shown in Fig 32, c. The network of primary ("alert") radio stations A_1, A_2, A_3 and A_4, which are simultaneously transmitting stations of the radiotelemetric test area transmits the signals of the first arrivals of the seismic waves at the central station A of the dispatch panel. These signals go to the control circuit C which generates the signal for inclusion of the transmitter B of the dispatch panel including all of the recorders with respect to the internal radio network of the set of Tayga equipment (1, 2, 3...) which are inside the loop formed by the radio stations A_1, A_2, A_3, A_4. The number of recorders and their mutual position depend on the problems to be solved.

§6. Means of Improving Radiotelemetric Equipment

The experience accumulated during several years of observations at the radiotelemetric test area makes it possible to indicate the paths of improving the radiotelemetric equipment. The problem basically reduces to expansion of the dynamic range and increase in informativeness of the radiotelemetric channel, that is, multiplexing of the communications channel.

Dynamic Range. The dynamic range of the radiotelemetric channel is 60 decibels. The recording system (display and in slaved mode) used at the present time makes it possible to realize no more than 40 decibels. Inasmuch as the channels of the telemetric recording system are tuned to the reception of the weakest earthquakes exceeding the level of the seismic background at the information transmitting point by no more than 35-40 decibels, all of the stronger earthquakes are unreadable on the seismograms. In addition, when recording strong signals there are restrictions in the converting elements of the equipment and strong nonlinear distortions appear on the recording.

In order to expand the dynamic range of the equipment used, experiments were run to develop automatic gain control at the input of the amplifying-transmitting channel.

Let us consider some of these circuits.

The two-channel two-level recording circuit is depicted in Fig 33, a. Its dynamic range can reach 80 decibels, the earthquake recordings are clear, and they respond conveniently. The operation of this system is simple. A deficiency is the necessity for continuous recording on two channels, which leads to high consumption of paper and also involves additional equipment (modulators, demodulators, recorders). If the indicated deficiencies do not play a significant role, the system can be used effectively for operation of the radiotelemetric channel.

The stepped gain control circuit on one recording channel is included in the transmitting spaces between the preamplifier and the modulator (Fig 33, b). When the signal reaches a defined magnitude, it is attenuated by the divider R_1, R_2 in the given ratio and it goes to the modulator input. The advantages of the system include simplicity and reliability of operation.

The deficiency is the transmission process at the time of switching from one level to another, the duration of which is two or three periods of the seismic signal. This can complicate the processing of the recordings somewhat.

The amplification regulation system with a common modulator and separate modulator amplifiers (Fig 33, c) is a compromise by comparison with the first two versions. Here on switching from one level to another the transition processes are several times shorter with respect to duration (no more than one period), and they are smaller with respect to amplitude, for the switching takes places after the amplifier.

In the investigated procedures the control of the switches K_1 and K_2 is realized by the control circuit (Fig 33, d). The circuit is assembled from the transistors T_1-T_3. It is a threshold element and is connected to the output of the preamplifier or to the output of the modulator amplifier. The rest of the circuit performs the function of a time relay. The potentiometer R_2 regulates the switching level, and R_{11} regulates the time for returning to the initial state (recording on the basic level). The circuit feed is common with the amplifier-modulator module.

The accumulated experience of 4 years of operation of the seismological radiotelemetric test area for the automated stations demonstrated a number of theoretical advantages of such systems. They include the following:

a) Operativeness; data on earthquakes (direction of the source for distant earthquakes and position of the center for nearby earthquakes) can be determined a few minutes after arrival of the first wave;

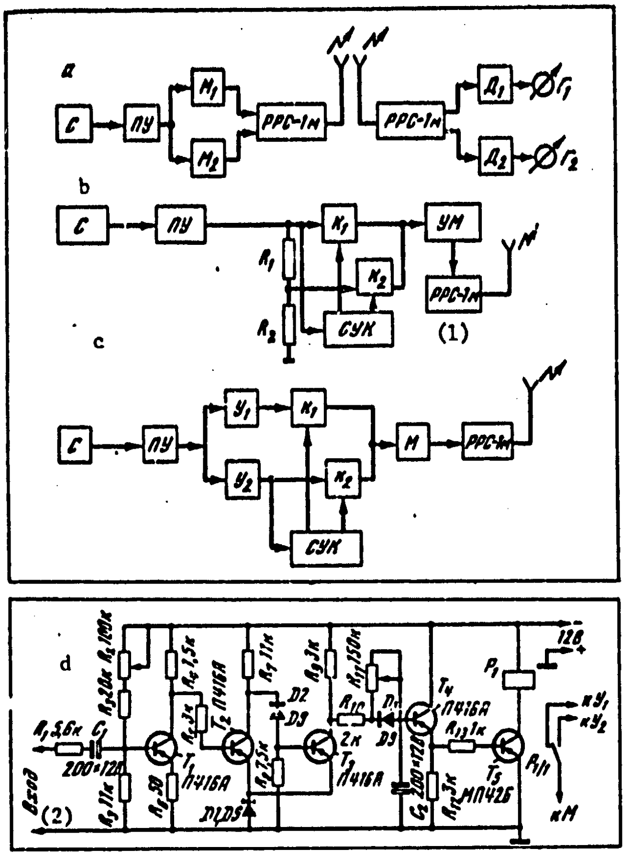

Figure 33. Block diagram of the two-channel two-level recording (a), stepped automatic gain control with respect to one channel (b), automatic gain control with the common modulator and separate amplifiers (c) and a schematic diagram of the switch control (d).
С -- seismograph; ПУ -- preamplifier; М -- modulator; У -- amplifier; УМ -- amplifier-modulator; СУК -- switch control circuit; Д --demodulator; K_1, K_2 -- switches; Г -- galvanometer

Key:
1. RRS-1M
2. input

b) High precision of all constructions as a result of a united time service and high scanning speed of the oscillograms obtained by the slaved recording system;

c) Economicalness of operation and maintenance. The stations operate in the automatic mode, and the entire test area is serviced by three coworkers.

The improved equipment and the developed procedures and techniques for multichannel stationary radiotelemetric information transmission on satisfaction of the required conditions of stability of radio communications and reliability of the power supply can be used as the basis for area observation systems. Nevertheless, it appears expedient to improve the equipment further in order to:

a) Increase the dynamic range of the recording;

b) Multiplex the communications channels for transmission of the signals of the tricomponent seismometer setup over one radio channel;

c) Increase the noiseproofness of the system;

d) Improve the slaved recording system for remote earthquakes for regional research;

e) Develop economical receiving and transmitting units which insure autonomous station records in the absence of an AC network.

CHAPTER IV. FIELD DATA AND PROCESSING PROCEDURE

The observations in the radiotelemetric test areas with automatic stations are beginning to be used at the present time in different seismological research [61-63]. The experience and the results of 4 years of operation of the Alma-Ata test area is of procedural interest in this connection.

In spite of the fact that the study of the seismicity of Northern Tyan'-Shan' has been the subject of many studies [9, 12, 26, 30, 47], the activity of the local section of Alma-Ata and its environs has been inadequately studied. This is explained to a great extent by the quiet of the seismic activity characteristic of recent years in a given area. The deep-well seismology and radiotelemetric recording system have opened up theoretically new possibilities of discovering and studying weak local earthquakes. The observations of local earthquakes (the values of t_{S-P} at the Talgar station do not exceed 10 seconds) are providing new information on the peculiarities of the seismic characteristics of a territory of more than 18,000 km^2 with Alma-Ata at the center.

§1. Operation of the Test Area and Characteristics of the Data Obtained

Station Operating Times and Characteristics. In the creation of the Alma-Ata radiotelemetric test area of automated high-frequency stations it is possible to distinguish two stages. The first stage is connected with the introduction of two automated stations in September 1971 -- the Alma-Ata deep-well station and the Talgar ground surface station. The second stage begins in March 1972, and it is connected with the introduction of the third Ozero ground surface automatic station. Since that time, which is taken as the beginning of operation of the test area, the Talgar, Alma-Ata and Ozero stations have in practice operated continuously. In this paper a study is made of the observation data obtained up to June 1976. During this time all three stations operated simultaneously for about 1500 days. From the end of May 1973 the fourth automatic well station of the Ali test area began operations. The signals from these stations were recorded continuously on a display seismogram, and they were recorded by a slaved recording system on magnetic tape (beginning in July 1973). The centralized recording data of the four automated stations were the basic initial data for studying the seismic characteristics.

Table 7

(1) Станция	Сроки работы (2)		Длительность регистрации (5)		Продолжительность одновременной работы трех и более станций (8)	
	Число, месяц, год (3)	Число дней (4)	Число дней (6)	% от календарных дней работы (7)	Число дней (9)	% от дней регистрации (10)
(11) Алма-Ата	(18) С 31.VIII.71 (19) до 1.VII.76	1766	1620	92	1417	87
(12) Талгар	(18) С 22.IX.71 (19) до 1.VII.76	1744	1663	95	1484	89
(13) Озеро	(18) С 10.III.72 (19) до 1.VIII.76	1574'	1467	93	1448	99
(14) Али	С 24.V.73 до 1.VII.76	1134	1067	94	1067	100
Ново-Алексеевская (15)	С 28.III.72 до 6.VII.72 и с 6.II.75 до 1.VII.76	611	555	91	-	-
(16) Плато	С 19.VII.72 до 10.IX.72	53	34	-	-	-
(17) Курты	С 25.IX.72 до 31.I.73	128	82	-	-	-

Key:

1. station	11. Alma-Ata
2. operating time	12. Talgar
3. date, month, year	13. Ozero
4. No of days	14. Ali
5. recording time	15. Novo-Alekseyevskaya
6. No of days	16. Plato
7. % of the calendar work days	17. Kurty
8. time of simultaneous operation of 3 or more stations	18. from
9. No of days	19. to
10. % of recording days	

The observations at the Novo-Alekseyevskaya central recording station in the well and on the surface were of an experimental nature. The temporary mobile stations, Plato and Kurty, functioned for a short period of time: the former, for a month, and the latter, about 3 months. They were used to test various observation conditions.

The information on the operating times of the different stations and the recording times of each of them are presented in Table 7. It is indicated there how many days each of the stations made recordings simultaneously with two or more stations of the system. The recordings of no less than three stations are required to construct an earthquake epicenter and determine the depth of the center.

From the table it is obvious that the recording time on each of the reference stations was no less than 92% of the total number of calendar work days.

The quality of the recordings was good on the whole although at the different stations of the test area it differs somewhat. The Ozero station is characterized by better quality of recordings, for it has maximum sensitivity and is closest of all to the regions with increased density of the epicenters. More than 15% of all of the earthquakes are recorded only by it and not by other stations of the system. The Talgar and Ali stations which are similar with respect to sensitivity are characterized by identical recordings with respect to quality which are somewhat inferior to the Ozero station. During the daytime the Alma-Ata station has the lowest sensitivity. This is connected with the fact that even at a depth of 1000 meters here the vital activity of the large city does not stop being felt. At nighttime the recordings of this station are comparable with the recordings of the Talgar and Ali stations. The increased noise background level at the Alma-Ata station frequently leads to a reduction in accuracy of noting the time of arrival of the P-waves on the recordings of weak local earthquakes.

Examples of the display seismograms of local, nearby and distant earthquakes recorded by the basic stations of the test area are shown in Fig 34 (see also §5).

Local Earthquake Recording Data. During 4 years of operation of the test area, the automatic stations recorded more than 18,500 earthquakes -- distant, nearby and local. Inasmuch as the main problem was to study the seismic characteristics of the local area -- the vicinity of Alma-Ata, primary attention was given to recording earthquakes with $t_{S-P} \leq 10$ seconds which we shall provisionally call local earthquakes hereafter. In Table 8 data are presented from the recordings of all of the stations with $t_{S-P} \leq 10$ seconds illustrating the operation of the radiotelemetric system along with information on the local earthquakes.

In order to characterize the operation of the RTS, the Talgar seismological station which is equipped with standard equipment and operates stably in practice without interruptions of recording was selected as the control. If we take the number of earthquakes recorded by the Talgar station as 100%, then, as is obvious from Table 8, the first 2 years (1972-1973) the system recorded 92-98% of the local signals (earthquakes and explosions). In subsequent years (1974 and 1975) this index rose to 112-124%.

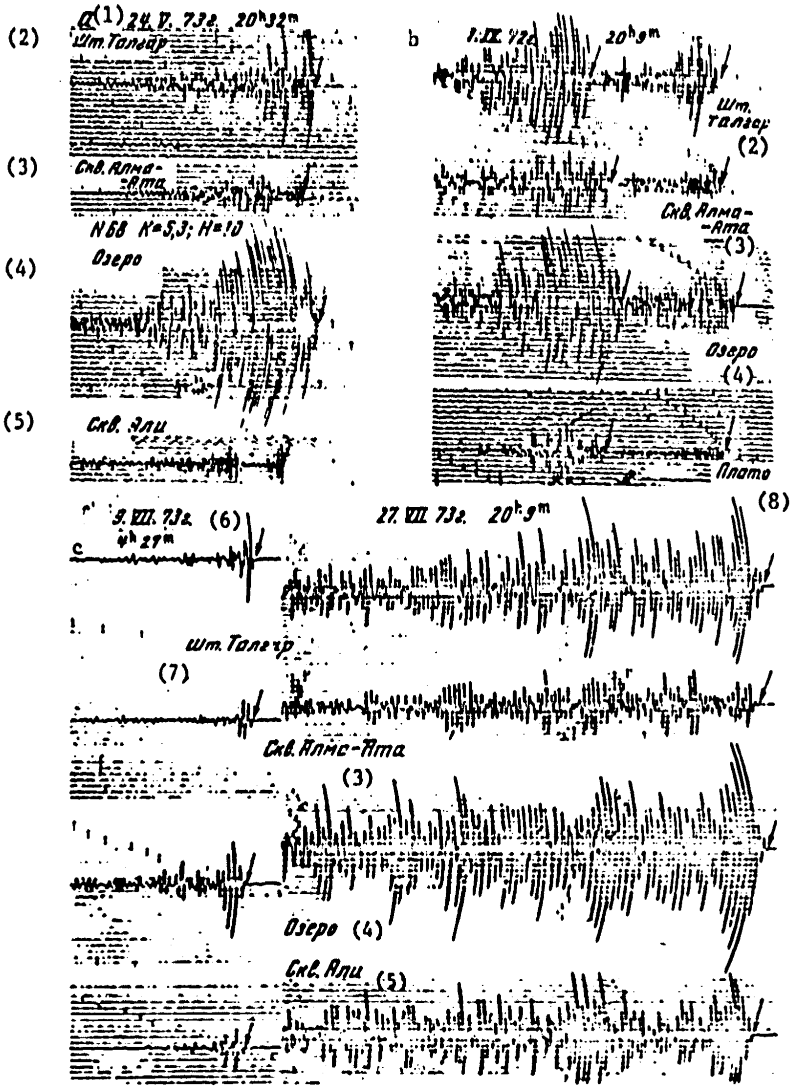

Figure 34. Examples of recordings by the test area stations of local (a), nearby (b) and distant (c) earthquakes

Key:

1. 24 May 1973; 2. Talgar drift; 3. Alma-Ata well; 4. Ozero;
5. Ali well; 6. 3 July 1973; 7. Talgar drift; 8. Plato.

Table 8

Станция или система (1)	Признак группы (2)	(3) Количество сигналов (4) июнь-декабрь 1972 г.	1973 г.	1974 г.	1975 г.	(5) январь - июнь 1976 г.	(6) июнь 1972 г. -июнь 1976 г.
			(7) Землетрясение и взрыв				
(8) Талгар	(9) Зарегистрировано	86/100	215/100	277/100	227/100	100/100	905/100
	(10) Пропущено	6/7	42/19,5	59/21,3	67/29,6	14/14	188/20,8
РТС (11)	(9) Зарегистрировано	79/91,8	210/97,7	309/111,5	281/123,7	99/99	978/108
	(10) Пропущено	4/4,7	3/1,4	6/2,2	12/5,3	15/15	40/4,4
	(12) Пропущено в период наладки	9/10,5	34/15,8	1/0,4	1/0,4	0/0	45/5
Озеро (13)	Зарегистрировано только этой станцией (14)	4/4,7	35/16,3	46/16,6	43/19	10/10	138/17,5
СЖР (15)	Записано с июня 1973 г. (16)	-	35/-	120/46,6	113/49,7	19/19	29[illegible]/32,7
			Взрыв (23)				
(17) РТС	Медео (18)	10/11,7	35/16,3	64/23,1	80/35,3	22/22	211/23,4
	Котур-Булак (19)	5/5,8	8/3,7	7/2,5	11/4,8	4/4	35/3,9
	(20) Капчагай	-	8/3,7	14/5,1	4/1,8	1/1	27/3,0
	(21) Прочие пункты	-	3/1,4	7/2,5	3/1,3	-	13/1,4
	(22) Общее количество	15/17,5	54/25,1	92/33,2	98/43,2	27/27	286/31,7

Key:

1. Station or system
2. Group attribute
3. No of signals
4. June-December 1972
5. January-June 1976
6. June 1972 to June 1976
7. Earthquake and explosion
8. Talgar
9. Recorded
10. Skipped
11. RTS
12. Skipped during adjustment period
13. Ozero
14. Recorded only by this station
15. SzhR
16. Recorded from June 1973
17. RTS
18. Medeo
19. Kotur-Bulak
20. Kapchagay
21. Other stations
22. Total number
23. Explosion

Note. The number of the signals is indicated to the left of the slash, and the percentage of the corresponding number of signals recorded by the Talgar standard station is indicated to the right of the slash.

On the whole, during the entire investigated period the RTS recorded 73 more signals than the Talgar station, The interruptions in operation of the RTS are connected with loss of electric power, thunderstorms, replacement of tapes, preventive maintenance of the equipment, and so on (see Chapter IV). The number of missed recordings as a result of interruption of recording was reduced as operating experience was accumulated from 11-16% in 1972-1973 to 0-0.4% in 1974-1976 with an average of 4.4%.

Table 9

(1) Признак группы	Количество записанных землетрясений и построенных эпицентров (2)					
	июнь–декабрь 1972 г. (3)	1973 г.	1974 г.	1975 г.	январь–июнь 1976 г. (4)	июнь 1972 г.–июнь 1976 г. (5)
(6) Записано РТС						
	64	156	217	183	72	692
(7) Построен эпицентр						
(8) По двум станциям	18	47	35	24	3	127
(9) По трем	21	34	39	31	11	136
(10) По четырем и более	0	8	42	24	14	88
(11) Общее число	39/61	89/57	116/54	79/43,2	28/38,9	351/50,7
(12) Не построен эпицентр						
(13) Слабая запись	19	17	41	57	33	167
(14) Записано одной станцией	5	39	59	44	11	158
(15) Прочие причины	1	11	1	3	0	16
(16) Общее число	25/39	67/43	101/46	104/56,8	44/61,3	341/49,3
(17) Построен эпицентр						
(18) По трем и более станциям регинальной сети Казахстана	9/43	20/48	15/18	-	-	-

Key:

1. Group attribute
2. No of recorded earthquakes and constructed epicenters
3. June-December 1972
4. January-June 1976
5. June 1972 to June 1976
6. Recorded by the RTS
7. Epicenter constructed
8. By two stations
9. By three stations
10. By four or more stations
11. Total number
12. Epicenter not constructed
13. Weak recording
14. Recorded by one station
15. Other causes
16. Total number
17. Epicenter constructed
18. By three or more stations of the Kazakhstan regional network

[see note on following page]

[Note to Table 9, preceding page]:

Note. The percentage of corresponding number of earthquakes recorded by the RTS is indicated to the right of the slash. The percentage is calculated with respect to total number of epicenters constructed by three, four or more of the RTS stations in the last row.

A fifth of the local earthquakes and explosions recorded by the RTS stations are not observed at the Talgar station, and the RTS skipped on the average 4.4% (see Table 8). These are predominantly signals recorded only by one station of the Ozero system, the most sensitive and closest both to the most seismically active region and to the location of the most frequent explosions -- Medeo. One such signal can be seen in Fig 66, a. The automatic stations of the Talgar test area, Alma-Ata and especially Ali hardly recorded this signal at the same time as at Ozero its intensity was limited by the dynamic range of the equipment.

The slaved recording system (SZhR) was put into operation in the middle of 1973, and in the first half of 1976 it was shut down for preventive maintenance; therefore we shall estimate its operation from the point of view of recording local signals in 1974 and 1975. In 1974 the slaved recording system recorded 47% of the total number of all local signals, and in 1975, 50% of the total number of all local signals (explosions and earthquakes) recorded by the RTS. However, if we exclude the recordings of weak local earthquakes and earthquakes recorded only by one station from the total number of local signals in 1974 and 1975, which should not be recorded in accordance with the logic of the slaved system, the precision of local signals recorded by the SZhR on magnetic tape increases on the average to 80% in 2 years. The basic causes of missing signals by the SZhR are the following in order of significance: weak recording -- below the response level of the logic of the system, the "including" or "confirming" stations are not in operation, low quality (warped) magnetic tape, replacement or end of magnetic tape, and so on.

Let us briefly characterize the signals with $t_{S-P} \leq 10$ seconds, the statistics of which are presented in Tables 8 and 9. Out of 978 signals recorded by the RTS in 4 years, the local earthquakes amounted to 692, and the nearby industrial explosions where explosions predominate (about 75%) from the construction site of the dam in the Medeo Canyon amount to 286 (32%). The information on these explosions in the period from 1 June 1972 to 1 July 1976 are presented in the explosion catalog presented in Appendix II.

Out of 692 recordings of local earthquakes it was possible on the average to process only 351 (51%); 224 hypocenters (64%) were constructed by the recordings of three or more stations on the whole, and 127 epicenters were determined by the sections according to the data of two stations (Table 9). With the years, as the operation of the RTS improved (starting up of new stations, increasing their sensitivity, and so on) the number of hypocenters determined by the recordings of three or more stations increases percentagewise to the total number of constructed epicenters. Thus, whereas in 1972-1973 the number of hypocenters was about 50%, in 1974-1976 it was 70 to 90%.

The basic causes for which the epicenters could not be constructed were weak recordings (impossibility of exact reckoning of the time of arrival of the P-wave) and the presence of a recording at only one of the stations of the system.

The earthquake bulletin for which the epicenters were constructed (Appendix I) contains information about the number of stations by which the position of the center was detected. In cases where the data of the stations from the Kazakhstan regional network (Kurmenty and Chilik) were involved in the processing marks are made.

At the end of Table 9 a comparison is presented of the number of epicenters constructed by the recordings of three or more of the RTS stations and the regional network in 1972-1974. The stations in the regional network occupy an advantageous position with respect to the investigated earthquakes inasmuch as the latter are inside the polygon formed by the Kurmenty, Chilik, Ili and Fabrichnaya seismic stations. However, by the regional network data, as a rule, only the earthquakes of higher than seventh to eighth energy classes are processed. Therefore, it is natural that the number of epicenters of local earthquakes constructed by the regional network data does not exceed 50% (and in 1974 only 18%) of the number constructed by the RTS data for which the sixth energy class of the earthquake is represented.

§2. Processing Procedure

The basic advantages of the radiotelemetric recording system are increased accuracy and operativeness of processing of the data. The centralized multichannel recording with a united time service noticeably decreases the errors in reckoning the time of the first and last arrival and it increases the reliability of generation of useful signals. The united time service permits determination of the coordinates of the local and nearby earthquakes and also the azimuths of the direction of the epicenters for distant earthquakes by the time difference of arrival of the first waves at the system stations. In connection with the exclusion of errors of the time service for each station, the accuracy of reckoning the difference in time of arrival on the display recordings is ±0.2-0.3 seconds, and for the oscillographic copies from the magnetic tapes ±0,03-0,05 sec, which gives rise to the high accuracy of all of the subsequent constructions.

In many cases during operative processing it is very important to determine the direction of the center in time. The qualitative determination of the direction of the epicenter within the limits of the sections can be made simply by the display seismogram, using the sequence of arrivals of the first wave at the different stations. For this purpose it is convenient to use a template (see Fig 35). The direction sector in the outer circle is determined by the station for which the time of arrival of the P-wave is minimal. The narrower sector of the inside circle is determined by the station where the P wave arrives second. The location of the stations in the test area insures a large amount of detail in determining the azimuths of the eastern and southeastern directions and less detail in the southern and southwestern directions.

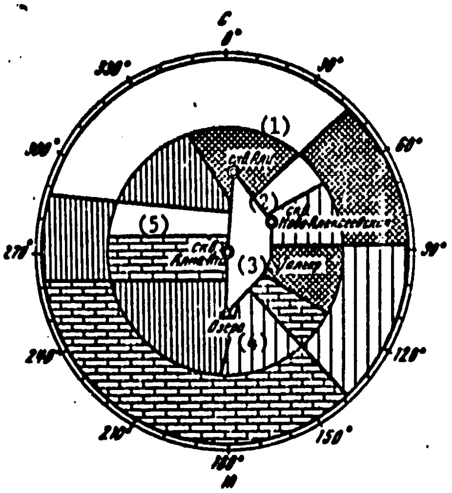

Figure 35. Template for determining the direction sector to the epicenter by the sequence of arrival of the first wave at the test area stations

Key:

1. Ali Well
2. Novo-Alekseyevskaya Well
3. Talgar
4. Ozero
5. Alma-Ata Well

In the quantitative processing we have limited ourselves to investigation of local earthquakes with a value of t_{S-P} not exceeding 10 seconds (for the Talgar station), thus outlining the investigated territory by the circle with its center at the Talgar station 77 km in radius with an area of more than 18,000 km^2.

As is known, for such small epicentral distances the difference in times of arrival of the longitudinal and transverse waves is reliably determined. This parameter was used when finding the coordinates of the center, but it is necessary to know the fictitious velocity in this case.

Determination of the Fictitious Velocity $V_f = V_p V_S/(V_p - V_S)$.

The velocity ratio of the longitudinal and transverse waves was determined by the direct P-S waves of local and near earthquakes recorded by the stations of the test area. The radiotelemetric multichannel recording insured high accuracy of determining the time difference of arrivals of the P and the S waves on the station recordings; 140 earthquakes were selected, in the first arrivals of which the direct wave was recorded (t_{S-P}<25 seconds) with clear arrivals of the direct P and S waves. By the time difference of arrivals of the P and S waves for three pairs of stations the relation was constructed for the difference Δt_S as a function of Δt_P (a total of 280 points, Fig 36). In order to designate the directions of the approach of the waves in Fig 36 on the bottom right the regions of positive and negative values of Δt are indicated schematically for three pairs of stations. The relations for the velocity ratio V_P/V_S as a function of the direction of approach of the waves was not discovered. As is obvious from the graph, the dispersion of the values of Δt with respect to the display seismograms (the empty symbols) near the averaging line is ±0.5 seconds, and the dispersion of the values of Δt by the oscillograms of the slaved recording system (the dark symbols) is reduced to ±0.2 seconds. The dispersion of the experimental points exceeds the accuracy of determination of Δt which can be explained by the possible errors in determining the time of arrival of the S-waves by the recordings of the vertical seismographs.

By the slope of the graph of $\Delta t_S/\Delta t_P$, the velocity ratio $V_P/V_S = \Delta t_S/\Delta t_P = 1.767$ and the propagation rate of the fictitious waves $V_f = V_P/(V_P/V_S - 1) = 7.7$ km/sec were determined.

The velocity of the longitudinal waves $V_P = 5.9$ km/sec was taken by the regional hodograph compiled by the data on the earthquakes [30, 31]; it agrees with the deep seismic sounding data [25].

Determination of the Position of the Hypocenters. When processing the materials in the different stages, various methods of constructing the hypocenters were tested and used.

Nomogram Procedure. In the first processing phase, nomograms proposed by V. G. Katrenko for the Tashkent radiotelemetric test area [38] were used to define the epicenters. Only the times of arrival of the longitudinal waves reckoned with high accuracy and insuring operativeness of the processing are used for thd construction.

The nomograms are a family of isolines of the epicentral distances R calculated for fixed depths of the center H and constructed in the coordinates of the differences in time of arrival of the P-waves at three pairs of stations. Each isoline is calculated for a specific epicentral distance and direction azimuths to the epicenter varying from 0 to 360°.

The maximum accuracy (±1-2 km) is achieved when determining the coordinates of the centers of local earthquakes located within the area of the circle with a diameter of approximately twice the average distance between the test area stations. With an increase in epicentral distance the accuracy falls off.

The nomograms are constructed in polar coordinates, for the center of which the Alma-Ata station was first selected, but since the accuracy of determining the arrival of the P-waves was not always sufficiently high as a result of the high background noise, later the Talgar station was taken as the center of the system. The nomograms were calculated on the Mir-1 computer. An example of one of them with the Alma-Ata station as the center is presented in Fig 37. The nomograms were constructed for different pairs of stations. The best pair with respect to resolution of the isolines in the direction of the epicenter is selected for processing. In the case of a 5-km step size with respect to depth in the interval of H from 0 to 25 km it is necessary to select 12 nomograms (with one center) to process the data of four stations. This is a deficiency of the investigated method, and it pertains to the local earthquakes. For earthquakes with R>60 km the parameter H is excluded, and the number of nomograms is reduced to three. For earthquakes with R>200 km the group ceases to operate for determination of R and only one nomogram is sufficient to determine the azimuth at the epicenter (see Fig 90).

In addition to inconvenience of selecting a large number of nomograms, their deficiency is low accuracy of determining the depth of the center H. For the possibility of increasing the accuracy of determining the hypocenters which are inherent in the radiotelemetric multichannel recording, the selection step size for the depths of 5 km is too large, and decreasing the step requires additional nomograms. This is not justified, for the accuracy of determining H quickly decreases with an increase in the epicentral distance (Fig 38). At R>20 km from the central stations (Alma-Ata or Talgar) the resolution with respect to depth is low, and for R=30 km it is in practice zero. At the same time under the conditions of the Alma-Ata test area for the majority of the observed centers the epicentral distances from the Alma-Ata and Talgar stations are more than 30 km.

In the nomogram procedure only the P waves are used. Exclusion of the S waves from the investigation, the arrivals of which usually are clear on the recordings of the local earthquakes eliminates additional information which permits control of the convergence of all of the data and the exclusion of gross errors. Therefore the nomograms were used to determine the position of the industrial explosions (H=0) and for operative approximate determination of the coordinates of the epicenters.

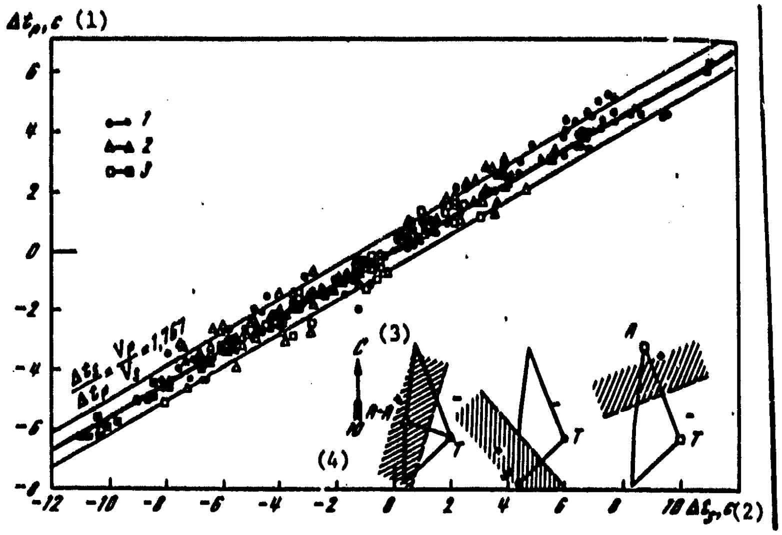

Figure 36. Difference in time of arrival of the S-waves (Δt_S) at two stations as a function of the difference in the time of arrival of the P-waves (Δt_P) according to the data on the local and nearby earthquakes for three pairs of stations.
1 -- Ozero-Talgar, 2 -- Alma-Ata-Talgar, 3 -- Ali-Talgar.
The light symbols are in accordance with the display recordings, and the dark symbols, by the slaved recording seismograms.

Key:

1. Δt_P, seconds
2. Δt_S, seconds
3. north
4. south

The divergence with the data of other methods when determining the epicenters by the nomograms is explained by neglecting the spatial position of the system stations; for simplicity hereafter we shall say "neglecting the day surface relief."

Isikawa Procedure. It turned out that the determination of the positions of the centers by the Isikawa procedure [4] using the fictitious velocity V_f gives large errors. The determinations made by different triplets of stations gave error triangles with 10 km sides and more. The depths of the centers were also found to be different. Examples of such constructions are shown in Fig 39. For example, let us consider the construction of the epicenter of earthquake No 124. Three positions of the epicenters 5 to 6 km from each other were determined by the Isikawa procedure with respect to three triangles of stations Alma-Ata-Ozero-Talgar, Ali-Alma-Ata-Talgar, Ali-Ozero-Talgar. The depths at the points of intersection of the chords are different, and for the different station triangles they are 16, 20 and 22 km respectively. The observed construction errors, as analysis has shown, were basically caused by neglecting the different altitudes of the observation points.

Actually, the difference in absolute altitudes for the test area stations exceeds 3000 meters: the Ozero station is located high in the mountains with an altitude of 3000 meters, the Alma-Ata station is in the plains, and its seismometer is submerged in a well to a depth of 1000 meters. In addition, the seismogeological conditions are different for the stations. The Ozero and Talgar stations are on bedrock. At the Ali station there are 50 meters of sediment between the seismometer and the roofs of the basement. Under the seismometer of the Alma-Ata station there are 3200 m of sedimentary rock. All of this led to the necessity for selecting a single reduction level. The depth of the basement under the Alma-Ata station -- 4200 meters under the day surface -- was taken as this level. The diagram of how the stations differed with respect to elevation relative to each other and above sea level and also the position of the reduction level are indicated in Fig 41, a.

Time Field Method. The necessity for introducing time corrections for the relief gave rise to expediency of constructing the epicenters by the time field method. In order to recalculate the observed times for the P-wave to reach the reduction level it is sufficient to take cross sections of the time field by the horizontal planes at depths equal to the amounts the stations are above the reduction level and to take them as the zero depth levels. For the different stations the depth of these levels is different. For the Ozero station it is 6360 meters if we consider that the time field is constructed with the center at the point where the depth is equal to zero; for the Talgar station it is 4600 meters, for the Ali station it is 3500 meters, for Alma-Ata it is 3240 meters. The only time field of the P wave, just as for the uniform medium with $V_P=5.9$ km/sec was constructed for the first three stations. For the Alma-Ata station the time field was constructed for a two-layer horizontal-stratified medium: the sedimentary series 4.2 km thick with $V_P=4.0$ km/sec and the halfspace -$V_P=5.9$ km/sec.

Further operations to determine the position of the centers using the time fields were of a standard nature [8, 52]. Examples of these determinations can be seen in Fig 40.

Let us consider the determination of the hypocenter of earthquake No 203 by the time field method with and without consideration of the relief by the four stations (Fig 40, a). The epicenters turned out to be close, 2 km from each other, and the depths of the centers, 14 and 20 km respectively. However, in the first case 14 km was reckoned from the reduction level, and in the second case, from a day surface, the elevation of which is unknown. Reducing the depth by 6 km (14 instead of 20 km) increases the error triangle by 10-15 times. Thus, the radiotelemetric recording made it possible to raise the accuracy of determining the depths at distances not exceeding 30 km to the nearest station to ±1-2 km which led to the necessity for considering the spatial position of the stations.

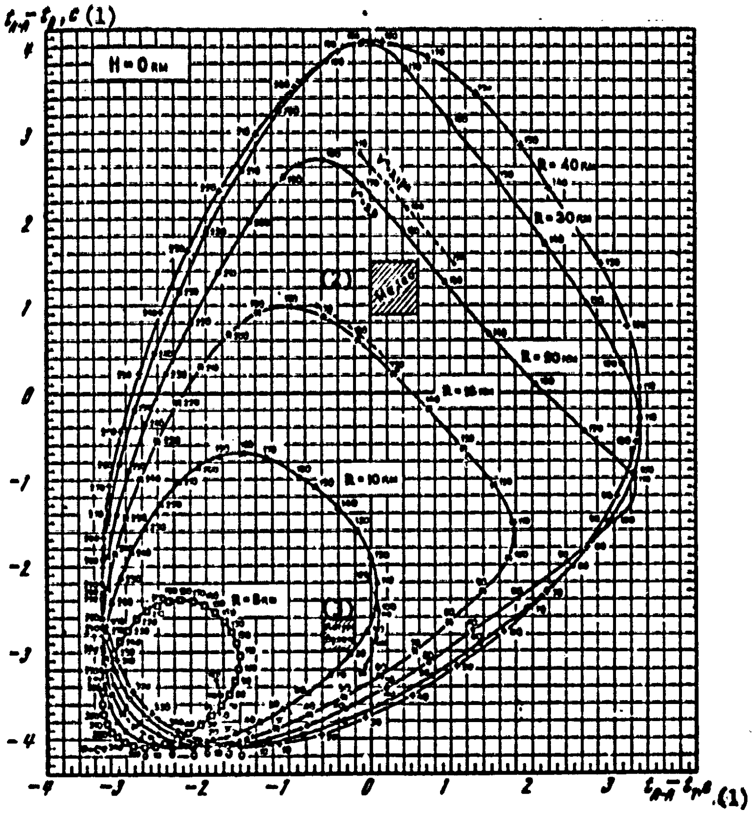

Figure 37. Nomogram for determining the position of the epicenters The differences in time of arrival of the direct longitudinal waves at different pairs of stations are plotted on the axes. The isoline parameter R is the distance from the epicenter to the Alma-Ata station. The numbers of the isolines are the azimuths of the epicenters.

Key:

1. seconds
2. Medeo
3. Kotur-Bulak

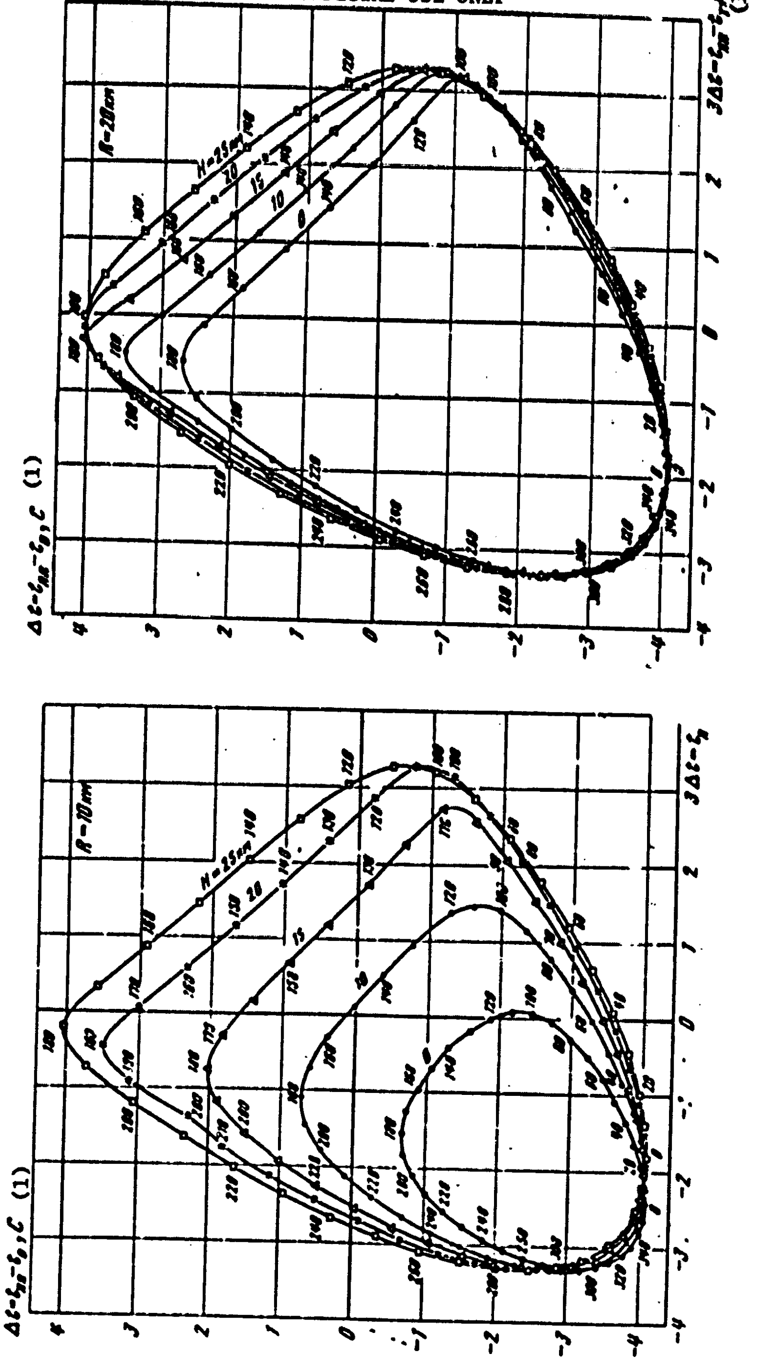
Δε-ε_ms-ε_0, C (1)
3Δε-ε_ms-ε_f (1)
R=20 km
H=25 km
20
15
10
0
4
3
2
1
0
-1
-2
-3
-4
Δε-ε_ms-ε_0, C (1)
3Δε-ε_n
R=10 km
H=25 km
20
15
10

Figure 38

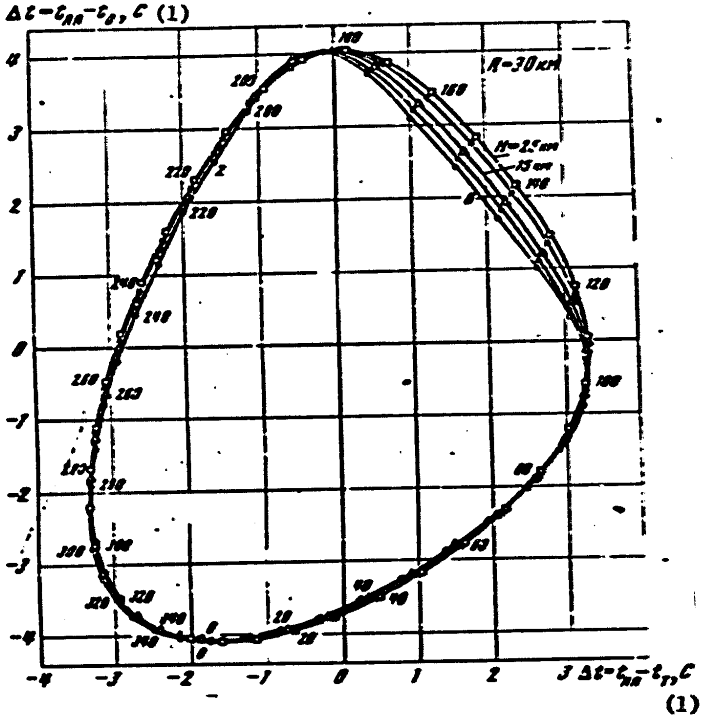

Figure 38. Nomograms for the three epicentral distances R

Key:
1. seconds

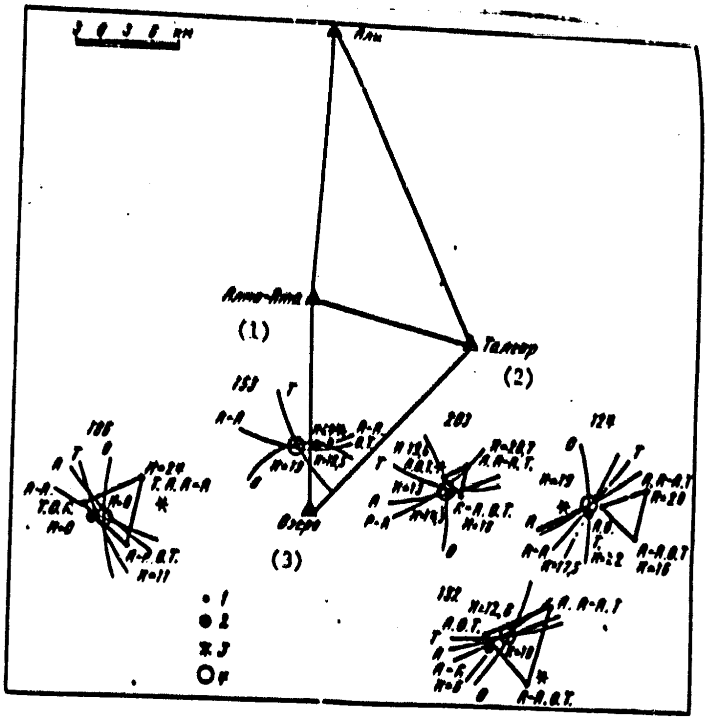

Figure 39. Determination of the earthquake epicenters by the Isikawa procedure without considering relief (1) and with introduction of a correction for the relief (2), by the nomograms (3) and by the time field method considering relief (4)

Key:

1. Alma-At⁄a
2. Talgar
3. Ozero

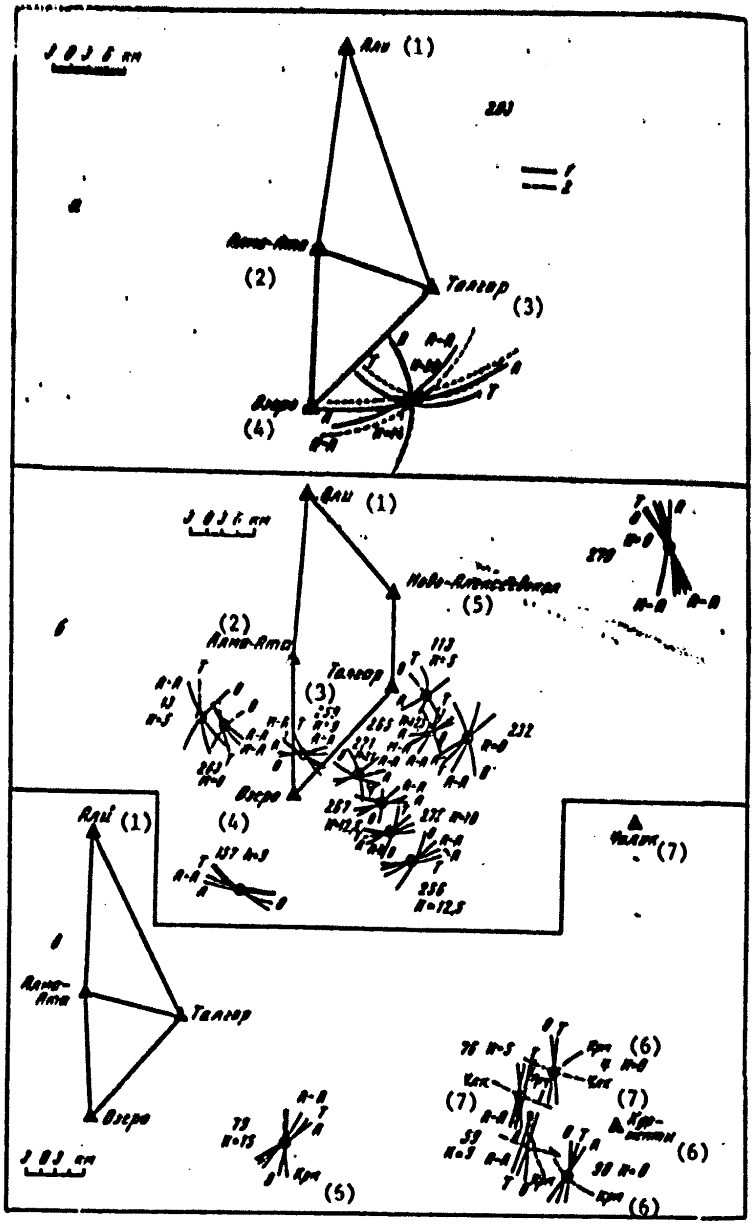

Figure 40. Determination of the earthquake epicenters by the time field method
[See following page for legend and key]

[Legend and key to Figure 40, preceding page]:

a -- considering (1) and without considering relief (2); b -- according to the data of three, four and five stations of the test area; c -- using the data from Chilik and the Kurmenty stations

Key:

1. Ali
2. Alma-Ata
3. Talgar
4. Ozero
5. Novo-Alekseyevskaya
6. Kurmenty
7. Chilik

Corrections for Relief. The consideration of the different elevations of the observation points changes the position of the hypocenter determined without consideration of the relief, that is, it leads to a change in the coordinates of the center R, ϕ (in the polar coordinate system) and H. In order to estimate the magnitudes of these corrections under the conditions of the Alma-Ata test area, calculations were made for three station triangles: Talgar-Ozero-Ali, Talgar-Ozero-Alma-Ata, Talgar-Ali-Alma-Ata, four depths -- 0.5, 10, 20 km -- and for 60 points located in the circle 40 km in radius with its center at the Talgar station. On the correction maps (examples are presented in Fig 41, b) the isolines $\Delta R, \Delta\phi$ and ΔH have a complex shape, especially $\Delta\phi$; their configuration varies for different depths and different triplets of stations. For the deep earthquakes ($H \geq 15$-20 km) the corrections changing the position of the epicenter can reach $\Delta R = \pm 3$ km, $\Delta\phi = \pm 15°$ and even exceed them. With a decrease in depth of the earthquake centers these corrections decrease, ΔR becomes no more than ± 1.5 km, and $\Delta\phi = \pm(2$-$5)°$. The corrections for the depths of the centers for all of the earthquakes are identical, and they are within the limits of 0-(-7) km. The introduction of the correction for the relief into the position of the hypocenters determined by the Isikawa procedure by the Talgar-Ozero-Ali station triangle (Fig 39) made them close to the hypocenters found by the time field method. However, in connection with the labor consumption of the processing by this method, the construction of the hypocenters basically was done by the time field method considering relief.

Final Processing Scheme. For earthquakes recorded by no less than three stations, the following sequence of operations was used to determine the position of the center.

1. The search for the hypocentral distance $R_1 = 7,7\ t_{S-P}$ km and the time at the center $T_0 = t_{P_1} - R_1/5.9$ by the recording of the station for which t_{S-P} is determined most reliably.

2. Calculation of the time to get from the center to the remaining stations $T_n = t_{P_n} - T_0$.

3. Selection of the depth of the center corresponding to the intersection of the isochrons with minimum error by the isochron templates or time fields.

The constructions were done on a 1:300000 scale. The values of t_{S-P} were determined with respect to all of the stations; redundant information was used to estimate the internal convergence of all of the determinations.

Only some of the fictitious waves failed to be used, for the value of t_{S-P} is determined by the stations with a different degree of reliability (the application of only the vertical seismograph is fraught with inaccuracies in determining the arrival of the S-waves at the same time as the arrivals of the P-waves are determined more reliably). Examples of construction of hypocenters in different directions from the test area according to the data of three, four and five stations are presented in Fig 40, b. For all of the determinations the intersections of the isochrons are within the limits of the circle (a diameter of 2 km on the scale of the map) designating the epicenter.

For estimation of the accuracy of the constructions, in particular for more remote easterly epicenters, data are presented from the regional network stations of the Kazakh SSR Academy of Sciences, Chilik and Kurmenty. As can be seen in Fig 40, c, the agreement of the data is good; all the isochrons intersect within the circle.

Theoretical calculations to estimate the accuracy of determining the position of the epicenters and the depths of the centers by the described procedure considering the position of the Alma-Ata test area stations were not performed. The experimental estimates of the accuracy of determing the position of the epicenters and the depths of the centers of the basic number of earthquakes (within a radius of 40 km from the Ozero station) give values of ±1-2 km. For the edge earthquakes adjacent to the eastern part of the circle bounding the test area, the accuracy drops to ±3-5 km.

In cases where the earthquake was recorded by only two stations, the position of the center could not be determined by the indicated procedures. However, in order to use these recordings to estimate the seismic characteristics (the number of such earthquakes has reduced with the years, Table 9) the determination of the epicenter was made by the intersection method, the radii of which are equal to the hypocentral distances for each station $R_n=7.7\ t_{S-P}$. For the construction, the intersections of the circles at two points are obtained, the azimuths of which differ by 180°. However, as a result of the actual position of the centers of the earthquakes south of the northern Tyan'-Shan' fracture zone (see Fig 79) it turned out to be possible to exclude one of the two points from the investigation, for it fell in an aseismic territory. If this exception could not be made, the earthquake was not processed. The accuracy of determining the epicenters by two stations is significantly lower, and for small R depends primarily on the depth of center inasmuch as with the described method of construction, the hypocentral distances were identical with the epicentral distances. Therefore, the deeper the center, the more removed the epicenter from its actual position. For small centers located west and south of the test area (see the depths map in Fig 82), the epicenters are determined by two

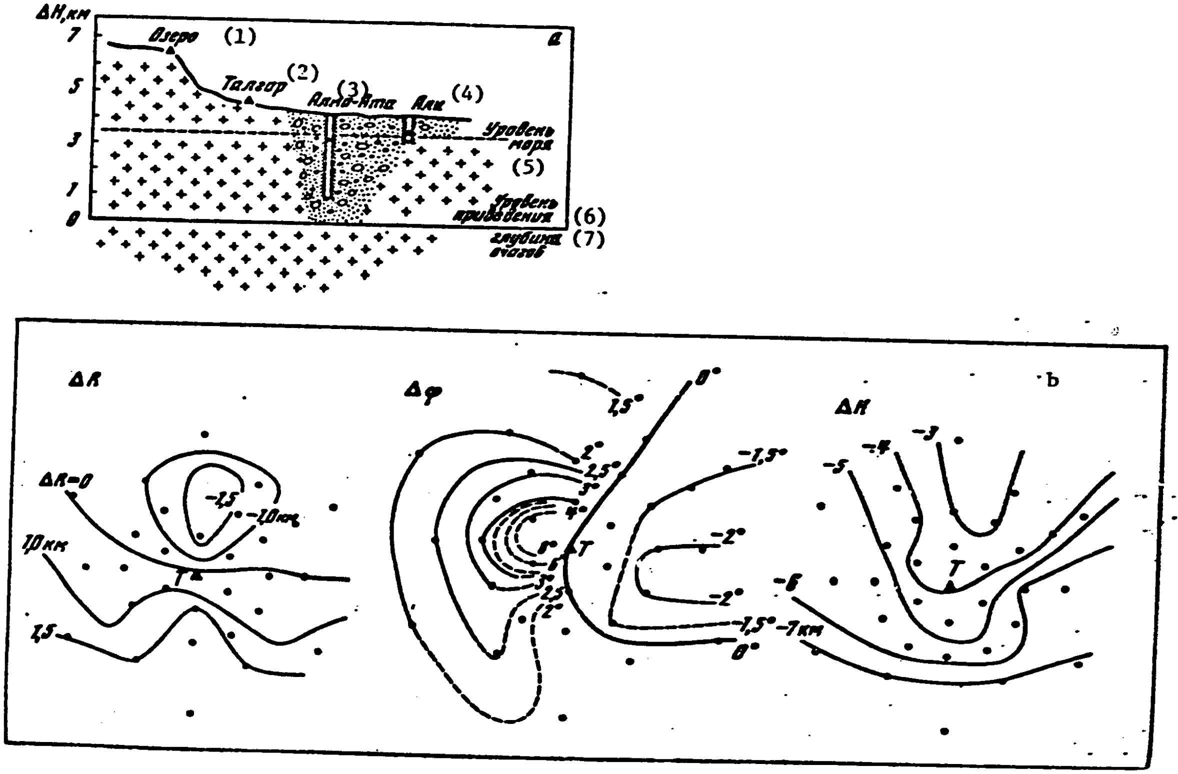

Figure 41. Diagram of the elevation of the stations above the reduction level (a) and maps of the corrections for relief at a depth of center of H=10 km (b) for the Talgar-Ozero-Ali station triangle

Key:

1. Ozero	5. sea level
2. Talgar	6. reduction level
3. Alma-Ata	7. depth of centers
4. Ali	

stations with greater accuracy than for the southeastly deep earthquakes for which the epicentral distances can be 5 to 10 km high. This is quite clear by the summary map of epicenters (see Fig 79). In the southwesterly direction the epicenters found by the two stations are grouped together with the epicenters constructed by three or more stations. In the southeasterly direction the epicenters as a whole are shifted somewhat farther to the southeast with respect to the entire mass of epicenters determined by the three stations.

§3. Energy Classification

The energy classification of earthquakes is of primary significance, for the distribution of the earthquakes in space and time is considered as a function of their energy. The observations at the Alma-Ata test area were made only by vertical seismographs; therefore we used the energy estimates of the earthquakes by the data from the Talgar seismic station where one of the test area stations was located. The accuracy of determining K considering the damping of the seismic energy in the given area is high -- $\delta K=0.2$ to 0.3 [36]. Unfortunately, energy estimates were not available for all of the earthquakes in the bulletin (the high background of Issyk-Kul' microseisms or skipping of recordings at the Talgar station). Therefore in order that the incomplete representativeness of the data not distort the estimate of the recurrence rate of the earthquakes of different energy classes, an effort was made to use the recording time τ of the weak earthquakes for the energy classification.

The correlation between the energy class K and the oscillation time τ was used by numerous authors for different areas [11, 39, 40], and good agreement was indicated with the data from direct determinations of K by the amplitudes of the P and S oscillations. We selected 122 earthquakes recorded by the Talgar station and the stations of the Talgar and Ozero test areas and thus having an energy estimate. The value of K of these earthquakes fell within the range from 4.5 to 10; the majority of the earthquakes are characterized by $K=5.5$ to 8.0. The number of shocks with $K>8.5$ and $K<5.0$ is small, and it amounts to individual cases.

In addition, 79 recordings of explosions from the different areas were taken into account: Medeo (57 recordings), Kotur-Bulak (11), Kapchagay (11). Thus, in all more than 200 recordings were considered.

The recording time was determined from the beginning of the oscillations to the time of merging of the recordings with the microseisms. The data obtained were plotted on a map (see Fig 42), where the value of lg τ in seconds was plotted on the x-axis, and the values of $K=\lg E$ joules were plotted on the y-axis determined at the KSE Talgar station by the energy template for the given area. The observed values of lg τ by the recordings of earthquakes and explosions of the different stations were plotted by different symbols. No separation of the symbols on the graph was observed;

all of the points occupy a quite broad region with explicit tendency toward increase in τ with an increase in K. The dotted lines on the same graph indicate the region of values of τ for Tadzhikistan [40]. Here the dispersion of the points with respect to the K scale is of the same order (about ±2), but the duration of the recordings for the same values of K is approximately twice as large.

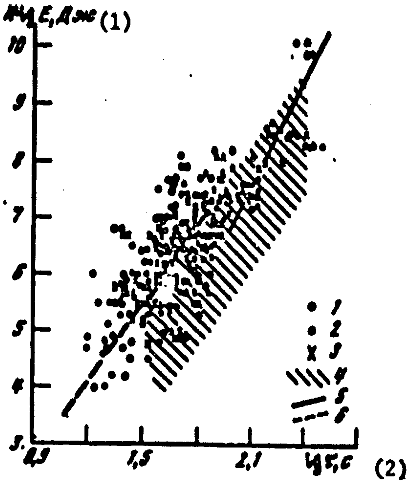

Figure 42. Duration of the recording of local earthquakes and explosions as a function of the energy class K
1, 2 -- by the recordings of earthquakes at the Talgar and Ozero stations respectively; 3 -- by the recordings of explosions; 4 -- the data of R. S. Mikhaylova [40] for Tadzhikistan; 5 -- the data of A. S. Malamuda [39]; 6 -- the line averaging the observed swarm of points

Key:
1. joules
2. seconds

The extrapolation of the graph to the region of small values of K was of interest for the majority of recordings for which there are no energy estimates belong to weak earthquakes. Certain authors [39] propose a linear dependence of τ on K (curve 5 in Fig 42), and others [11], close to linear. We have adopted a linear relation between τ and K, the more so in that the interval of interest for extrapolation to the region of values of K=3,5-5.0 where there are few or no observed points at all is small. The accuracy of determining K for the observed dispersion of the experimental data is low, and it is included within the limits of δK=±1.

The correctness of the averaging of the observed points (in Fig 42, curve 6) was checked by an independent method with respect to the slope of the summary envelopes of the tail section of the seismograms, the so-called C-wave [11]. The individual envelopes of the C-wave A(t) are constructed as a function of the time $t-t_0$ beginning with $t-t_0=(2-4)$ (t_p-t_0), where t_0 is the time at the center, and t is the current time on the seismogram. The general form of the envelopes C(t) is obtained by displacement of the individual graphs A(t) for earthquakes of different energy parallel to the y-axis so that the overlapping sections coincide. As is shown in [11], the value of τ basically determined by the duration of the C-wave and the level A(t) are related by the shape of the envelopes C(t) which, in turn, permits determination of the seismic event M and recalculation of it to K. We have used only the relative slope of the graph C(t) without absolute coordination with the K scale.

The summary envelopes C(t) for four stations of the test area are presented in Fig 43. They are compiled according to recordings of earthquakes and one explosion (Medeo), the data for which are presented in Table 10.

For the Ozero and Talgar stations, low dispersion of the points is observed, and averaging of them causes no difficulties. For the Alma-Ata station, and especially Ali within the time interval of $t-t_0=20-60$ seconds, large dispersion of the points is observed which is caused by buildup of the intensity and the tail section of the recordings, and averaging of them by one line is impossible. (On the graph C(t) for the Ali station the envelope is shown for the explosion in Medeo not inscribed in the law for the earthquakes, see §4).

Thus, judging by our data, the shape of the envelopes C(t) can undergo significant variations obviously in connection with the different station conditions. This must be considered when selecting the material. In reference [11] the stability of the shape of C(t) is discussed for different regions. However, a comparison of the envelopes C(t) for the Talgar and Ozero stations with the data presented in reference [11] indicates their different slopes -- with an increase in $t-t_0$ by an order C(t) for the Talgar and Ozero stations decreases by an order more than in [11].

A comparison of the graph of C(t) for Talgar and Ozero stations with the line averaging the observed points on Fig 42 indicates identical slope of them, which confirms the reliability of the interrelation between τ and K. Using this relation, the energy of the earthquakes for which there were no data for K was estimated by the recordings of the Talgar and Ozero stations. In particular, this energy classification was made for signals recorded only by the Ozero station. It turned out that the predominant values of K for these signals are included within the limits of 3.7-6.5, and the predominant values of $t_{S-P}=1.5$ to 2.8 (Fig 44). The minimum recording time of signals with $t_{S-P}=1.5$ to 2.5 seconds is 13-14 seconds, which corresponds to values of K=3.7 to 3.8. The estimation of the energy of the weakest shock gives a value of K on the order of two.

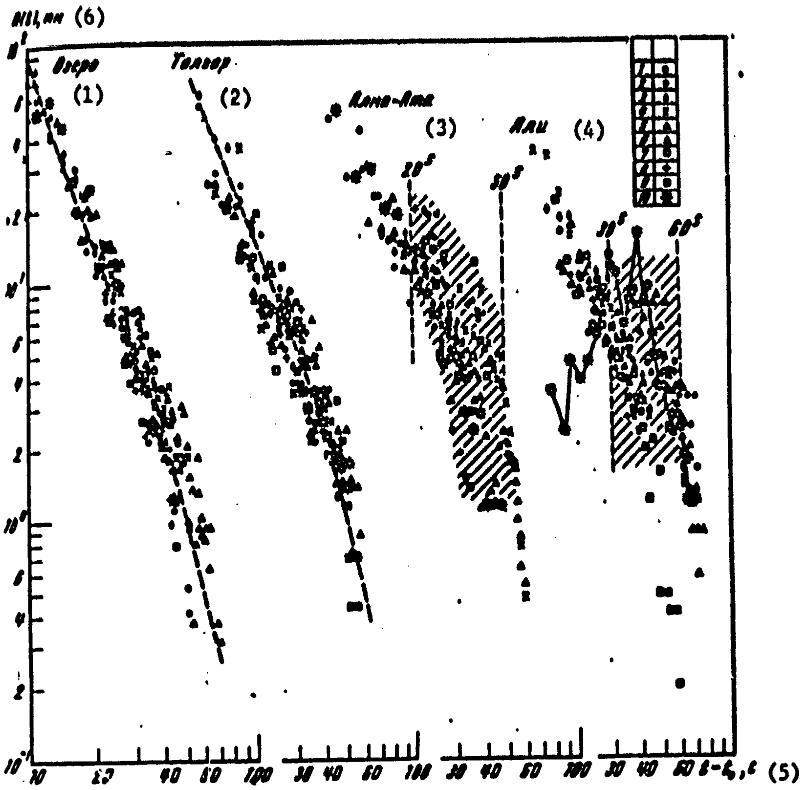

Figure 43. Summary envelopes of the recordings of local earthquakes of different energy classes and an explosion in Medeo

Key:

1. Ozero
2. Talgar
3. Alma-Ata
4. Ali
5. seconds
6. nm

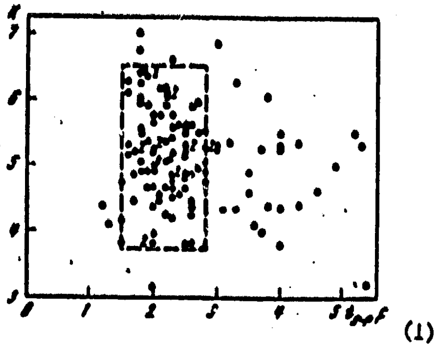

Figure 44. Distribution of earthquakes of different energy classes K recorded only by Ozero station, depending on t_{S-P}. The numbers on the points are the number of coinciding values.

Key:
1. seconds

Table 10

№ п/п (1)	Время, ч, мин (2)	K	Номер** (3)	№ п/п (1)	Время, ч, мин (2)	K	Номер** (3)
1*	19,04	7,2	175	6	9,02	6,1	200
2	3,34	6,8	177	7	8,38	7,7	214
3	22,21	6,8	180	8	2,56	–	229
4	12,01	8,5	187	9	15,29	8,7	240
5	0,27	6,8	197	10	Взрыв в Медео (4)		

Key:
1. Item No
2. Time, hours, minutes
3. Number
4. Explosion in Medeo

*Order numbers of the earthquakes coincide with the numbers of the provisional notation in Fig 42.

**The number on the map of the earthquake epicenters.

§4. Recording of Explosions

Along with the earthquakes, the RTS stations recorded industrial explosions both within the limits of the investigated region (R_T<80 km) and outside it. Information about the explosions was used to estimate the accuracy of the constructions and select the velocities. In connection with the large number of industrial explosions within the territory of the test area, the question arose of the necessity for recognition and exclusion of them from the investigation when studying the seismic characteristics of Alma-Ata.

The recordings of industrial explosions (see Table 8) in the territory of the test area amount to about 30% of all the recordings of local signals ($t_{S-P}(T) \leq 10$ seconds) obtained by the RTS stations. About 75% of all the explosions are in the vicinity of Medeo which is in direct proximity to Alma-Ata (16 km) near which earthquakes are concentrated. Therefore, special attention is given to the analysis of the recording of these explosions.

Location of Industrial Explosions within the Test Area. The locations of the constantly occurring explosions are the construction sites for the Medeo dam southeast of Alma-Ata, the Kotur-Bulak quarry between Alma-Ata and Talgar, the construction site on the west shore of the Kapchagay reservoir. In addition, individual explosions basically are used for construction purposes in different parts of the test area, predominantly in the northern, plains section. The section of the test area map with the regions plotted on it (Medeo and the Kotur-Bulak quarry) and also the epicenters of the individual explosions appears in Fig 45. The data on the explosions -- time, location, energy class K -- can be found in Appendix II.

The determination of the location of nearby explosions was made by the difference in time of arrival of the first longitudinal wave at the test area stations. In order to determine the coordinates of the explosions R and ϕ the nomograms turned out to be convenient for H=0 with the center of the coordinate system at the Talgar and Alma-Ata stations. The position of the Kapchagay explosions removed by 70 to 100 km from the Talgar and Alma-Ata stations was determined by the time field method, for for such distances the accuracy of determining the epicenters by the nomograms decreases significantly.

The differences in time of arrival of the first longitudinal wave at the test area station from the explosions in Medeo and Kotur-Bulak are the most stable. The differences in time of arrival of the waves (in seconds) from the explosions at the Talgar, Alma-Ata stations are presented in Table 11.

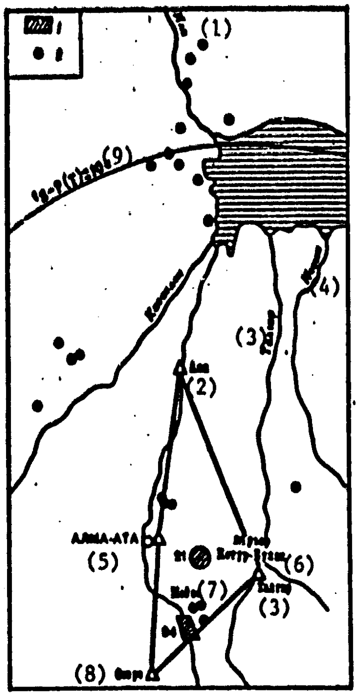

Figure 45. Diagram of the location of the areas (1) and the individual explosions (2) within the test area

Key:

1. Ili
2. Ali
3. Talgar
4. Issyk
5. Alma-Ata
6. Kotur-Bulak quarry
7. Medeo
8. Ozero
9. seconds

Table 11

(1) Место взрыва	$t_T - t_O$	$t_T - t_{A.A}$	$t_T - t_A$	$t_{A.A} - t_O$	$t_{A.A} - t_A$	(2) Погрешность, с
Медео (3)	0,9	−0,3	−5,0	1,2	−4,7	±0,3
Котур-Булак (4)	−2,4	0,4	−3,8	−2,8	−4,2	±0,2

Key:

1. Location of explosion
2. Error, seconds
3. Medeo
4. Kotur-Bulak

The large dispersion of the times of arrival of the waves from the explosions in Medeo by comparison with the explosions in the quarry arises from the fact that the explosions in the vicinity of Medeo were in a large area -- the dam construction site, the construction of roads in Gorel'nik, explosions on the Malaya Alma-Atinka River and in other locations.

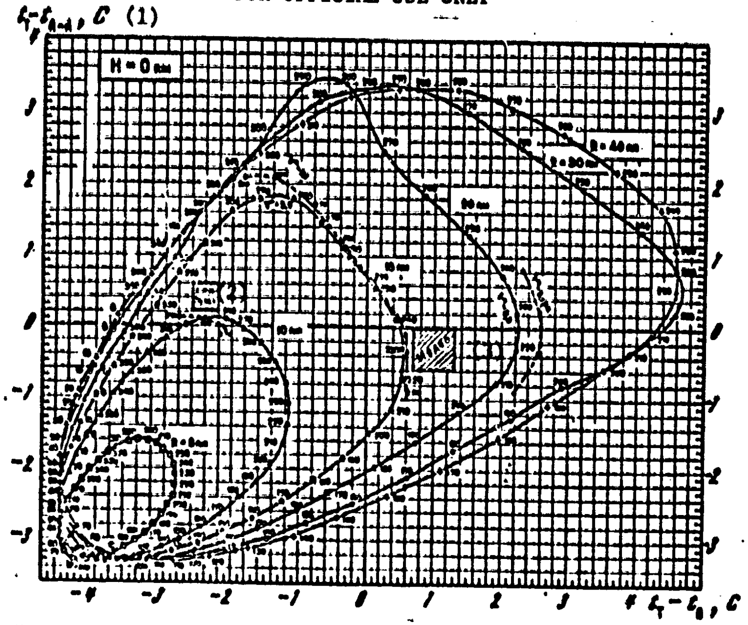

Figure 46. Nomogram for determining the epicenters of explosions. The center of the polar coordinate system is the Talgar station, R are the epicentral distances. The azimuths for the epicenters are indicated on the isolines.

Key:

1. seconds
2. Kotur-Bulak
3. Medeo

The seconds of the nomograms corresponding to the data in Table 11 are crosshatched in Fig 46. The experimental determinations of Δt fall within these rectangles. In the first phase the locations of the explosions were determined by the nomograms calculated for a velocity of V_P=5.9 km/sec. Here deviations from their true position occurred which are explained by the high value of the velocity. The calculation of the nomograms with a velocity of V_P=5.1 km/sec characteristic of a distance of 11-16 km (the dotted lines in Fig 46) made it possible to increase the accuracy of determining the location of the explosion. The positions of the areas corresponding to the sections crosshatched on the nomograms are indicated on the map in Fig 45 also by crosshatching. They coincide with the actual position of the explosions. In the indicated areas there are 94 explosions in Medeo and 21 explosions at the Kotur-Bulak quarry respectively. The recording and processing of the explosions made it possible to check and confirm the high accuracy of determining the time delays characteristic of the multichannel radiotelemetric recording and determining the accuracy of all subsequent constructions. The explosions in the quarry are the most indicative. The diameter of the circle in Fig 45 in which all of the repeated determinations fall does not exceed 1.0 km on the scale of the map.

Characteristic Features of Recordings of Explosions from Different Areas. In order to find the criteria of the difference in the recordings of the explosions from the recordings of earthquakes, the analysis of the explosion recordings, especially at places where weak local earthquakes occur has primary significance.

Explosions from the Medeo Area. These explosions were recorded during the entire time of operation of the radiotelemetric system (1972-1976). In all, 211 recordings of explosions were obtained not considering the unrecognized signals, for example, recorded by only one station, Ozero located close to Medeo. The largest number of explosions, 64 and 80, were recorded in 1974-1975. It is interesting that as a result of determination of a large number of seismograms and finding the defined criteria for recognition of explosions many of the recordings obtained before the beginning of operation of the RTS (in 1968-1969) which were classified as earthquake recordings turned out to be recordings of explosions. The examples of such recordings by the well station at Alma-Ata and the ground surface station at Talgar can be seen in Fig 47. The recordings are characterized by different shape (two types) and the magnitude of the parameters t_{S-P}. Fig 48 shows recordings of explosions in Medeo by the RTS stations -- display and oscillographic.

Let us compare the recordings between each other and at the different stations. The conditions of the explosions in the vicinity of Medeo are unstable -- the explosions are over a large area in prospecting holes, boreholes and quarries. The minimum charges noticed by the RTS stations are about a half-ton, sometimes 0.3-0.4 tons. The predominant values of K which were estimated in Talgar station by the recordings of the explosions, just as by the recordings of earthquakes are 5-8. The dependence of K on the size of the charge can be seen in Fig 49.

The shape of the recording of explosions at different locations -- at the dam, on the Medeo-Gorel'nik road, and so on -- is different, which can be seen from Figures 47 and 48. However, there are several characteristic, more stable types of recordings (Fig 48, a).

Let us compare the recordings of the different stations. The most intense recording is observed at the Ozero station as the nearest to the source, and the weakest, at the Ali station, the most removed. On the whole, the ratio of the recording intensities at the different stations is as follows: $A_O \geq A_T > A_{A-A} = A_{U-A} > A_A$ (Fig 48). The characteristic shape of the recording is observed at the Talgar station. The first longitudinal wave has a specific stable shape here. It is clearly expressed -- two or three extrema, low frequency ($f_P = f_S$) -- it predominates with respect to intensity on the recording or is commensurate with the amplitude of the subsequent oscillations

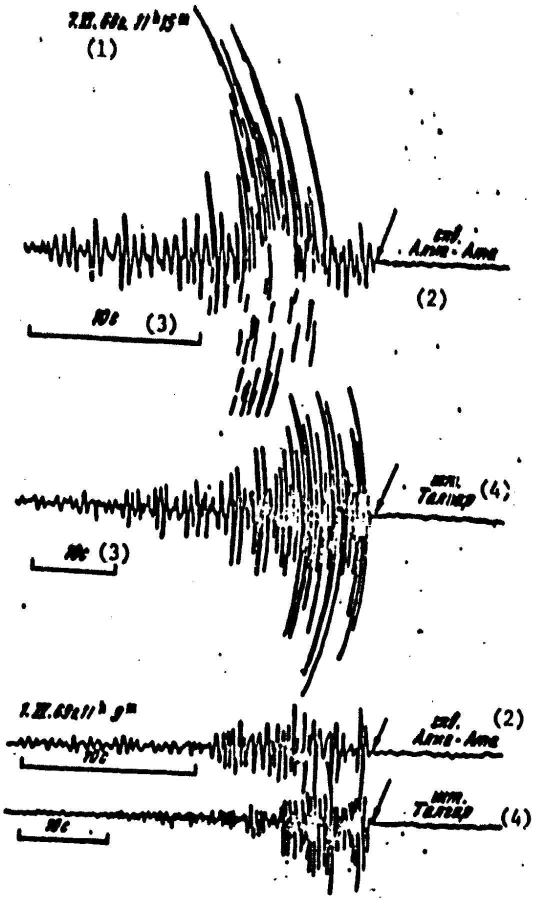

Figure 47. Recordings of explosions in Medeo by the Alma-Ata stations (well) and Talgar (drift) in 1968-1969.

Key:

1. 7 June 1968
2. Alma-Ata well
3. 10 seconds
4. Talgar drift

at the same time as at other stations — Ozero, Alma-Ata — most frequently $A_P < A_S$ and $f_P > f_S$, that is, the longitudinal wave is higher frequency, its shape is complex, unexpressed and unstable (Fig 48, b).

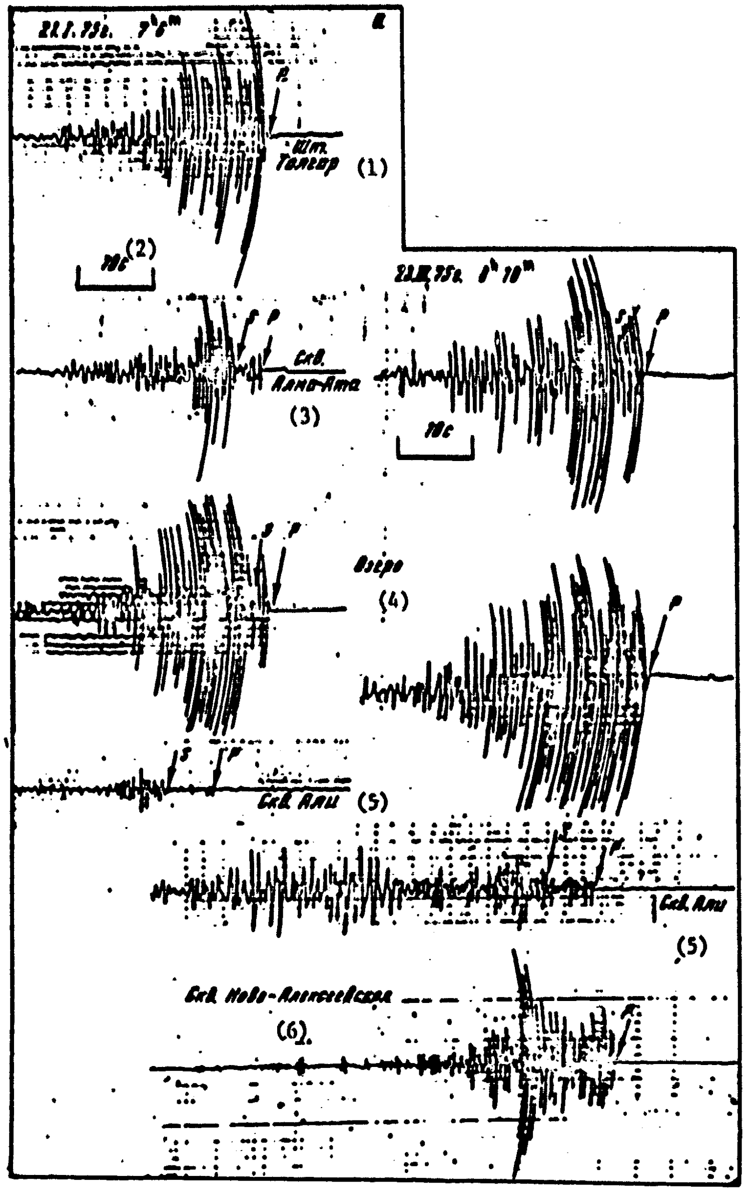

Figure 48. Display seismograms (a) and slaved recording seismograms (b) of explosions in Medeo

Key:

1. Talgar drift; 2. 10 seconds; 3. Alma-Ata well. 4. Ozero; 5. Ali well; 6. Novo-Alekseyevskaya well.

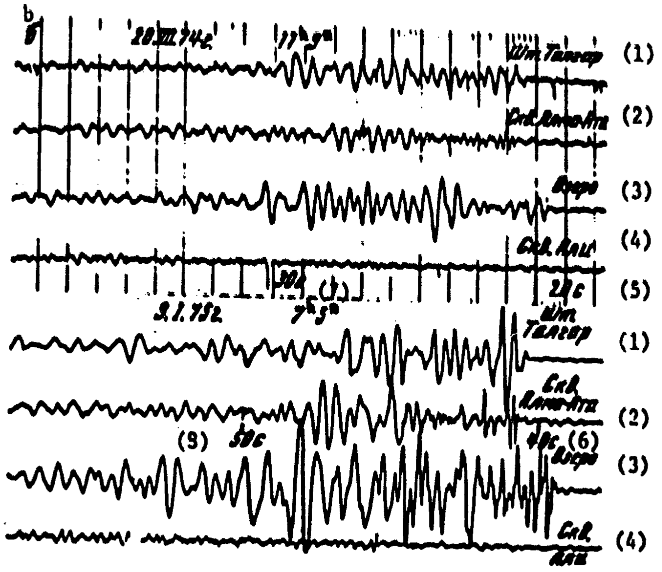

Figure 48, b (continued)

Key:

1. Talgar drift
2. Alma-Ata well
3. Ozero
4. Ali well
5. 20 seconds
6. 40 seconds
7. 30 seconds
8. 50 seconds

Another characteristic feature of the recording is observed at the Ali station where 20 to 30 seconds after the first arrivals an intense low-frequency train of surface waves is recorded frequently predominant with respect to intensity over the anomalously high-frequency initial part of the recording (including the P and S waves, Fig 48, a). No such "tails" are observed at the recordings of other stations, and the amplitude decreases sharply with an increase in recording time t. An analogous characteristic, but less clearly expressed, is observed also on the recordings of earthquakes at the Ali station.

For the explosion recordings an unclear arrival of the transverse wave is characteristic which is most frequently observed at the Talgar station and sometimes at the Ozero station. At the Alma-Ata station the arrival of the S-wave usually is good as a result of the difference in frequency composition and the P and S oscillations.

Explosions in the Kotur-Bulak Quarry. Just as the explosions in Medeo, they are recorded systematically, but much more rarely, on the average 8 to 10 explosions a year (see Table 8 and Appendix II). Here, more frequently than in Medeo, there are large explosions, and the excitation conditions are different. This is reflected in variation of the dependence of K on the weight of the charge (Fig 49). The stability of the excitation conditions and the constancy of the location of the explosions give rise to a stable characteristic shape of the recording. Let us compare it with the different stations.

The examples of recordings of explosions in the Kotur-Bulak quarry are presented in Fig 50. The most intense recordings are observed at the closest Talgar and Alma-Ata stations, and at the rest the amplitudes are comparable. The recording at the Ali station is distinguished by the presence of intense low-frequency oscillations in the tail section 25 seconds after the first arrivals which exceed with respect to amplitude by two times or more all of the preceding oscillations (Fig 50, a). At Ozero station the shape of the recording also has a typical configuration -- the S wave is almost not expressed with respect to intensity and frequency. The transverse wave is poorly isolated at the Talgar and Alma-Ata station, but for a different reason -- the value of t_{S-P} is small, and the intensity of the P-wave is large (Fig 50, a). The P and S waves are separated more reliably as a result of the difference in their frequency composition by the oscillograms of the frequency selection seismic station (Fig 50, b).

Explosions from the Vicinity of Kapchagay. The recordings were started in 1973. There are comparatively few of them (see Table 8). The explosions were in a large area (see Fig 45), and the shape of the recording is unstable. Examples of seismograms are shown in Fig 51.

The maximum intensity of the recording is observed at the Ali station which is closest to the explosions. The arrivals of the S-waves are even. At the remaining stations -- Talgar, Ozero, Alma-Ata -- the recording usually has a characteristic shape which is typical of remote explosions. It is weakly expressed dynamically.

Difference in Recordings of Explosions and Earthquakes. When studying the seismic characteristics of the city, a great deal of attention must be given to the discovery of the criteria for recognizing the explosions in Medeo, for they are in a seismically active region. There are many of them, and unreliable classification of them as earthquakes is fraught with the construction of fictitious centers shifted in the southeasterly direction with respect to Medeo.

Let us formulate the basic criteria for distinguishing the recordings of explosions in Medeo from earthquakes,

The kinematic signs are necessary and of primary significance. These include the values of t_{S-P} and the differences in times of arrival of the waves at the test area stations (see Table 11). In the case where there are insufficient kinematic signs, it is necessary to refer to the dynamic signs.

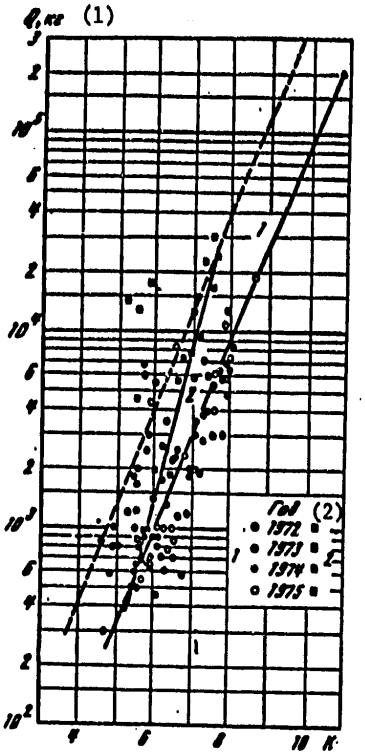

Figure 49. Energy of the oscillations K as a function of the weight of the charge Q for the explosions in Medeo (1) and Kotur-Bulak (2). The dotted line was constructed by the data of F. F. Aptikayev for an explosion in Medeo [6]

Key:

1. Q, kg
2. year

We shall distinguish two dynamic signs -- frequency composition and recording shape. The frequency composition of the recordings of earthquakes and explosions in Medeo differ stably. The average spectra of the frequency selection seismic station of the P and S waves from earthquakes and explosions are compared in Fig 52. The spectra of the S waves from explosions at all of the stations are significantly lower frequency; on the 1.3 and 2.6 hertz filters the relative amplitudes $A_f/A_{5.1}$ hertz of the explosion recordings are 2 to 4 times greater than for the earthquakes. The intensity of the recording on the high-frequency filters of 5 and 10 hertz for the earthquakes is essentially greater than for the explosions. For the P-waves this law is clearly expressed only at the Talgar station.

[redacted]

The criterion for the recording shape is less specific than frequency. The general characteristic of the recordings of explosions includes less clear arrivals of the S-waves, worse dynamic expression of the S-oscillations and the worse, the greater the epicentral distance (this is especially noticeable on the recordings at the Ali station). The ratio A_S/A_P for the explosions is less than for the earthquakes. The specific shape of the envelope of the recording A(t) at the Ali station for explosions is expressed significantly more sharply than for the earthquake (see Fig 43). Whereas for earthquakes the intensity of the tail part of the recording is smaller or, in the best case, comparable with the intensity of the preceding oscillations, for the explosion the low-speed components predominate with respect to intensity on the seismogram. Finally, another dynamic characteristic, also pertaining to the Ali station, is that the recordings of the explosions are always much weaker than at the other stations. Frequently they are in practice absent (except Kapchagay). At the same time the recordings of earthquakes at the Ali station are comparable with respect to intensity with the recordings of the other stations.

The time of day when an event occurs can serve as an indirect attribute of the explosions: the majority of the explosions occur in the range of 10-12 hours Greenwich (1600 to 1800 hours local time, see Appendix II).

The recordings of an explosion and an earthquake in the vicinity of Medeo are illustrated in Fig 53 for comparison. The differences in time of arrival of the waves at the test area stations for groups of recordings I and II are close. The consideration of the dynamic criteria helps to distinguish an explosion from an earthquake, namely:

1) The earthquake recording at all stations is essentially higher frequency. This is quite obvious by the oscillograms from the frequency selection seismic stations -- on the 5 and 10 hertz filters the disturbance from the explosion is almost absent at the same time as the intensity of the earthquake recording on all filters is comparable;

2) At the Ali station the intensity of the recording of the explosion is much weaker than an earthquake (by comparison with other stations);

3) The clear arrival of the S-wave is not as obvious on the seismogram of an explosion at the Ali station as on an earthquake recording;

4) The intensity ratio of the tail and initial sections of the oscillations on the explosion recording (Ali station) is more than on the earthquake recording.

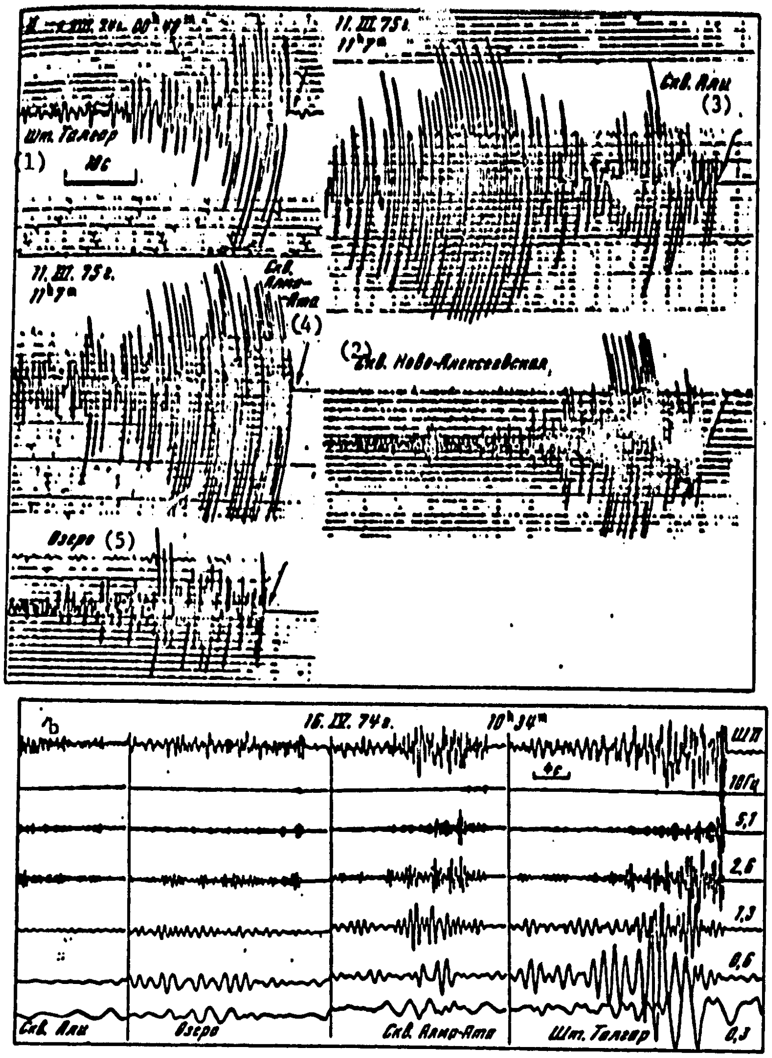

Figure 50. Seismograms (a) and oscillograms of the frequency selection seismic station (b) of explosions in Kotur-Bulak quarry

Key:

1. Talgar drift; 2. Novo-Alekseyevskaya well; 3. Ali well; 4. Alma-Ata well; 5. Ozero

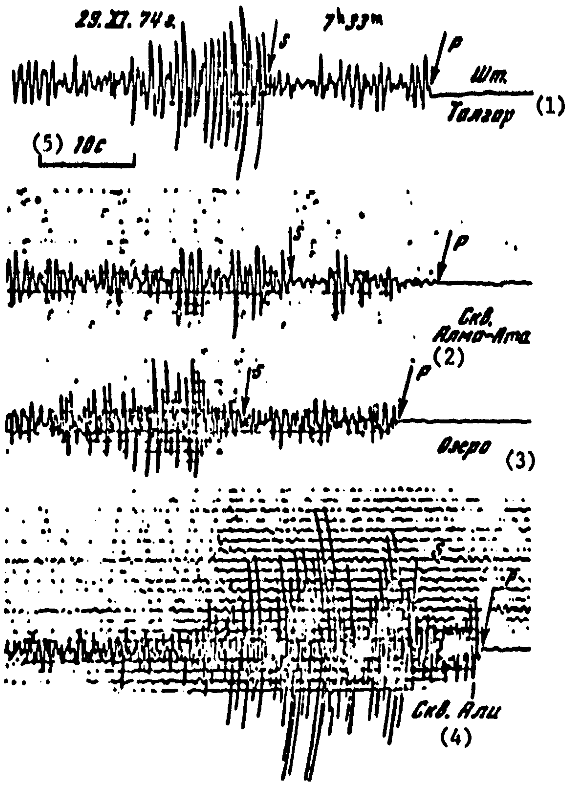

Figure 51. Explosion seismograms in the vicinity of Kapchagay

Key:

1. Talgar drift
2. Alma-Ata well
3. Ozero
4. Ali well
5. 10 seconds

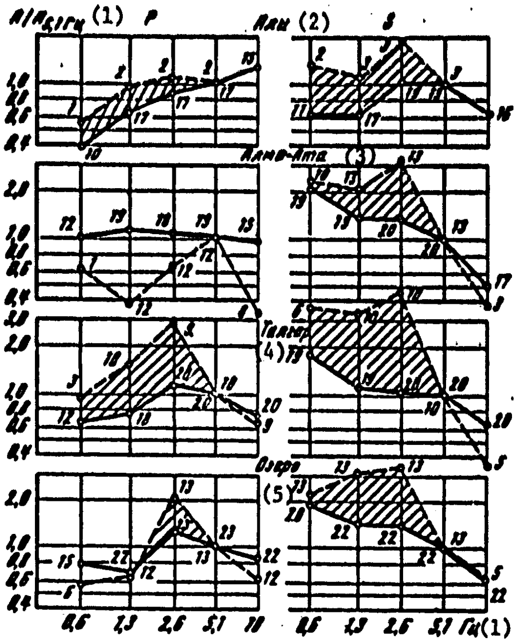

Figure 52. Average spectra of the P and S waves of earthquakes (solid lines) and explosions in Medeo (dotted line).

Key:

1. hertz
2. Ali
3. Alma-Ata
4. Talgar
5. Ozero

§5. Effect of Observation Conditions on Structure of the Seismograms

The development of seismic research and, in particular, the trend toward more complete interpretation of the wave field are more and more frequently leading to the necessity for considering the effect of local station conditions on the structure of the seismograms.

The seismological situation in the research area and the use of random wells for the observations have caused location of the stations in the radio-telemetric test area under sharply differing conditions (see Chapter II, III).

We have studied the effect of the reception conditions on the shape of the first wave and structure of the initial part of the recording of remote earthquakes and also the shape of the recording of local earthquakes. Unfortunately, the single-component recording has essentially narrowed the possibilities of analysis, and hereafter it will be necessary to keep in mind that all of the presented estimates are given by recordings of the vertical component of the oscillations only.

Effect of Observation Conditions on the Recording of Distant Earthquakes. The initial part of the recording of distant earthquakes in the various seismological studies is of special interest. This pertains, in particular, to the problems of interference reception in order to isolate the useful signal, study the exchange transmitted waves, and so on.

The initial parts of the recordings of distant earthquakes recorded at one station, as a rule, differ from each other. The recordings of a single earthquake obtained at different stations also differ. These differences are connected with the conditions both at the source (center) and in the reception area. The large volume of seismological research performed in recent years basically when studying exchange waves has made it possible to study the effect of the source area. It was demonstrated [51] that first of all the depth of the center has a strong effect on the initial part of the recording. The simple initial part of the recording represented by one wave out of two or three oscillation phases corresponds usually to depths of centers of 200 km or more. With a decrease in depth, the initial part of the recording is complicated. The earthquake recordings are the most complicated, the centers of which are located in the crust.

Table 12

Area	Azimuth from the Talgar station, degrees	No of earthquakes
Alaska, Aleutians	20-50	10
Kurils Kamchatka, Japan	50-80	17
Marianas Islands	80-100	10
Indonesia	110-150	40
Afghanistan, Hindukush	210-230	14
Chile, Argentina, Bolivia, Peru	270-320	16
Arctic Ocean	330-0	10

Table 13

(1) Год	(2) Общее число записей	(3) Число сопоставляемых записей						
		Талгар, Алма-Ата, Озеро (4)	Талгар, Алма-Ата, Озеро, Курты (5)	Талгар, Алма-Ата, Курты (6)	Талгар, Озеро, Курты (7)	Талгар, Алма-Ата, Озеро, Али (8)	Талгар, Озеро, Али (9)	Талгар, Алма-Ата, Али (10)
1972	55	34	4	8	10	–	–	–
1973	83	52	4	4	7	32	53	37
1974	50	25	–	–	–	23	33	23
(11) Итого	188	111	8	12	17	55	86	60

Key:

1. Year
2. Total number of recordings
3. No of compared recordings
4. Talgar, Alma-Ata, Ozero
5. Talgar, Alma-Ata, Ozero, Kurty
6. Talgar, Alma-Ata, Kurty
7. Talgar, Ozero, Kurty
8. Talgar, Alma-Ata, Ozero, Ali
9. Talgar, Ozero, Ali
10. Talgar, Alma-Ata, Ali
11. Total

Studies were also made of the shape of the recordings as a function of the areas in which the earthquakes occur. The simplest form of recording is observed most frequently for the earthquakes in Kamchatka, the Kurile-Japanese zone, the Pacific Ocean and Indonesia. No clear dependence of the shape of the first wave and the structure of the initial part of the seismograms on the epicentral distance is noted.

The effect of the reception conditions has been studied appreciably less. We selected distant earthquakes recorded by three or four stations of the test area in 2 years -- from March 1972 to April 1974. The basic principle for selecting the material was simplicity of shape of the recording of the first wave -- the presence of a short pulse -- at even one of the test area stations. For analysis 188 recordings of distant earthquakes were taken which are coordinated with the different epicentral zones located in different azimuths with respect to the test area which made it possible to exclude the effect of the direction of arrival of the waves. Table 12 shows the basic epicentral zones, their azimuths and the number of investigated earthquakes in each of the zones.

In addition, a study was made of the recordings of individual earthquakes from Europe, India, Oceania, Iran and other areas.

Sharply different station conditions lead to the fact that the recordings at the different stations differ significantly from each other. Therefore, even the high quality of visual comparisons turned out to be inadequate to discover the basic laws of these differences.

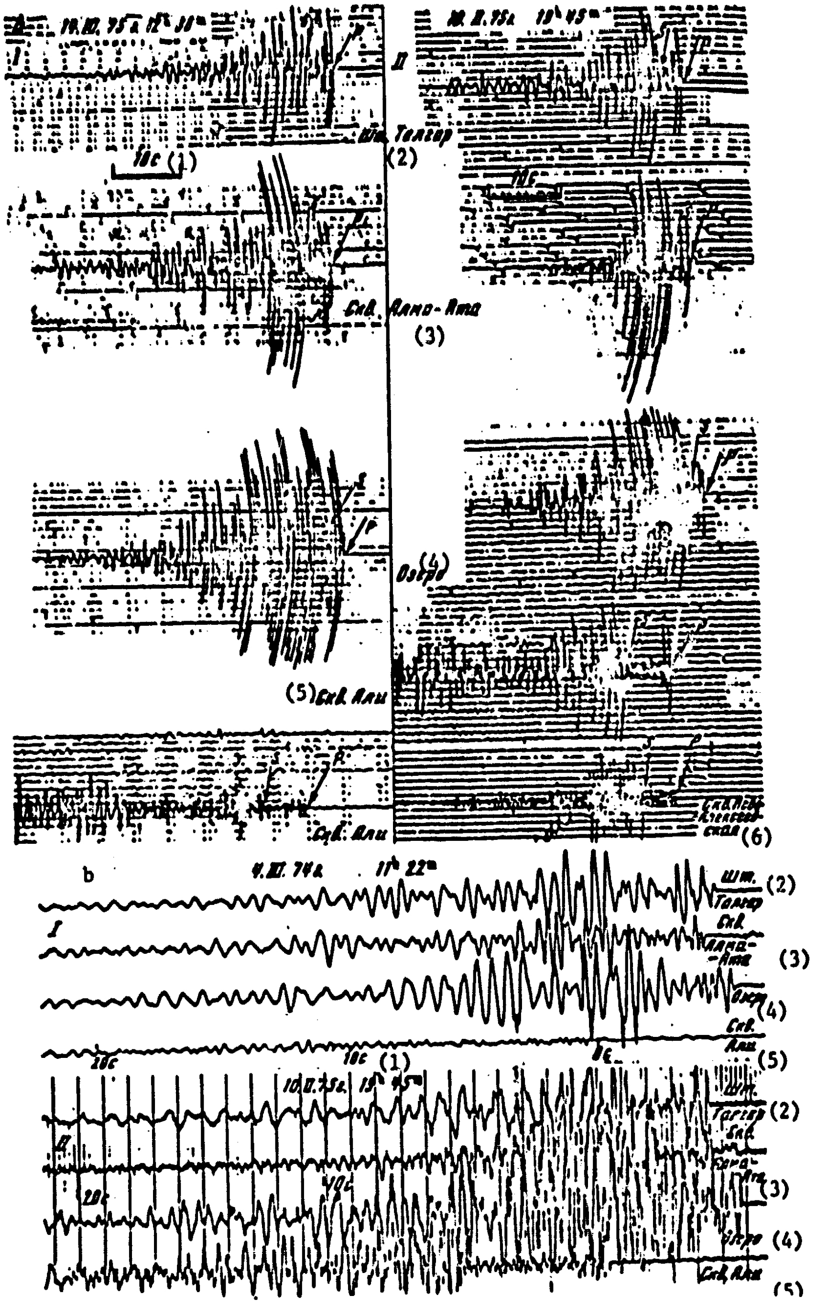

Figure 53. [See following page]

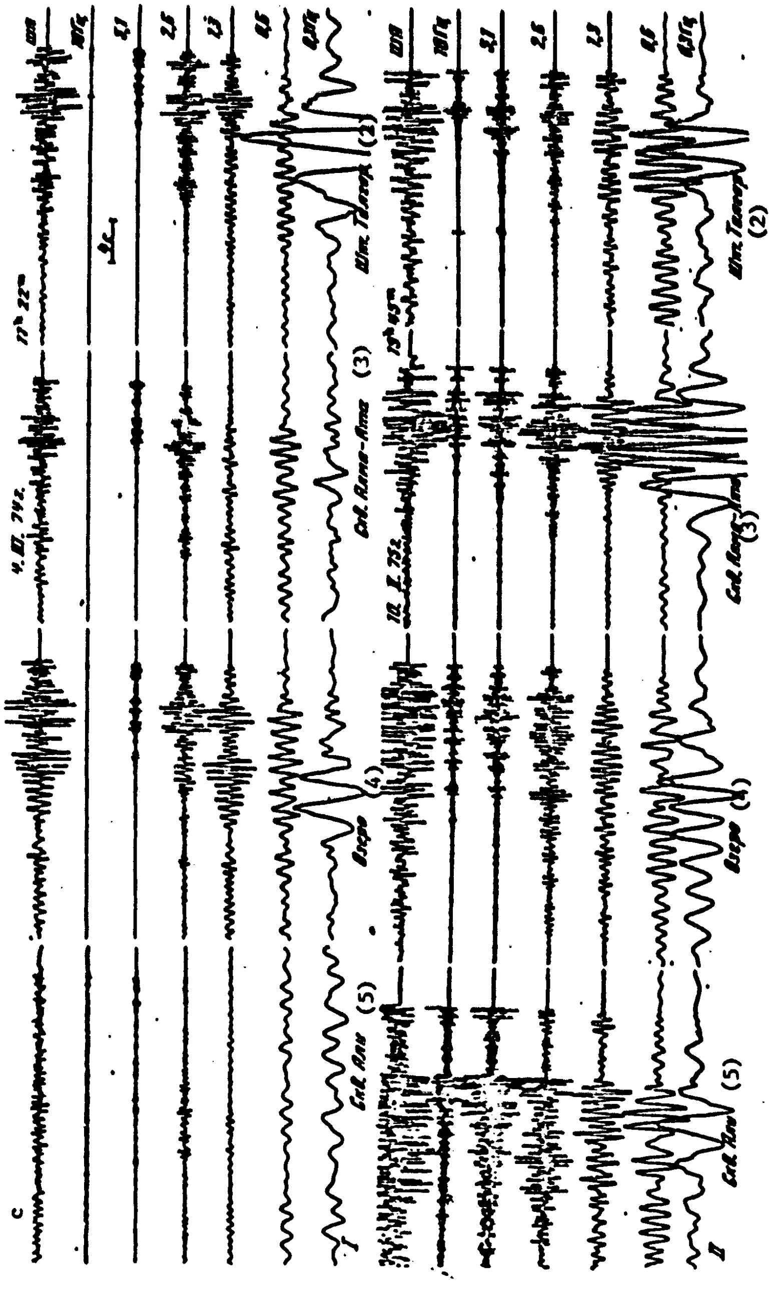

Figure 53, c [see following page]

Figure 53 [See preceding page]. Display seismograms (a) and slaved recording seismograms (b) and oscillograms of the frequency selection seismic station (c) of an explosion (I) and an earthquake (II) in the vicinity of Medeo

Key:

1. 10 seconds	6. Novo-Alekseyevskaya well
2. Talgar drift	
3. Alma-Ata well	
4. Ozero	
5. Ali well	

Figure 54. Earthquake distribution with respect to nature of recording at the Talgar, Ozero, Alma-Ata and Ali stations

a -- the simplest (1) and the most complicated (2) structures of the seismograms of the initial part of the recordings;
b -- shape of the recording of the first wave simplest (1), most complicated (2);
c -- frequency of the first wave, highest (1), lowest (2)

The recordings of groups of stations presented in Table 13 were used for comparison.

The results of comparing the recordings at the Talgar, Alma-Ata, Ozero and Ali stations are presented in Fig 54.

Initial Part of the Recording. When analyzing the structure of the initial part of the recording (about 40 seconds) consideration was given to the number of waves, their intensity, mutual arrangement, correlatability on the recordings of the different stations. The results of the analysis lead to the following conclusions.

Among the ground stations of Ozero, Talgar and Kurty located on outcrops of bedrock, but under essentially different conditions of the ground relief -- high in the mountains, in the foothills and on the plains -- the simplest initial part of the recording is observed at the Talgar station. The simplest structure of the recording is recorded 10-15 times more frequently here than at the Ozero station.

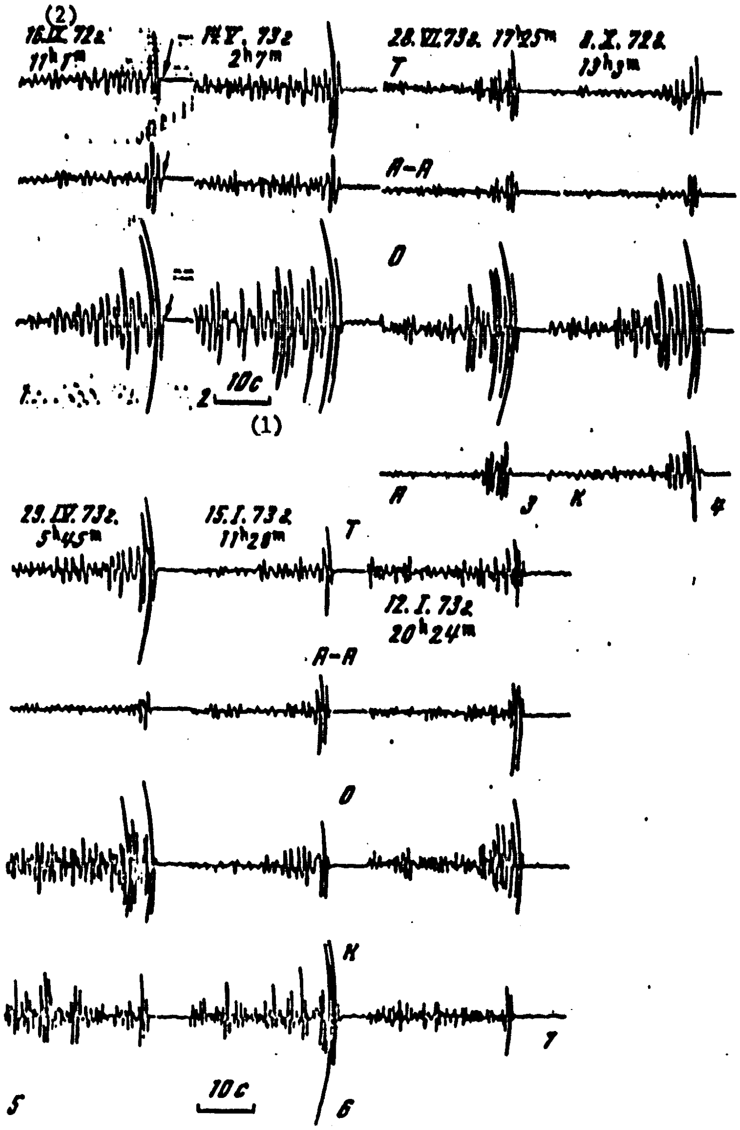

Figure 55. Comparison of the recordings of distant earthquakes by the ground surface and deep wells on RTS stations (times of arrival at all stations are comparable)

Key:

1. seconds
2. 16 September 1972

The most complex structure of the initial part of the recording is observed at Ozero station in 70 to 90% of the cases (when comparing the recordings of different groups of stations). The initial part of the recording here is the most extended, intense and least resolved by comparison with the recordings of other stations (Fig 55).

Such a sharp complication of shape of the recording on the station located in the mountains was of great interest. In order to exclude the effect of any strictly local causes connected with the installation site of the instrument, observations were made at three points within a few kilometers of each other -- on the shore of Bolshoye Alma-Atinskoye Lake, at the coronary station and the GAISh Observatory. At all of these points the recording differed persistently by significantly greater complexity than at the remaining stations of the test area.

Although the Kurty station is located in the plains, it is characterized by a significantly more complicated structure of the initial part of the recording than the Talgar station and somewhat simpler or commensurate with respect to complexity of the recording of the Ozero station. All the subsequent part of the recording at the Kurty station (Fig 55, recordings, 5, 6) is represented by groups of oscillations, sometimes inferior with respect to intensity to the first wave, at the same time as at the other stations the first pulse predominates with respect to intensity. The complex structure of the recording at this station obviously is caused by nonuniformities of the upper part of the section. The observations at the Kurty station were short-term, and they are inadequate for statistical estimates of the material.

Deep-Well Stations. It is not possible to compare recordings in a well and at its head on the day surface directly. The wells of the test area are located in populated places, under conditions of high surface noise levels; therefore the recordings at the day surface and at depth are not comparable. Usually earthquakes which are recorded in a well with readable amplitude are not recorded at all on the day surface. On the contrary, the recordings of stronger events which give readable amplitudes on the day surface are completely washed out at the deep-well station. Therefore the oscillograms of the well stations can be compared and they can be compared with the seismograms of the ground stations of Talgar, Ozero and Kurty.

At the Alma-Ata, Ali and Novo-Alekseyevskaya well stations the initial part of the recording, as a rule, is much simpler than at the Talgar ground station and the more so at the Ozero and Kurty stations. The recording in the well is characterized by a short first pulse and a smaller number of waves or their absence in subsequent arrivals. The subsequent oscillations are more frequently weaker than the first wave. The seismograms of distant earthquakes in Fig 56, a illustrate this relation in the example of recordings in the Alma-Ata and Ali Wells and in the Talgar and Ozero ground stations.

The number of cases where the simplest structure of the recording at the Alma-Ata station is observed is 70%, at the same time as at the Talgar station it is 20%, and at the Ozero station, 1.5% (Fig 54, a). This form of recording at the Talgar and Alma-Ata stations is observed simultaneously in the majority of cases.

The difference in structure of the recording at the Talgar and Ali stations is less sharply expressed. Here about 30% of the recordings are comparable with respect to complexity, and out of the remaining ones the simplest recording at the Ali station is encountered on the average 2 times more frequently than at the Talgar station. Thus, by Fig 54, a it is obvious that in 45% of the cases the Ali station has the simplest form of recording (in 25% of them it is comparable with the recordings of the Alma-Ata station) at the same time as at the Talgar station the simplest form is observed only in 20% of the cases. In the majority of them this is simultaneously with the Alma-Ata station.

If we compare the structure of the recording of the deep-well stations to each other, then it turns out that it is comparable on the whole. If it differs, then the simpler form is observed more frequently at the Alma-Ata station. The seismograph is buried to a depth of 1 km in the 4-km series of terrigenic sediments. The more complex shape of the recording is characteristic of the Ali station where the seismographs are located in direct proximity to the basement (Fig 56, b).

At the Novo-Alekseyevskaya deep-well station, observations were performed in a significantly smaller volume than at the Alma-Ata and Ali stations. The recordings are the closest with respect to shape to the recordings of the Alma-Ata station. Let us note that the conditions of the observations at the Novo-Alekseyevskaya and Alma-Ata stations are also close. The examples of comparison of the recordings of these stations are shown in Fig 56, c.

It must be emphasized that the similarity of the shape of the initial part of the recording of the well stations is greater than the ground stations (see, for example, Fig 56, b). In cases where the low frequencies predominate on the seismograms, which is characteristic of distant earthquakes, the shape of the recording of not only the first wave, but also all of the predominant waves in the subsequent arrivals can repeat well at all of the test area stations -- ground and deep well -- in spite of such different observation conditions. The examples of these recordings can be seen in Fig 56, b, seismograms 3, 4.

Fig 57 shows the seismogram of a distant earthquake reproduced from the magnetic tape of the slaved recording system. When matching the times of arrival at all the stations, good correlatability of individual intense oscillations in subsequent arrivals is clearly obvious on the recording.

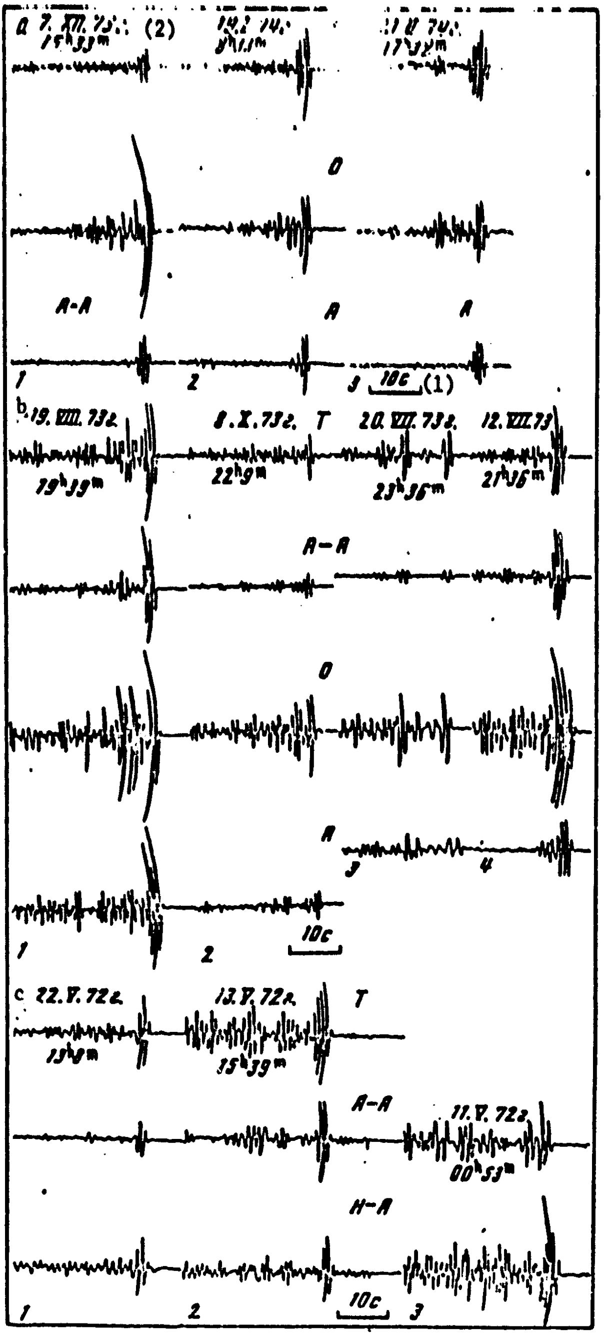
a 7.XII.73
(2)
15h33m
14.I.74
8h11m
17h32m
O
A-A
A
A
1
2
3
10c
(1)
b 19.VIII.73
8.X.73
T
20.VIII.73
12.VIII.73
19h39m
22h9m
23h35m
21h35m
A-A
O
A
3
4
1
2
10c
c 22.V.72
13.V.72
T
13h9m
15h39m
A-A
11.V.72
00h53m
H-A
1
2
10c
3

Figure 56

Figure 56 [see preceding page]. Simple shape of a recording in the well stations of Alma-Ata and Ali (a), comparison of the recordings of the deep well and ground surface stations (b) and peculiarities of the recordings of the Novo-Alekseyevskaya well station (c)

Key:
1. 10 seconds
2. 7 December 1973

Shape of the First Wave. In order to solve some of the special problems, for example, estimate the operating efficiency of groups of stations forming the interference systems, to study and interpret the exchange waves, and so on, the shape of the first oscillation has great significance. The shape of the first wave was estimated by the number of extreme and the nature of the envelope.

When comparing the recordings of the ground stations at Ozero, Talgar and Kurty it is possible to draw the conclusion that the simplest form of the first wave, just as the entire initial part of the recording, is observed at the Talgar station. Sometimes the shape of the first oscillation at this station is the simplest -- it is made up of two to three extreme (Fig 58, a). However, even in cases where the first pulse is not distinguished by such a simple shape, it is still simpler than at the Ozero station.

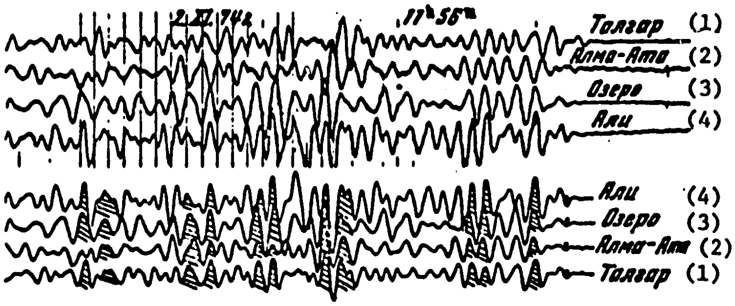

Figure 57. Slaved recording seismogram observed (at the top) and after matching the times of arrival (bottom)

Key:
1. Talgar
2. Alma-Ata
3. Ozero
4. Ali

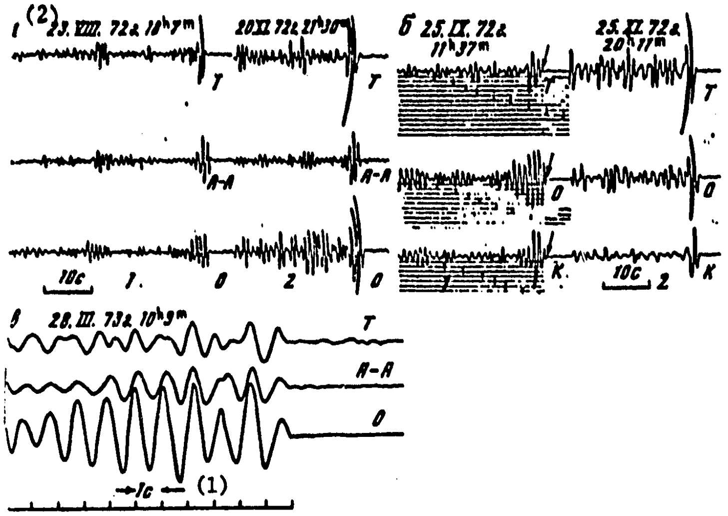

Figure 58. Initial part of the recording of distant earthquakes. a -- similar structure of the initial part of the recording at all stations; b -- shape of the recording of the first wave different (1) and comparable (2); c -- complex interference nature of the initial part of the recording at the Ozero station

Key:
1. 1 second
2. 23 August 1972

Although a complex shape of the initial part of the recording is observed at the Kurty station, the first wave turns out to be frequently just as simple as at the Talgar station (see Fig 55, seismograms 5, 6) and sometimes even simpler (Fig 55, recording 7).

The simplest shape of the first wave, just as the initial part of the recording, is observed in the overwhelming majority of cases (70-80%) at Ozero station located in the mountains and it is an unbroken train of oscillations of great duration (see Fig 56, a). In essence even here it is impossible to talk about the first wave, for a large number of waves are imposed on each other. This law is stable, and it does not depend on the area where the event occurred.

Comparing the recordings of the Talgar, Alma-Ata and Ozero stations out of the investigated 111 earthquakes in 76% of the cases the first wave has the most complex, extended form at the Ozero station, at the same time as this is observed in only 16% of the cases at the Talgar station (see Fig 54, b).

However, it is necessary to note that recordings are encountered (about 15%) where the pulse of the first wave at the Ozero station has the simplest shape. Frequently this is noted simultaneously also at the Talgar station (see Fig 56, b, seismogram 3; Fig 58, a, b, seismogram 2). This occurs when the first pulse turns out to be outside interpretation with the complex train of oscillations following it (Fig 55, recordings 5, 6; Fig 56, b, recording 1).

In rare cases the shape of the first wave at the three ground stations is comparable. Thus, in Fig 58, b, two recordings are presented, the first of which is typical and illustrates the difference in shape of the recording of the first oscillations at the three ground stations. The second recording is characteristic, and it is encountered rarely. It illustrates the good repetition of the shape of the recording of the first wave at all of the ground stations.

At the deep-well stations of Alma-Ata, Novo-Alekseyevskaya, and Ali, the shape of the first pulse is usually much more complex than at the Talgar station, but it is essentially simpler than at the Ozero station (see Fig 58, a). Thus, for example, when comparing the recordings of the Talgar, Alma-Ata and Ozero stations it turns out that in 43% of the cases the shape of the recording of the Alma-Ata well is the simplest (here in 12% of the cases, simultaneously with the Talgar station). At the same time the simplest shape of the wave at the Talgar station is observed in 55% of the cases, and at the Ozero station, in ly 15% of the cases (see Fig 54, b).

The recording of the wells is distinguished by a larger number of extrema (by one or two) and greater duration than at the Talgar station (see Fig 58, a). In Fig 58, c, a seismogram of the initial part of the recording of a distant earthquake is presented with matched times of arrival at three stations -- Talgar, Alma-Ata and Ozero. It is obvious that at Talgar station the pulses at the beginning of the recording have the simplest shape. At the Alma-Ata station they are much more drawn out, and at the Ozero station they merge into a long, unresolved train of oscillations.

For explanation of the observed changes in shape of the recording of the wells by comparison with the simplest recording of the first wave by the Talgar ground station, a calculation was made of the interference oscillation formed as a result of superposition of wave reflected from the day surface on the wave approaching from the bottom. The pulses of simple shape and at different frequency observed at the Talgar station were selected as the initial pulses. The time of arrival of the reflected wave at different depths was determined by the vertical seismic profiling data in the Alma-Ata well.

Fig 59 shows the results of the calculation for three earthquakes, the first pulses of which differ significantly with respect to frequency. The pulses recorded in the Alma-Ata well and in the Talgar drift are shown in Fig 59, a, b for each earthquake; in all cases those at Talgar are simpler. In Fig 59, c calculated pulses are presented for different depths from

700 to 1600 meters. It is obvious that a depth of 1200 meters the pulses are extended by comparison with the initial pulses, and with respect to shape they approach the pulses observed in the Alma-Ata well. The complication of the pulse shape is different for different frequencies. Thus, whereas in a pulse with a period of T=1.1 second at a depth of 1200 meters only the amplitude ratio of the second and third extrema varied, for the pulse with a period of 0.8 seconds the complication of the shape is expressed in the manifestation of additional extrema, and for a pulse with T=0.5 seconds, two hole extrema, which increases the pulse duration by 1.5 times by comparison with that observed on the day surface.

At the different well stations -- Alma-Ata and Ali or Alma-Ata and Novo-Alekseyevskaya -- the shapes of the first pulses are frequently close (see Fig 56, b, Fig 56, c, seismograms 1, 2) or somewhat more complex at the Ali station (see Fig 55, seismograms 3, 4). On the whole the number of cases where the simplest (just as the most complex) shape of the first wave is observed at the Alma-Ata and Ali stations is commensurate.

Out of the ground stations, the one closest to the well stations with respect to the shape of the first wave is the Talgar station. In Figures 55 and 56 it is possible to see the similarity of the recordings of the Talgar, Alma-Ata (see Fig 55, seismograms 2, 3; Fig 56, b, seismogram 4), Talgar and Ali (Fig 56, a, recording 3; Fig 56, b, seismograms 1, 2), and Talgar and Novo-Alekseyevskaya stations (Fig 56, c).

A comparison of the recordings of different well stations leads to the conclusion that the difference in shape of the first wave, just as the initial part of the recording is appreciably less here than between the earthquakes of the ground stations (see, for example, Fig 56, b, seismograms 1, 2). This is obviously explained by the fact that the well stations are located in a comparatively uniform series of terrigenic deposits.

In rare cases good similarity of the shape of the first wave on the recordings of all of the test area stations is observed (Fig 56, b, seismograms 3, 4).

Frequency Peculiarities of the First Wave. The estimates were made visually by the display recording and in small volume, by the oscillograms of the frequency selection station (ChISS) obtained by reproducing the magnetic tapes of the slaved recording system.

It must be noted that the predominant oscillation frequencies at the different stations differ little from each other, and in 30% of the cases the recording frequency of the first wave at all stations of the test area are identical. This is explained basically by the fact that the maximum frequency spectrum of the first oscillation of the distant earthquakes is usually outside the pass band of the frequency characteristic of the seismic channel. As an example we have the frequency selection seismic station oscillogram of one of the distant earthquakes in Fig 60, a. Inasmuch as

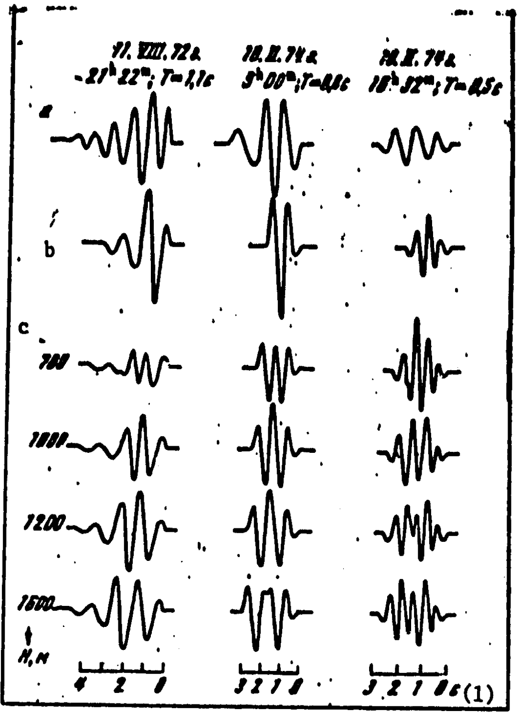

Figure 59. Recording of the first wave in the Alma-Ata well, H=1200 meters (a), in the Talgar drift (b) and calculated for different depths (c)

Key:
1. seconds

the recording with 0.3 hertz filtration is diminished by 6.4 times with respect to amplitude, it is clear that the maximum of the spectrum of the first oscillation is on a frequency not exceeding 0.3 hertz.

In cases where the spectrum of the initial signal contains components with frequencies above 1 hertz, the frequency of the recording as a function of the thickness of the sediments under the station is most clearly manifested. The highest frequency oscillations are recorded at the Kurty and Talgar ground stations located on bedrock (see Fig 55). On comparison of the recordings of the Talgar, Ozero and Alma-Ata stations in 53% of the cases the recording at the Talgar station is the highest frequency (simultaneously 11% at the Alma-Ata station and 7% at the Ozero station) and in only 12% of the cases, the lowest frequency, half of them simultaneously with the Alma-Ata station (see Fig 54, c).

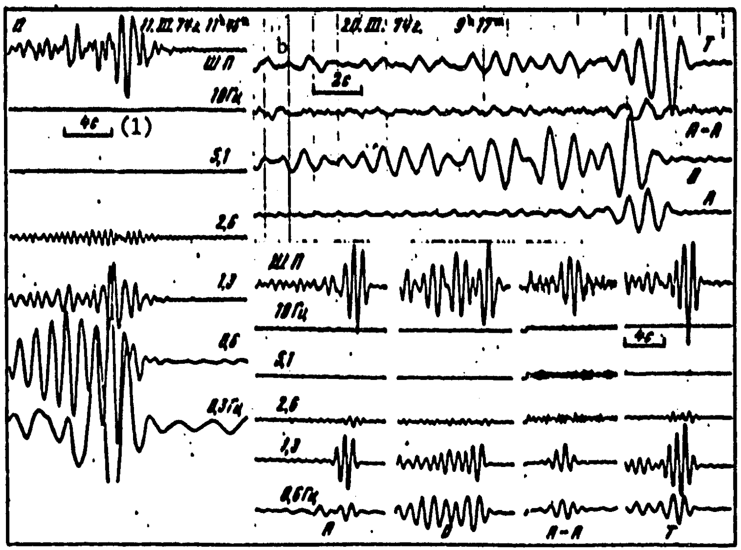

Figure 60. Oscillograms of frequency selection seismic station of distant earthquakes
a -- Talgar station, recording amplitude with 0.3 hertz filtration diminished by 6.4 times; b -- Talgar, Alma-Ata, Ozero and Ali stations, recording amplitude with 0.6 hertz filtration diminished by 6.4 times. The slaved recording seismogram is presented at the top.

Key:
1. seconds

At the Kurty station located in quiet relief, the highest frequency recordings are observed by comparison with the rest of the stations of the test area (see Fig 55, recordings 5-7).

The lowest frequency recordings are received at the Alma-Ata station where the thickness of the sedimentary mantle under the seismograph is about 3 km. In 40 to 50% of the cases the recordings at the Alma-Ata station turn out to be the lowest frequency, more than half of them simultaneously with the Ozero station. The low-frequency nature of the recording of the first wave at the Ozero station located in the mountains is in all probability connected with the phenomenon of interference of a large number of waves under the conditions of the complex relief at the day surface.

In the Ali and Novo-Alekseyevskaya wells the frequencies of the first oscillation are usually higher than in the Alma-Ata well, and they are often commensurate with the frequencies of the recordings at the Talgar station.

This is observed especially frequently for the Ali station (Fig 56, b, Fig 56, c, seismogram 3), which is the result of the effect of the sedimentary series (under the seismograms in the Ali well a total of 50 m of sediments, in the Novo-Alekseyevskaya well, about 1.7 km).

For illustration, Fig 60, b shows the recordings of the stations of the radiotelemetric test area and the seismograms of the frequency selection seismic station of a distant earthquake by which it is obvious that the oscillation components above 2 hertz have low intensity (one the 0.6 hertz filter the recording amplitude is diminished by 6.4 times). If we estimate the ratio of the amplitudes of the oscillation components at frequencies of 0.6 and 1.3 hertz for different stations, it turns out that wherever the instruments are located on bedrock (the Talgar ground station) and in direct proximity to bedrock (the Ali well station), the relative intensity of the high frequency components (1.3 hertz) is greater than at the Alma-Ata station located in a series of sedimentary deposits.

Effect of Observation Conditions of the Recording of Local Earthquakes. In order to study the effect of the reception conditions on the shape of the recording of local earthquakes ($t_{S-P} \leq 10$ seconds), the seismograms of all local earthquakes recorded by no less than three stations in the test area over a 3-year period from 1 June 1972 to 1 June 1975 were analyzed. It turned out that there were about 160 of them. A comparison of the recordings was made qualitatively for the ground stations (Talgar, Ozero) and the deep-well stations (Ali, Alma-Ata, Novo-Alekseyevskaya), primarily by the slaved recording seismograms where the scanning rate is 6 times greater than on the display seismograms and also by the frequency-selection station seismograms.

Whereas for the distant earthquakes the structure of the initial part of the recording in the shape of the first wave were investigated separately, for local earthquakes the duration of the recordings of which usually is 20 to 30 seconds, it is natural to investigate the entire recording and to consider the number of waves in groups of P and S-oscillations, the intensity ratio A_P/A_S, the overall duration and frequency composition of the recordings of different stations for its characteristic. It must be noted that in the case of nearby earthquakes such factors as the epicentral distance, the azimuth to the center, the depth of center and the earthquake energy can have defining effect on the nature of the recording and mask the effect of the observation conditions on the shape of the recording. It is necessary to take these peculiarities into account.

The results of comparing the recordings of local earthquakes obtained at stations under essentially different conditions lead to the conclusion that on the whole for local earthquakes the same laws are observed as for distant earthquakes.

Effect of the Parameters R, H and K on the Shape of the Recording. It is necessary at least qualitatively to estimate the effect on the shape of the recording of the epicentral distance R, the depth of center H and the energy of the earthquake K under the conditions of the Alma-Ata test area.

The distance R has a strong influence on the structure of the recording of the vertical component, especially when the center of the earthquake is located close to any station. It attenuates with removal of the center from the test area. Although the centers of the local earthquakes occupy a different position with respect to the test area stations (see the map in Fig 79, Chapter VI), for the majority of them the Ozero station turns out to be nearest, the Ali station turns out to be the most remote. In order to study the effect of the observation conditions, it was necessary to select earthquakes so that the effect of the parameter R will be excluded for the compared recordings insofar as possible.

The effect of the parameter R on the intensity of the longitudinal wave, rather on the A_P/A_S ratio and the recording time, is clearly illustrated, for example, by the seismogram of earthquake No 265 (see Fig 68). This ratio on the recording of the vertical component depends strongly on the direction of approach of the wave. For the same earthquake the maximum value of A_P/A_S and the greatest duration of the recording are observed at the Talgar station closest to the center (see the map in Fig 80, d). On going away from the center the ratio A_P/A_S on the recording of the vertical component decreases, and it becomes minimal for the most remote Ali station. This is connected both with absorption of energy and with a change in direction of approach of the waves. On going away from the epicenter, the recording time is also reduced (the Ali station is an exception in this respect).

The other two parameters H and K, which also influence the shape of the recording, can be neglected when comparing the recordings of one earthquake at different stations. However, when discovering the effect of the station characteristics on the recordings of different earthquakes, they cannot be neglected. As an example of the effect of the parameter H on the shape of the recording Fig 61 shows the recordings of three earthquakes with different depths of center. All of the centers are located south of the Ozero station (see Fig 80, c) and they are characterized by values of $K=6-7$. As is quite obvious by the seismograms, with an increase in depth (for $R\approx$const) the intensity of the longitudinal oscillations and the A_P/A_S ratio decrease.

The effect of the parameter K characterizing the energy of the earthquake is expressed in an increase in the ratio A_P/A_S and the recording time with an increase in K,

The geographic position of the center of the earthquake has defined influence on the shape of the recording.

Thus, when analyzing the recordings of local earthquakes it is necessary to deal with the total effect of many parameters on the shape of the recording, and it is not always possible to isolate the effect of only the

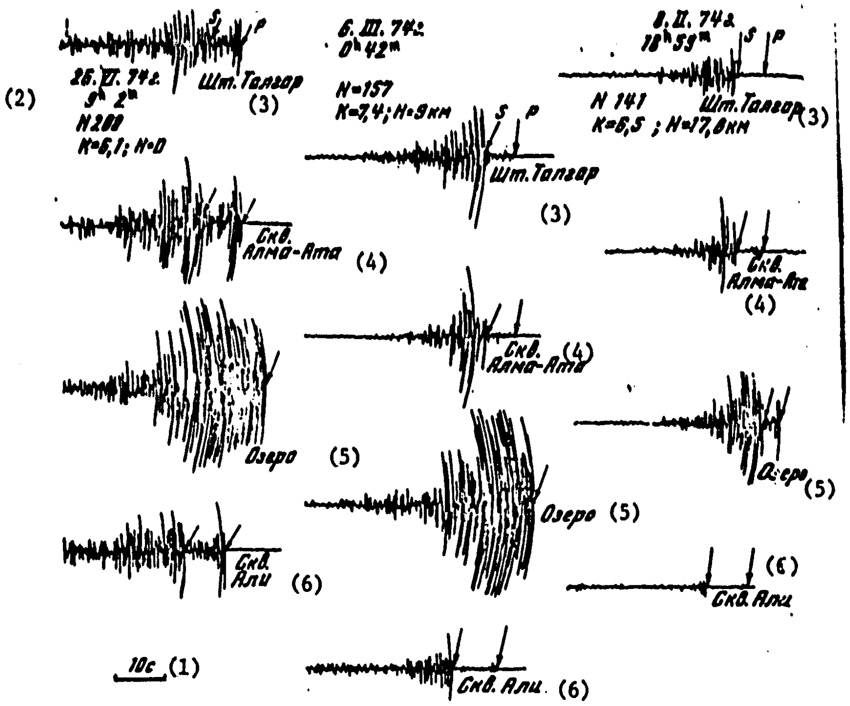

Figure 61. Recording of local earthquakes at different depths of center II

Key:

1. seconds
2. 26 June 1974
3. Talgar drift
4. Alma-Ata well
5. Ozero
6. Ali well

observation conditions in pure form among them. Therefore we shall discuss only the most stable laws,

Ground Stations. A comparison of the recordings of the ground stations at Ozero and Talgar for earthquakes identically removed from both stations indicates more complex shape of the recording at the Ozero station, which was also noted for distant earthquakes. If the epicentral distances for the two stations are different, then more complex recording is observed at the station which is closer to the center. Let us illustrate what has been said by some examples, Fig 62 shows the recordings of four earthquakes, two of which are located closer to the Talgar station (a), and two closer to the Ozero station (b). On the recordings in Fig 62, a, the most unresolved and prolonged oscillations are recorded by the Talgar station, and in Fig 62, b, by the Ozero station. This can be seen most clearly on the slaved recording seismograms. The fast damping of the high-frequency components and predominance of the low frequencies in the tail section of the recording most characteristic for the Talgar station on all recordings attract attention. This is especially clearly exhibited in the oscillograms from the frequency selection seismic station. For example, earthquake No 231 (Fig 63) at Ozero station located two times closer to the center than Talgar has a more complex recording -- more extrema, more prolonged and resolved recording on all filtrations except the lowest frequency 0.6 hertz (recordings with 0.3 hertz filtration frequently turn out to be unreadable as a result of the high background). On a frequency of 0.6 hertz the recording of the Talgar station predominates with respect to intensity and duration. The analogous picture can be observed also on other oscillograms of the frequency selection seismic station.

Now let us consider some examples of recordings for which the effect of the parameter R is excluded, that is, for the two ground stations Talgar and Ozero the epicentral distances are close (Fig 64). The depths of all centers H=13-15 km, and the energy class of the earthquakes K=7.4 to 7.7 vary within their own limits. On all the seismograms the recordings at Ozero station turn out to be more complex, more prolonged, less resolved than at the Talgar station.

The recordings at Ozero and Talgar stations, which are similar with respect to shape, are encountered rarely, and they are basically characteristic of the most remote earthquakes. Some examples of such recordings can be seen in Fig 65.

The most useful sensitivity realized at the Ozero station and closeness to the basic centers give rise to the recording of part of the signals (on the average 15%) by only this station (Fig 66). These are predominantly very close shocks with t_{S-P}=1.5-3.0 seconds. Some of the recordings are characterized by significant amplitudes, at the same time as at other stations the useful oscillations hardly exceed the background (Fig 66, a). The largest number of such signals were recorded in 1974-1975 (see Table 8).

When analyzing the shape of the recording of local earthquakes at the ground stations of the test area it was of interest to compare the recordings of the earthquakes from closely located centers (possibly the same center) obtained at different times. The selection of such recordings was made in Fig 67. The centers of these earthquakes are approximately 27 km southeast of Ozero station (see Fig 80, c, d). The depths of centers H=11-14 km are close. All of the earthquakes are characterized by in practice the same values of K=6.6-7.4. The stability of the shape of the recordings at the Talgar and Ozero stations attracts attention. In the deep-well stations the recordings are much weaker, and analysis of their shape is complicated.

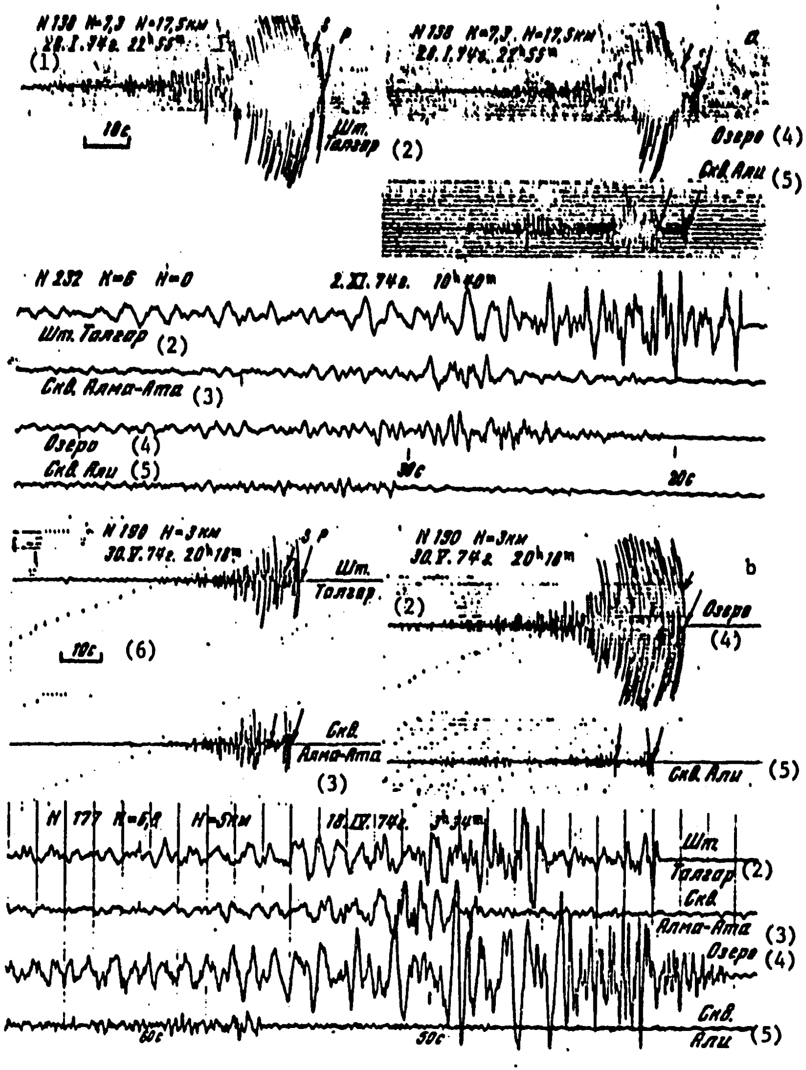

Figure 62. Recordings of local earthquakes for different epicentral distances and location of the centers closer to the Talgar (a) and Ozero (b) stations

Key:

1. 28 January 1974
2. Talgar drift
3. Alma-Ata well
4. Ozero
5. Ali well
6. seconds

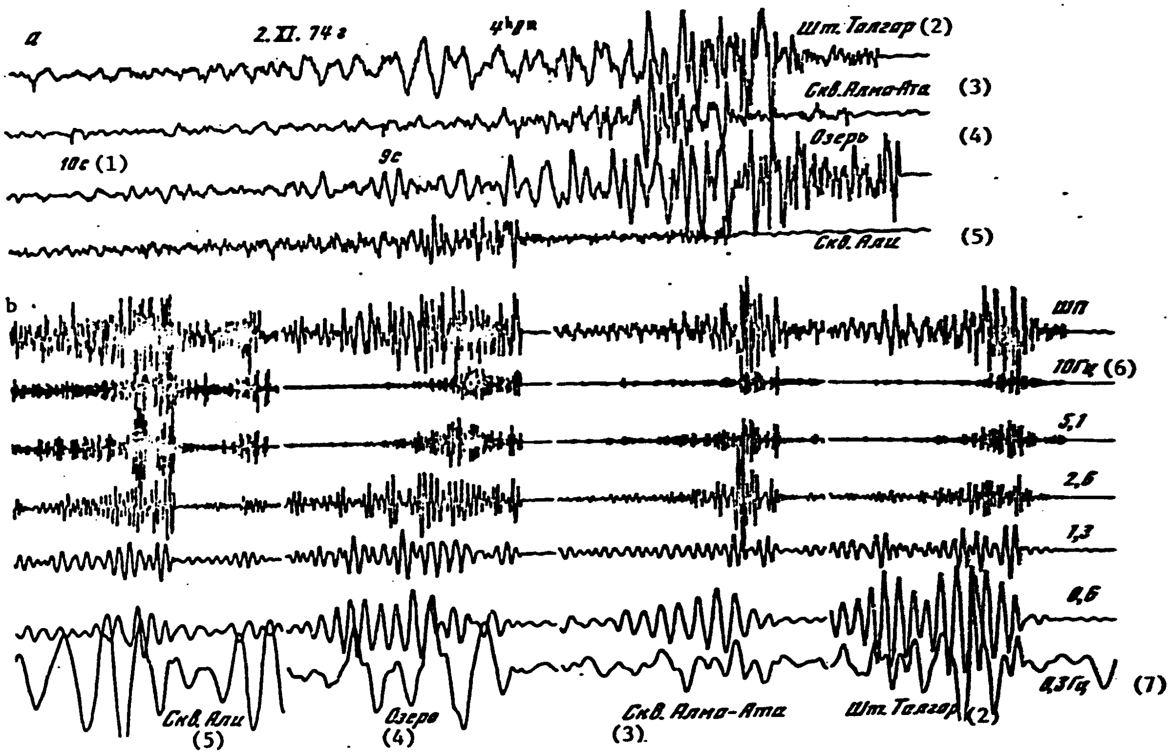

Figure 63. Recording of a local earthquake No 231 (K=6.5; H=12 km) on the slaved recording seismograms (a) and the frequency selection seismic station seismograms (b)

Key:

1. 10 seconds
2. Talgar drift
3. Alma-Ata well
4. Ozero
5. Ali well
6. 10 hertz
7. 0.3 hertz

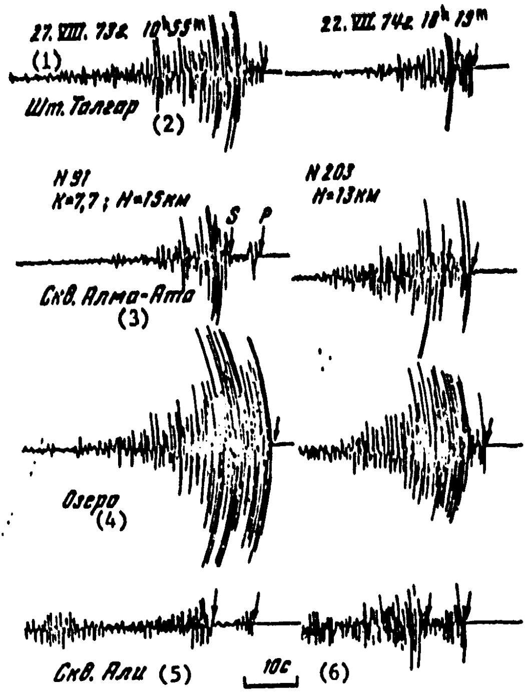

Figure 64. Recordings of local earthquakes.
Earthquake centers equidistant from Talgar and Ozero stations

Key:

1. 27 August 1973
2. Talgar drift
3. Alma-Ata well
4. Ozero
5. Ali well
6. 10 seconds

The time intervals between adjacent earthquakes are not the same -- 2 days, 17 days, 8 months. On the upper two seismograms (an interval of 2 days), impressive similarity of the recordings at the same stations is observed. Not only the low frequency configuration of the recording characteristic of Talgar station repeats well, but even its complication with high frequency. The next seismogram was obtained 8 months later, but the correlation of the recording at the Talgar station is good, just as before; only individual high-frequency contractions are distinguished. The high-frequency recording of the Ozero station is reproduced worse. It is possible to propose that in the segment of the trajectory from the center to the Ozero station a change in state of the medium took place during this

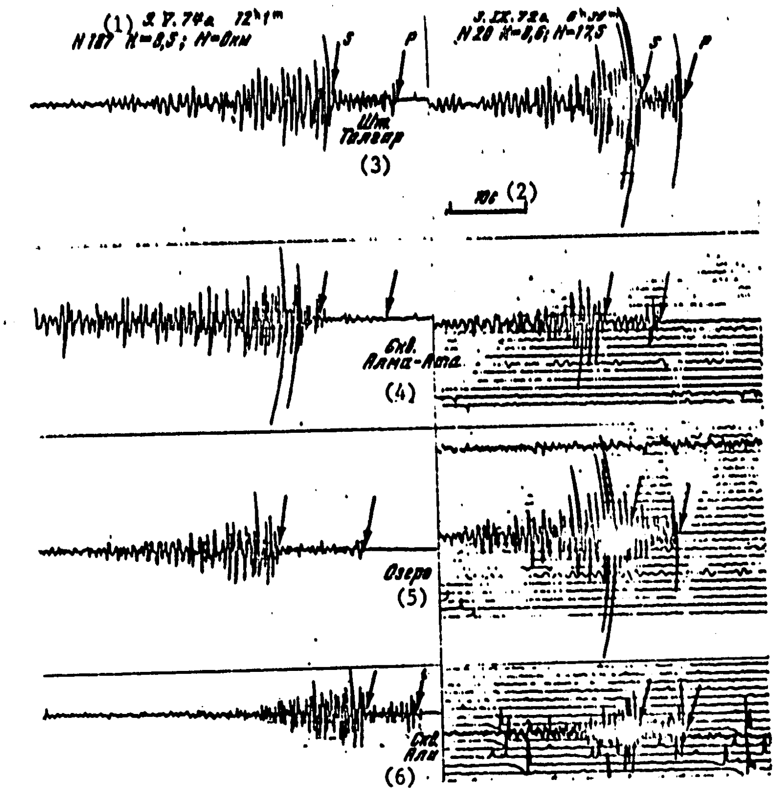

Figure 65. Earthquakes with close shape of the recording of all of the test area stations

Key:
1. 9 May 1974
2. 10 seconds
3. Talgar drift
4. Alma-Ata well
5. Ozero
6. Ali well

time which was "noted" in the high-frequency components, at the same time as on the path of the center to Talgar either the medium remained unchanged or its variation was not reflected in the low-frequency component of the recording. Actually, between the center and the Ozero station several earthquake centers occurred during these 8 months, and between the center and the Talgar station they were not observed (see the maps in Fig 80, c, d). Of course, it is impossible to exclude the possibility of nonidenticalness of the center influencing the high-frequency probability recording. Finally, on the last seismogram for both stations similarity is observed (in general features) between the shape of the oscillation recording and the shape of the waves in the first two seismograms at the same time as

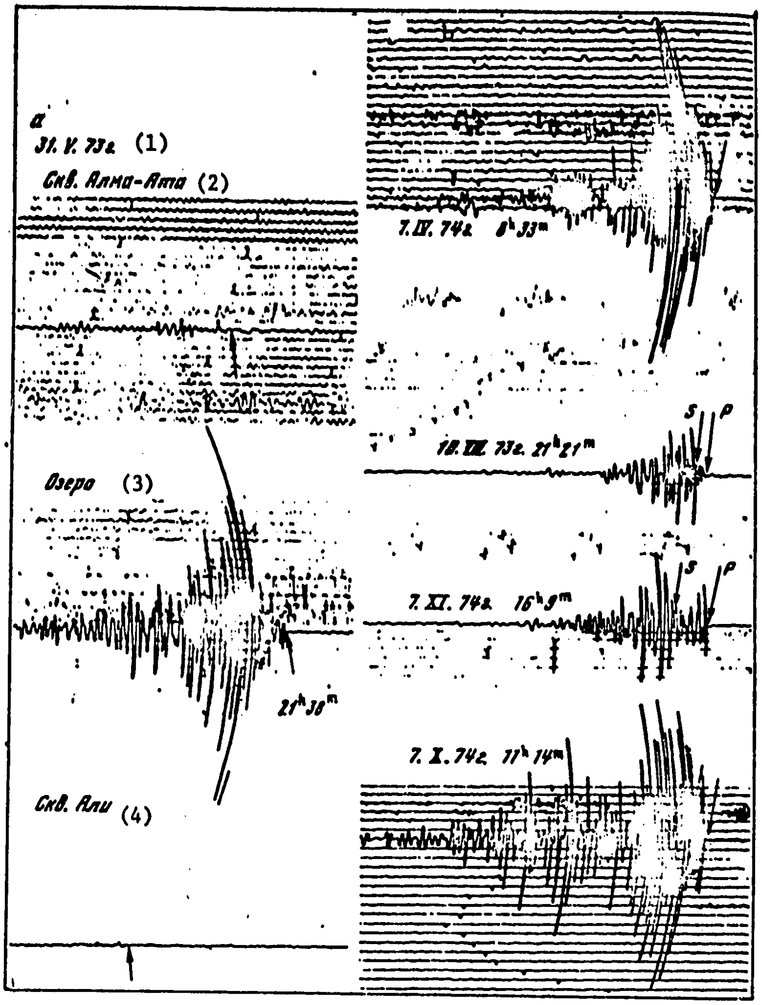

Figure 66. Recordings of earthquakes recorded only by Ozero station

Key:

1. 31 May 1973
2. Alma-Ata well
3. Ozero
4. Ali well

the relative intensity of the longitudinal oscillations (and shape at the Ozero station) changed several times. The last seismogram was obtained 9 days after an earthquake occurred 60 km to the west (4 January 1975) which was the strongest during the observation period (K=11.5), which could be felt in the condition of the environment and could lead to an increase in longitudinal wave absorption.

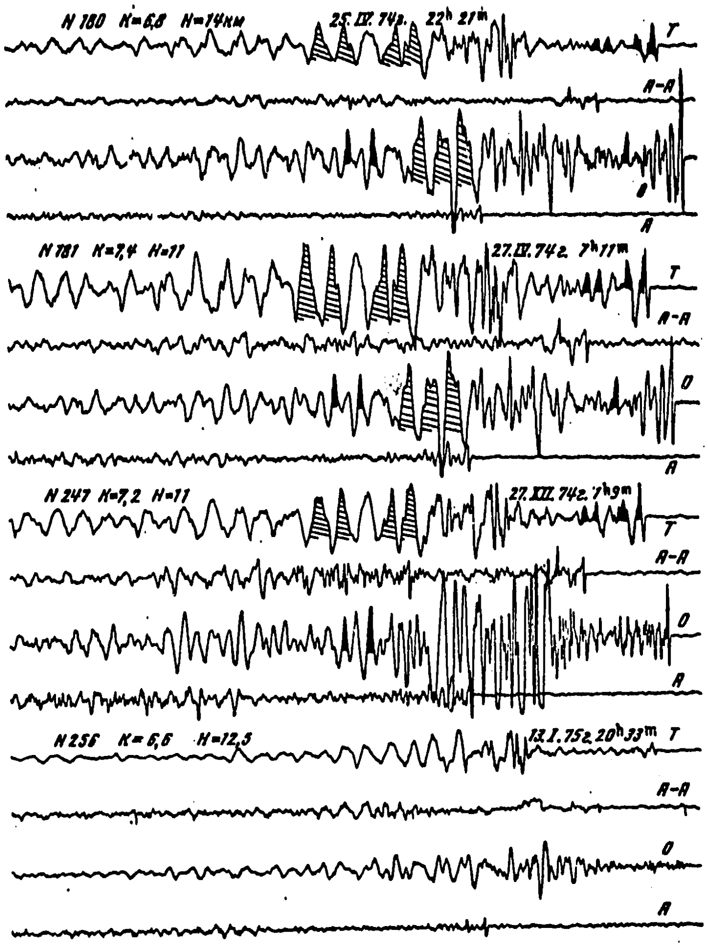

Figure 67. Recordings of earthquakes at the Talgar, Alma-Ata, Ozero, and Ali stations occurring in one place

Deep-Well Stations. Where the shape of the recording of distant earthquakes at the deep-well stations is much simpler than at the ground stations, this is not so obvious for local earthquakes. When comparing the shape of the recording at the deep-well and ground stations for local earthquakes it is difficult to exclude the effect of the factor R, for all of the deep-well stations are north, and the majority of the epicenters are in the south and southeast, closer to the ground stations.

Frequently the shorter and simpler forms of recording at the Alma-Ata well station and especially the Ali well station, as the most remote, can be connected with this (see Fig 62, No 190; Fig 61, No 141).

In the case where $R_{A-A} \approx R_T$, the recordings of the Alma-Ata and Talgar stations are comparable with respect to shape (see Fig 61) at the same time as the recording of the Ozero station which was closest to the epicenter is the most complex.

For the western centers $R_{A-A} \approx R_O$ the recordings of the Alma-Ata and Ozero stations turn out to be similar with respect to shape at the same time as the Talgar station, which is far from the western centers is characterized by a simpler shape of the recording (see Fig 68, No 186). The recording of earthquake No 265 (Fig 68), on the contrary, is more complex at the Talgar station, for the center is close to the station, and at the Alma-Ata and Novo-Alekseyevskaya well stations the recording is simpler and close with respect to shape to the recording of the Ozero station (Fig 62, No 232). The recordings of more remote earthquakes can turn out to be comparable with respect to shape at all of the test area stations -- ground and deep-well (see Fig 65).

For the observations at internal points of the medium, the waves reflected from the day surface can have significant influence on the shape of the recordings. For the high frequency local earthquakes the interference of the incident and reflected waves, as the calculations have demonstrated (see Fig 59), can lead to the most different effects, in particular, to the appearance of additional extrema and extension of the recording. However, the experimental data frequently give the inverse picture -- the recordings in the wells for local earthquakes, just as for distant ones, are characterized by simpler shape. Obviously, the effect of the day surface on the shape of the incident pulse turns out to be frequently more significant [15] than its distortion by superposition of the reflected waves when recording at the internal points of the medium.

As an example let us compare the recordings of the earthquake of 8 June 1968 in the Alma-Ata well and at the Talgar station (Fig 68). On the well seismogram the recording of the S-wave is shorter; sometimes by one or two extrema, and it is more complex than the Talgar station.

Let us compare the shape of the recordings at different deep-well stations. This problem is not simple, for in addition to the influence of the factor R, which is especially strong for the northernmost station of Ali, anomalous recordings are observed at the station -- intensive low-frequency oscillations appear in the tail section, The number of recordings in the Novo-Alekseyevskaya well is limited. The recordings of all three well stations are compared in Fig 53, a, II, The recordings of the local earthquakes at the Alma-Ata and the Novo-Alekseyevskaya stations are similar with respect to shape. At the Ali station in the tail section of the recordings low-frequency intense oscillations are recorded with reduced

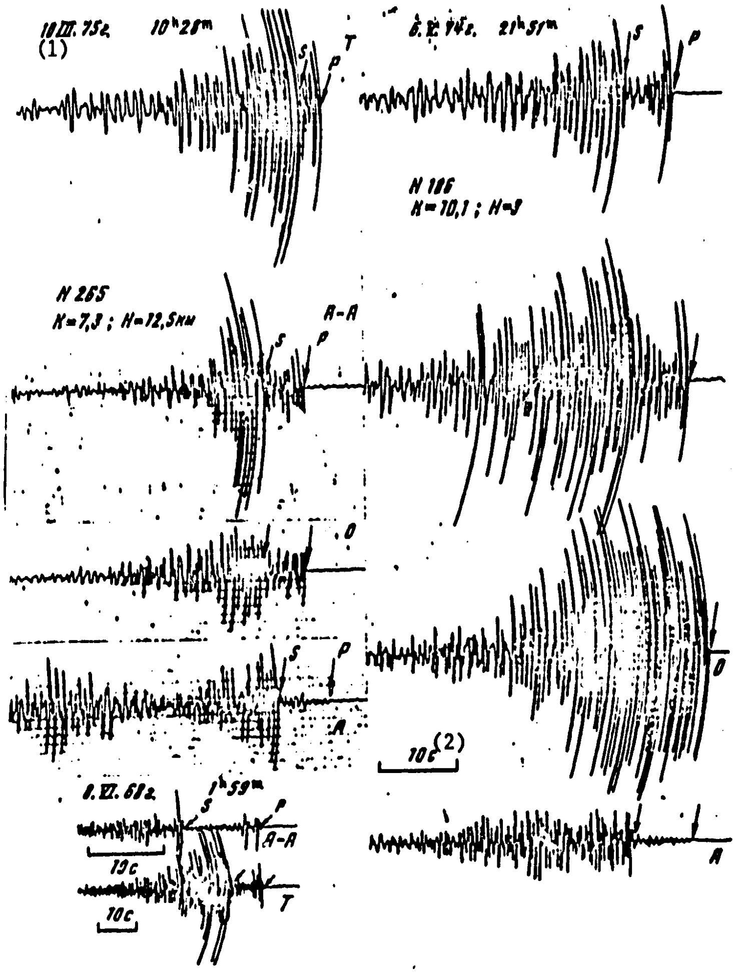

Figure 68. Recordings of earthquakes at the ground surface and deep-well stations

Key:

1. 10 March 1975
2. 10 seconds

velocity frequently commensurate with respect to intensity with the group of S-oscillations (see Fig 64, Fig 68, No 265). On some of the recordings the intensity of the "loop" decreases (see Fig 61, No 157; Fig 62, No 138, No 190); in rare cases the low speed oscillations are absent (Fig 61, No 141; Fig 65), and then the Ali station is characterized by the simplest shape of the recordings. It was not possible uniquely to relate the peculiarities of the recording at the Ali station to position and parameters of the center R, ϕ, H. It is only possible to note that the majority of recordings with low-frequency "loop" are caused by deeper earthquakes located to the southeast of the test area, and the short recordings are connected both with shallow and deep centers located to the northeast and southwest.

Table 14

Станция (1)	Количество (2) осредненных спектров	(3) Частота, Гц			(9) Крутизна	
		на уровне 0,7 (4)	на уровне 0,5 (5)	преобладающая* (6)	Левый склон (7) 0,5/0,7	Правый склон (8) 0,7/0,5
		(10) P-волны				
(11) Талгар	24	2,0–3,0	1,7–3,5	2,4	0,85	0,86
(12) Озеро	19	1,9–4,5	1,5–6,2	2,9	0,79	0,73
(13) Али	5	1,4–6,5	0,8–8,5	3,0	0,60	0,80
(14) Алма-Ата	25	2,7–6,5	1,7–7,5	4,2	0,63	0,87
		(15) S-волны				
(11) Талгар	23	1,0–3,0	0,6–3,5	1,7	0,60	0,89
(12) Озеро	19	1,0–3,0	0,6–3,7	1,7	0,55	0,81
(13) Али	5	1,6–3,5	–3,8	2,4	–	0,81
(14) Алма-Ата	24	1,5–3,2	–3,8	2,2	–	0,81

Key:

1. Station
2. No of average spectra
3. Frequency, hertz
4. on the 0.7 level
5. on the 0.5 level
6. predominant
7. left slope 0.5/0.7
8. right slope 0.7/0.5
9. Steepness
10. P-wave
11. Talgar
12. Ozero
13. Ali
14. Alma-Ata
15. S-wave

*By the predominant frequency we mean the geometric mean of the values of the limiting frequencies of 0.7 level.

Everything that has been stated about the peculiarities of the shape of the recording of local earthquakes at the ground and well stations of the test area reflects the complexity of the situation and complicates the solution of the problem of the effect of the reception conditions on the shape of the recording.

Frequency Characteristics of the Recordings of Local Earthquakes and Explosions. Let us consider the effect of the observation conditions on the frequency composition of the recordings. It was reasonable at first to analyze the frequency characteristics of the explosion recordings in Medeo Canyon, which took place in practice at one location, and their number was the greatest by comparison with other explosions. The frequency selective seismic station oscillograms of 26 explosions were obtained, the energy class of which is basically equal to K=6-8. No dependence of predominant spectral frequency on the class K was observed in this narrow energy range.

If we exclude the effect of the epicentral distances, it is possible to expect that differences in the frequency spectra of explosion recordings at the stations of the test area are connected with the peculiarities of the observation conditions.

The basic information about the spectra of the P and S-waves of explosions in Medeo is presented in Table 14, and the average relative (reduced to f=5.1 hertz) frequency-selective seismic station spectra of these waves are presented in Fig 69, a. The spectra were processed by the generally accepted procedure [35, 58].

As a result of analyzing the spectral characteristics, it is possible to draw the following conclusions.

1. The spectra of the P-waves of the explosions in Medeo at the different stations differ from each other. The differences are observed both between the spectra of the ground stations and the well stations, as well as between the individual spectra at the ground stations (Talgar and Ozero) and the well stations (Alma-Ata and Ali). The observation conditions at the Talgar and Ozero stations are approximately identical, and their spectra are also similar. The differences which exist nevertheless (at the Ozero station the spectrum of the P-wave has more gently sloping sides and is somewhat broader than the Talgar station) can be explained by the fact that the Ozero station is located closer to the explosion point.

2. The spectra of the P and the S-waves of explosions at the Ali and Alma-Ata well stations are broader and higher frequencies than at the ground stations, which is connected with the complete (Ali) and partial (Alma-Ata) exclusion of the sedimentary series.

3. The spectra of the S-waves of explosions in Medeo at all of the stations on the whole are similar to each other, especially with respect to their right slopes. In the example of the S-wave spectra it is obvious that the observation conditions are felt in the frequency characteristics essentially more than the differences in distances; thus, the spectra of the S-wave at the Talgar and Alma-Ata stations located at an identical distance from the explosions (approximately 16 km) but under different

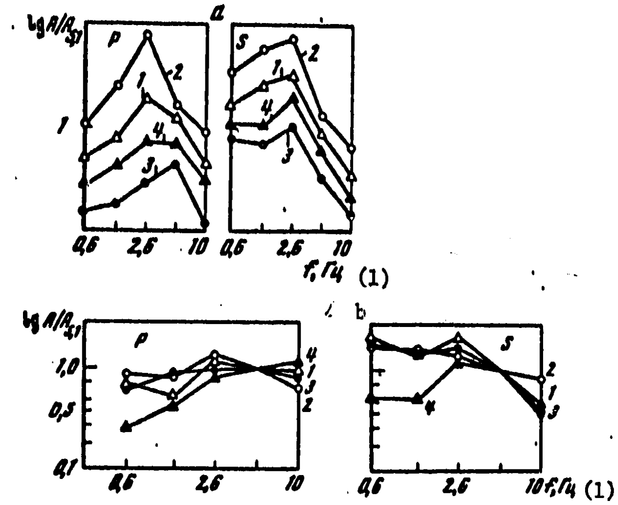

Figure 69. Average normalized spectra of the shift of the P and the S-waves of explosions in Medeo (a) and local earthquakes (b) at the Ozero station (1), Talgar (2), Alma-Ata (3) and Ali (4)

Key:

1. f, hertz

conditions, are different from each other. At the same time the spectra of the S-waves on the recordings of the Alma-Ata and Ali stations although located at different distances (about 16 and 50 km respectively) but under identical conditions, are identical.

In order to study the effect of the observation conditions on the frequency characteristics of the recordings of local earthquakes, more than 40 seismograms were selected for which it was possible to obtain high-quality frequency selection seismic station oscillograms. For the selected earthquakes the predominant value of K is included within the range of 6.0-7.5; H=0-15 km, t_{S-P} according to the Talgar station it is equal to 5.0-7.0 sec. In order to exclude the effect of random factors, average normalized shift spectra of the P and S oscillations were constructed for all the stations of the test area (Fig 69, b). An analysis was made of the amplitude ratio, which does not depend on the signal level —$A_f/A_{5,1}$ hertz.

The first thing that attracts attention is the anomalously high-frequency nature of the recording at the Ali station. This pertains to the P and the S-oscillations, and it is a consequence of the observation conditions (it is remarkable that the Ali station usually is removed to the maximum from the epicenters). This anomaly was observed sometimes also for distant earthquakes. The average spectra for the remaining stations (Talgar, Ozero, Alma-Ata) agree with respect to shape, but with small differences and more expressed for the P-wave. The spectra of the longitudinal waves at the Ozero and Talgar stations are very similar, and at the Alma-Ata station they are lower frequency. This is connected with the fixed series of sediments under this station.

The noted spectral characteristics of the recordings of the different stations are well illustrated by the frequency selection seismic station oscillograms for local earthquakes. Thus, according to Fig 53, c, II, it is obvious that at the Ali station the maximum recording amplitudes are noted on the 2.6, 5.1, and 10 hertz filters. For the other stations the relative intensity of the P and the S waves on these filters is much lower.

Thus, during the time of the 4-year observations from 1972 to 1976, the automated stations of the test area recorded more than 18,000 earthquakes, distant, nearby and local, including 978 signals with $t_{S-P} \leq 10$ seconds, which were investigated when studying the seismic characteristics of Alma-Ata. Of them there were 692 local earthquakes and 286 explosions. Among the latter 70% were explosions in Medeo.

More than 85% of all the earthquakes recorded by the test area stations belong to the fifth to seventh energy classes which are not representative for the Kazakh regional station network. The estimate of the energy of the weakest earthquakes recorded only by Ozero station gives a value of K on the order of two. The minimum recording time of the earthquakes with $t_{S-P}=1.5-2.5$ seconds is 13-14 seconds. Under the conditions of the Alma-Ata test area the earthquakes of energy class 6 are representative.

The relief of the day surface has the strongest effect on the structure of the seismograms. The recordings of the stations located in the mountains are distinguished by the greatest complexity and low resolvability. Many waves, polarized in different directions, are recorded here. The nonuniformities of the section under the conditions of azimuths of ground relief can have a strong influence on the structure of the seismograms.

The developed procedure for processing the multichannel seismograms of centralized radiotelemetric recording considering the spatial arrangement of the stations in the test area made it possible to determine the hypocenters of the earthquakes with high accuracy. The study of the peculiarity of the recording of explosions, including those occurring in Medeo in comparative proximity to the locations of greatest concentration of local earthquake centers demonstrated that the basic criteria for recognizing explosions and earthquakes are the frequency composition and the shape of the recording. The local earthquakes can be higher frequency than the explosions.

CHAPTER V. OBSERVATION RESULTS

The basic area of work was the equipment-procedural study. The seismic regime was studied by the way. However, the results obtained not only confirm the correctness of the developed procedure, but they can be of independent interest.

It is appropriate to consider the seismic regime of Alma-Ata in connection with the overall seismicity of Zailiyskiy Alatau.

§1. Seismicity of Zailiyskiy Alatau

The Alma-Ata seismically active region is wholly within the limits of Northern Tyan'-Shan'. In the north it is bounded by the Dzhungarskiy Alatau and its spurs; in the west it is bounded by the line from the city of Tokmak to the mouth of the Kurty River; in the south it is bounded by the north shore of Lake Issyk-Kul' and Kyungey-Ala-Too, and, finally, in the east, by the lower course of the Chilik River. The central part of the area is occupied by the Zailiyskiy Alatau Ridge, the axial part of which extends in northeasterly direction, reaching the highest elevation on the Talgar Peak.

The north slopes of the Zailiyskiy Alatau are expressed by low terraced foothills. The foothills make a sharp transition to the Iliyskaya basin which drops with insignificant slope to the Ili River basin.

The north slopes of the ridge are cut by the deep transverse slopes of the following rivers: Kastek, Karastek, Kaskelen, Aksay, Bol'shaya Alma-Atinka, Malaya Alma-Atinka, Levyy Talgar, Issyk, Turgen' and the longitudinal Pravyy Talgar and Asy River valleys. The south slope of the Zailiyskiy ridge is dismembered by short transverse river canyons, and in the western part it belongs to the Bol'shoy Kemin system; in the eastern part it belongs to the Chilik River system.

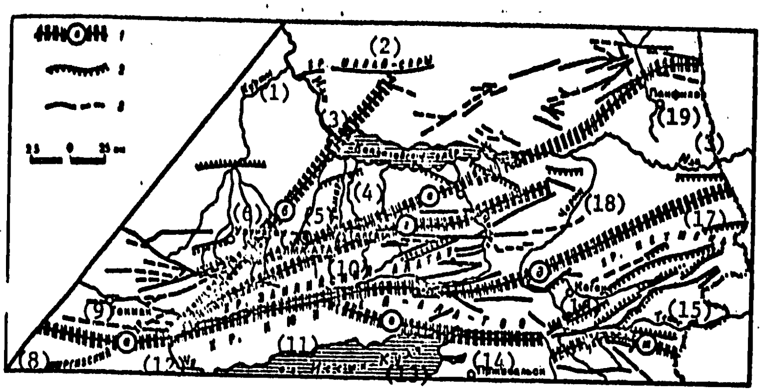

Figure 70. Tectonic diagram of North Tyan'-Shan'
1 -- deep fracture zones: Northern Tyan'-Shan' (a), Kaskelenskaya (b), Alma-Ata (c), Zailiyskaya (d), Kemino-Chilik (e), Tyupskaya (f), Terskeyskaya (g);
2 -- active regional faults; 3 -- inactive regional faults

Key:

1. Kurty
2. Malay-Sary Ridge
3. Ili
4. Kapchagay reservoir
5. Talgar
6. Uzunagan
7. Alma-Ata
8. Kirgizskiy
9. Tokmak
10. Zailiyskiy Alatau Ridge
11. Kyungey-Ala-Too Ridge
12. Chu
13. Issyk Kul' Lake
14. Przheval'sk
15. Tekes
16. Kagen
17. Ketshen' Ridge
18. Charyn
19. Panfilov

The Kyungey-Ala-Too Ridge extends in latitudinal direction almost parallel to the Zailiyskiy Ridge from the south of it. Its highest point is Chotkal Mountain, located to the southwest of the Talgar Peak. In the west the ridge ends up at the Chu River, and in the east it branches into two parts between which the broad section of the Chon-Aksu valley is located. The south slopes of the ridge, dropping down, end up as the shore of Lake Issyk-Kul',

The Zailiyskiy Alatau and Kyungey-Ala-Too Ridges, on approaching the more central section, form a single Kemino-Chu Mountain complex, to the northwest of which the city of Alma-Ata is located in the valley of the Malaya and Bol'shaya Alma-Atinka Rivers. To the west and east the distance between the ridges increases, and the ridges are split by the two river valleys of Chon-Kemin and Chilik which are elongated in the sublatitudinal direction.

The basic large structural elements of the investigated part of Northern Tyan'-Shan' are separated by deep faults existing since the Paleozoic. The intensity of the movements along the faults in the last stages of geological development was the greatest. The schematic[1] of the deep faults is depicted in Fig 70. The faults controlling the movements of the investigated region must be considered to be the Alma-Ata fault with the Zailiyskiy fault adjacent to it separating the mountain system of the Zailiyskiy Alatau from the Iliyskaya basin, and the Kemino-Chilik with the Tyupskiy branching from it. These faults have the greatest extent and are characterized by especially intense latest movements along them. Obviously, an important role in the tectonic development of the region is also played by the faults of short extent, the activity of which is exhibited in the Holocene.

The differentiated nature of the tectonic movements of Northern Tyan'-Shan' (the intense ascending displacements of the mountain structures and the descending basins) finds its reflection in the nature of the seismicity of the region. With respect to level of manifestation of modern weak seismicity Northern Tyan'-Shan' differs comparatively little from the seismicity of all of Tyan'-Shan'. However, against this comparatively "quiet" background the largest seismic disasters quite frequently occur. Thus, at the end of the last century and the beginning of this century four earthquakes occurred here, one of which (Kebinskoye 1911) is the largest; its magnitude reached 8.4-8.6. Close to it with respect to intensity was the Chilik earthquake of 1889. The magnitude of this shock is estimated at approximately 8. The weakest, but most destructive for Alma-Ata (previously Vernyy) was the Verdy earthquake (1887 and, finally, the weakest of them, the earthquake of 1938 (M=6.5), the center of which is located at the confluence of the Chon-Kemin and the Chu Rivers. The three strongest earthquakes appeared at the earth's surface in sections of significant extent of residual deformations (Fig 71). All of them have been preserved up to the present time.

The center of the earthquake of 1887 was located between the valleys of the Aksay and Talgar Rivers [41]. Here the earthquake deformations were exhibited most clearly on the Zailiyskiy fault. The degree of these deformations decreased from Aksay to Talgar.

The earthquake of 1889 was accompanied by large dislocations with a break in continuity and landslips in the valley of the Chilik River from its source to the meridional turning of the river to the north [42]. The disturbances of the surface and the landslips were also observed somewhat to the south in the vicinity of Dzhalanash settlement. The eastern edge of the center of this earthquake has a more intense manifestation at ground surface by comparison with the western edge. After the meridional turn

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[1] Compiled by V. N. Krestnikov, N. V. Chigarev, T. P. Belousov.

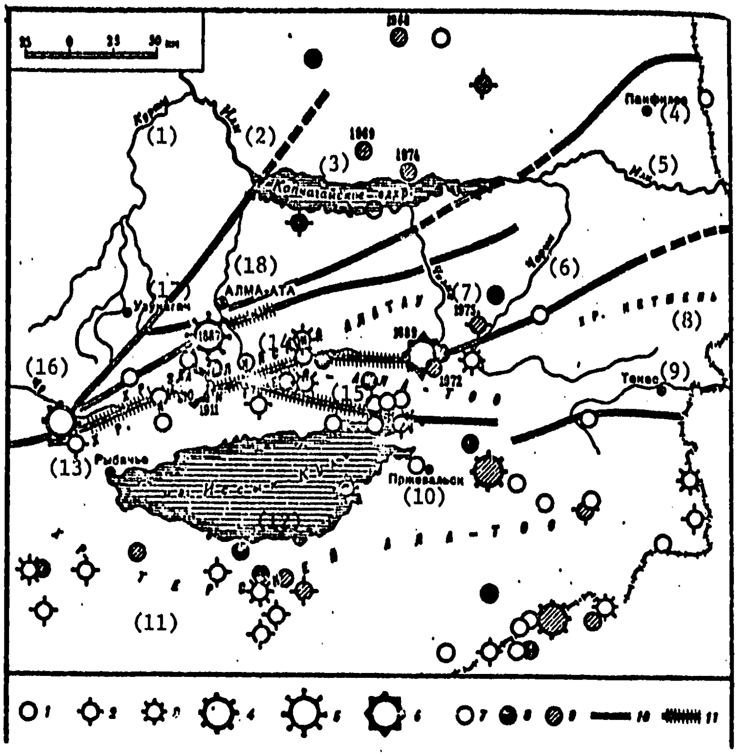

Figure 71. Map of strong earthquakes in Northern Tyan'-Shan'
Provisional notation: 1 -- K=12; 2 -- K=13; 3 -- K=14;
4 -- K=15; 5 -- K=17; 6 -- K=18; 7 -- 1929-1950; 8 -- 1951-1967;
9 -- 1965-1975; 10 -- deep faults; 11 -- regions of deformation of the day surface

Key:

1. Kurty
2. Ili
3. Kapchagay reservoir
4. Panfilov
5. Ili
6. Charyk
7. Chilik
8. Ketshen' Ridge
9. Tekes
10. Przheval'sk
11. Terskey-Ala-Too Ridge
12. Lake Issyk-Kul'
13. Rybach'ye
14. Zailiyskiy Alatau Ridge
15. Kyungey-Ala-Too Ridge
16. Chu River
17. Uzunagach
18. Alma-Ata

in the Chilik River at the present time no noticeable residual disturbances of the earth's surface are visible, but it must be noted that the isoseisms of this earthquake have clearly expressed northeasterly strike. The region of force 9 tremors encompassed a significant area in the eastern part of the Alma-Ata region. The force 8 isoseism extended from Dzhungarskiy Alatau in the northeast to the south shores of Lake Issyk-Kul', and from Chundzhi in the east to Talgar in the west. The axis of this recording is stretched to 260 km in the northeasterly direction and 160 km in the sublatitudinal direction [31].

The Kebin earthquake of 1911 exceeded all of the preceding ones with respect to force [7]. The most clearly deformation processes were expressed in the Chon-Kemin River valley over its entire extent and on the Tyupskiy fault from where it branches off the Kemino-Chilik fault to the northeastern shore of Lake Issyk-Kul'. Significant deformations are also observed now in the eastern section of the entire center region of this earthquake. In addition to the basic disturbances along the faults, deformations and landslips were observed on the Tyungey-Ala-Too Ridge and the Zailiyskiy Ridge. Thus, the entire southwestern part of the investigated region of Northern Tyan'-Shan' was encompassed by this earthquake. The rotation of the center of the earthquake from sublatitudinal in the Chon-Kemin valley to southeastern along the Tyupskiy fault is a highly characteristic and important characteristic of it.

The Kemin earthquake of 1938 had a small region of force-9 tremor at the confluence of the Chu and the Chon-Kemin Rivers [10]. Its force 8 isoseism was observed only in the westerly direction, and the force-7 encompassed a significant territory of Central Kirgizia and the entire region of Northern Tyan'-Shan' of interest to us.

The noted earthquakes are not the only ones according to the catalog data [43]. The earthquake of 1807 is known in the Medeo Canyon. There is undefined information about the earthquakes of the 18th century. K. I. Bogdanovich [7] reports a destructive earthquake in the 9th century. The geological data indicate the seismotectonic nature of the rock-dammed lake Issyk in the upper course of the Issyk River. There are substantiated geological data on the seismotectonic processes in the Kirgiz Ridge.

At the southern boundary of the investigated region 18 km east of Przheval'sk the Sarykamyshskoye earthquake occurred in 1970, the magnitude of which was 6.8 [13].

A brief description of the strong earthquakes in Northern Tyan'-Shan' indicates that their centers have significant dimensions, and the residual phenomena are in the majority of cases coordinated with the zones of deep faults controlling the tectonic life of the entire region. In addition, some of the peculiarities of the shape of the isoseisms of these shocks indicate that the centers of these earthquakes can be coordinated not only with the explicitly expressed faults, but they are also connected with the newly formed tectonic zones.

These data indicate that both with respect to strength of the known earthquakes and with respect to their recurrence rate, the region of Northern Tyan'-Shan' must be considered one of the potentially most dangerous regions of the USSR in seismic respects.

An instrument study of the earthquakes of Northern Tyan'-Shan' was started in 1929 -- the time of opening several of the seismic stations in Central Asia (Alma-Ata, Andizhan, Frunze, Samarkand) to supplement the Tashkent station existing at the time of B. B. Golitsyn. This quite meager network equipped with Nikiforov seismographs permitted determination of the position of the epicenters of the earthquakes corresponding to classes 11-12 with respect to energy K, although with large errors.

Fig 72 shows a map of the epicenter for the period from 1929 to 1950 when the station network did not change. In spite of the limited possibilities of the first network, it is impossible not to note the fundamentalness of this period of instrument observations giving the first clear concept of the nature of the seismicity of all Central Asia and, in particular, Northern Tyan'-Shan' [53].

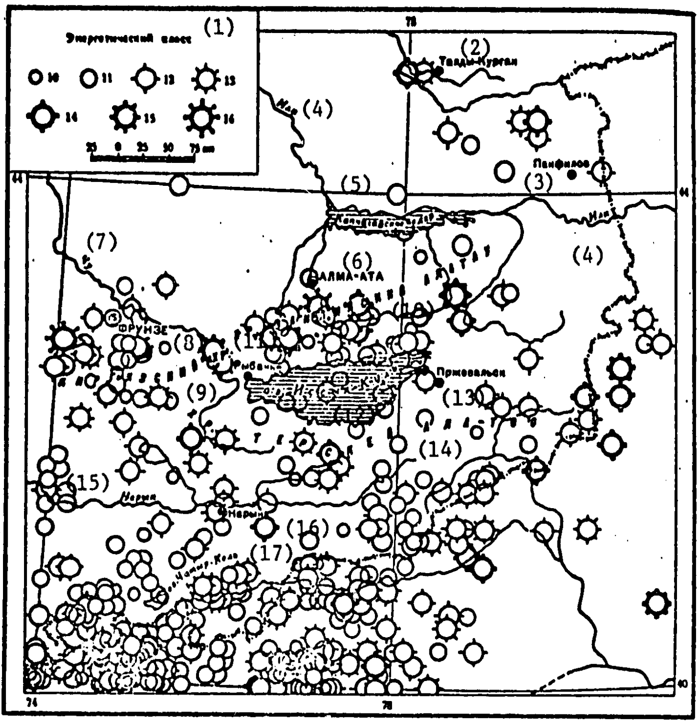

Figure 72. Earthquake epicenter map for 1929-1950

Key:

1. energy class
2. Taldy-Kurgan
3. Panfilov
4. Ili
5. Kapchagay reservoir
6. Alma-Ata
7. Chu
8. Frunze
9. Kirgiz Ridge
10. Zailiyskiy Alatau Ridge
11. Rybach'ye
12. Issyk-Kul' Lake
13. Przheval'sk
14. Terskey-Ala-Too Ridge
15. Naryn River
16. Naryn; 17. Chatyr-Kel' Lake

The year 1951 was the turning point in the development of seismological studies of Central Asia and especially Northern Tyan'-Shan'. Beginning in that year a new, significantly broader network of stations began operation in Asia, and Academician G. A. Gamburtsev organized the regional network of stations of the Earth Physics Institute of the USSR Academy of Sciences in Tyan'-Shan', permitting determination of the epicenters of earthquakes with quite high accuracy, in individual cases also their depths were determined, and making it possible to compile the energy classification of the seismic shocks [9]. This network included the following stations: Ili, Talgar, Fabrichnaya, Kurmenty, Chilik. The Alma-Ata station operated as before. The Przheval'sk and Rybach'ye stations supplemented the network on the south. As a result, sixth and seventh class earthquakes began to be recorded, although from the point of view of representativeness, the existing observation system for these classes of earthquakes was still insufficient. The increase in number of stations up to 1961 and their reequipment with the new SKM devices insured a further increase in accuracy of determining the geometric parameters of the earthquakes and also the energy classes.

Beginning in 1969 all of the seismic operations in Northern Tyan'-Shan' were transferred to the Geological Institute of the Kazakh SSR Academy of Sciences, and in 1976, to the Seismology Institute of the Kazakh SSR Academy of Sciences where the development of the seismic operations in Northern Tyan'-Shan' is continuing jointly with the Seismology Institute of the Kirgiz SSR Academy of Sciences.

The maps of the epicenters in Figures 71-74 give an idea of the seismicity of Northern Tyan'-Shan' in the vicinity of Alma-Ata for different time intervals. Figure 71 shows the epicenters of the strongest seismic shocks from energy class 12 and up during the entire period of instrument observations. A complete idea of the nature of the seismicity of the region is given by the map of the epicenters of energy classes 9 and 10 (Fig 73), inasmuch as these classes are the most representative for the entire observation time. However, it is necessary to consider that the accuracy of determining the epicenters before 1951 was essentially lower by comparison with the subsequent years.

In Fig 74 it is possible to isolate several localized seismic zones. First of all, let us note the seismically active zone extending from the sources of the Chon-Kemin and Chilik Rivers along the southwest slopes of the Kyungey-Ala-Too Ridge. This zone approaches the city of Alma-Ata with a small turn somewhat to the west and breaks off sharply. Then in the western part of the region, primarily along the north slopes of the Kyungey-Ala-Too Ridge to the Chu River a seismic belt is traced which has comparatively low activity. From the northeast corner of Lake Issyk-Kul' to the epicenter of the earthquake of 1889 there is a region of highest seismic activity. The dimensions of this zone are not great, but the greatest density of earthquakes in Northern Tyan'-Shan' is observed within its limits.

From the epicenter of the Chilik earthquake of 1889 two somewhat worse located directions of propagation of the epicenters are noted: one of them coincides closely with the Chilik River valley after its turn in the meridional direction, and the other has a northwesterly strike in the direction of the mouth of the Alma-Atinka River. It is possible to note small meridional accumulation of epicenters in the region along the Turgen' River in the central part of the first of the investigated zones. Within the limits of the remaining part of the territory the epicenters are scattered quite randomly, and there is an insignificant number of them.

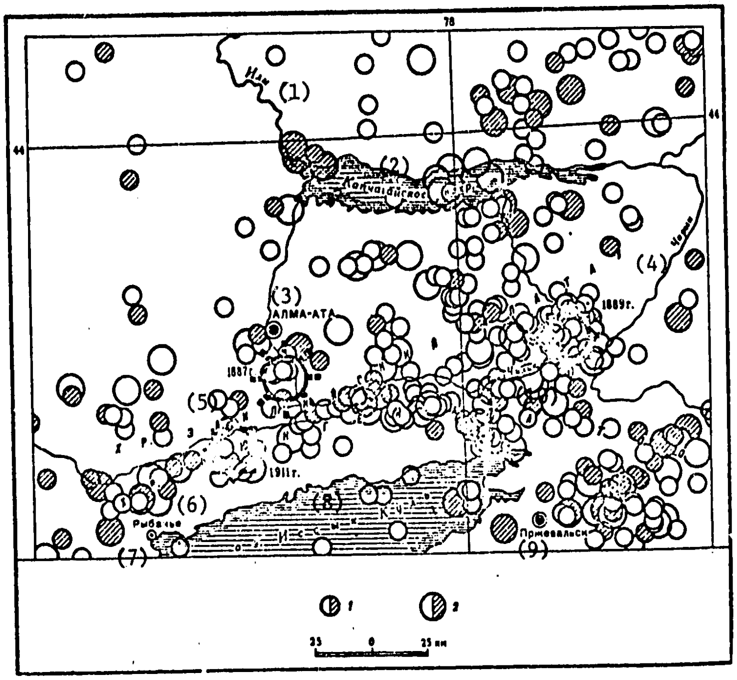

Figure 73. Map of earthquake epicenters for 1951-1967
The epicenters with K=9 (1) and K=10 (2) for 1961-1967 are crosshatched,

Key:

1. Ili; 2, Kapchagay reservoir; 3, Alma-Ata; 4, Charyn; 5. Zailiyskiy Alatau Ridge; 6. Kyungey-Ala-Too Ridge; 7. Rybach'ye; 8. Lake Issyk-Kul'; 9, Przheval'sk; 10, Chilik.

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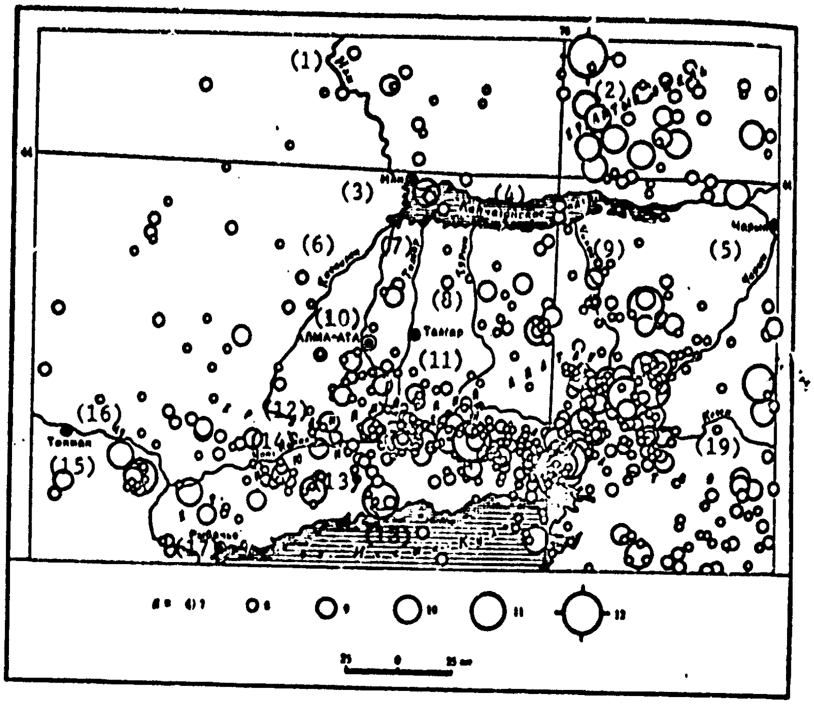

Figure 74. Map of earthquake epicenters from 1965 to 1968. The numbers on the earthquake symbols indicate the energy class K.

Key:
1. Ili; 2. Altyn Emel' Ridge; 3. Ili; 4. Kapchagay reservoir;
5. Charyn; 6. Kaskelen; 7. Talgar; 8. Turgen; 9. Chilik;
10. Alma-Ata; 11. Talgar; 12. Zailiyskiy Alatau Ridge; 13. Kyungey-Ala-Too Ridge; 14. Chon -Kemin; 15. Tokmak; 16. Chu; 17. Rybach'ye;
18. Lake Issyk-Kul'; 19. Kegen

On the map of the strongest shocks (see Fig 71) on the whole an analogous picture of the earthquake distribution is observed. The most active is the earthquake belt coinciding with the Kyungey-Ala-Too Ridge and its position in the direction of Alma-Ata. Some "fuzziness" of the observed distribution of the epicenters is explained by the lower accuracy of determination for 1951. It is necessary to pay attention to the fact that stronger and stronger shocks in recent years have occurred in the eastern parts of the region along the line coinciding with the meridional directions of the Chilik River.

Finally, let us discuss the map in Fig 74 constructed by the observation data for 1965-1968 separately. During this time the complex seismological expedition in Northern Tyan'-Shan' opened up a number of temporary stations which made it possible to increase the accuracy of determining the epicenters and their depths (Fig 75). From investigation of Fig 75 it follows that the majority of the earthquake centers of low energy classes are associated with the narrow range of depths from the first kilometers to 12. The deeper centers are encountered significantly more rarely (according to the data for recent years), and in the majority of cases they belong to the strong seismic shocks of class 11-12.

In Fig 74 the basic nature of the earthquake distribution is analogous to the earthquake distribution on the preceding maps. Nevertheless, it is possible to note some characteristic features. In the west two clear belts of epicenters of northwesterly strike are isolated which intersect the deep belt zones. The basic number of earthquakes in this map, the region of propagation of which occupies a significantly greater area, belong to energy class 7. Beginning with energy class 8 the earthquakes are located near the basic seismically active zones (see the beginning of this item). The "contraction" of the earthquakes of stronger classes into narrow zones is a quite characteristic feature of the manifestation of seismicity.

Thus, the seismic material indicates that the modern seismicity appears quite stably in different observation times, and the use of weak earthquakes to isolate the seismically active zones turns out to be justifiable in spite of the high degree of "diffusion" of the epicenters of the weakest shocks.

On all of the maps of the epicenters it is obvious that east of the city of Alma-Ata on the Alma-Ata and Zailiyskiy faults no clearly expressed grouping of the weak earthquakes is detected although the strong earthquakes of the past were connected with them.

The region of increase in modern seismicity is closely connected with the sections within the limits of which the disastrous earthquakes at the end of the past century and the beginning of this century were strongly exhibited. The available material does not permit a definite conclusion to be drawn about whether the modern weak activity is aftershock activity of the strong earthquakes of the past or the zones isolated with respect to weak seismicity will be future locations of strong earthquakes. Nevertheless, the fact that the seismic activity of recent years is gradually increasing in the eastern part of the region (on the meridian of the Chilik River) deserves fixed attention. The experience of studying strong earthquakes in the different seismically active regions of the earth indicates that the strong earthquakes occur most frequently against a background of a general rise in activity of the region adjacent to the center of a strong shock although before the shock itself on this background of increasing activity weakening of the seismic activity can be observed.

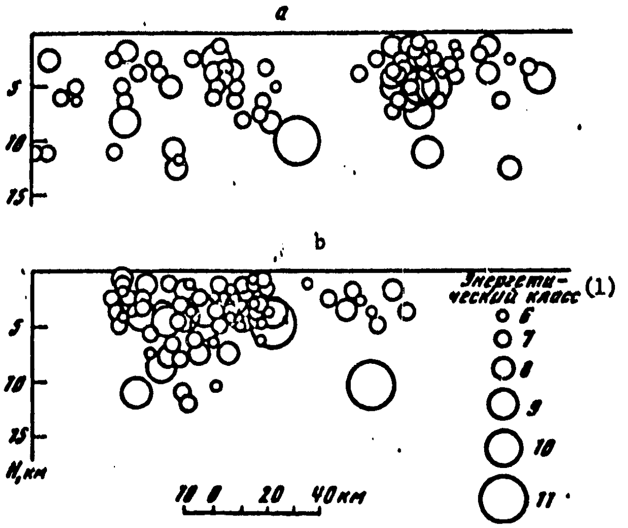

Figure 75. Diagram of the distribution of the depths of the earthquake centers in the directions from the northeastern corner of Lake Issyk-Kul' to Alma-Ata (a) and to the epicenter of the earthquake of 1889 (b)

Key:

1. energy class

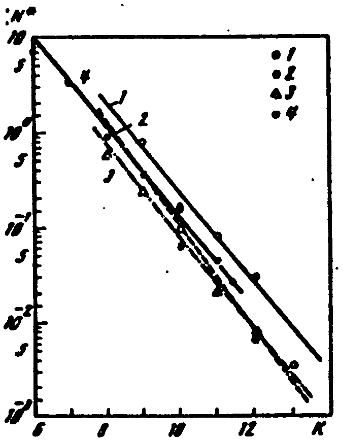

Figure 76. Recurrence rate of the earthquakes of Northern Tyan'-Shan'
1 -- 1929-1950; 2 -- 1951-1961; 3 -- 1962-1967; 4 -- 1972-1975 (RTS)

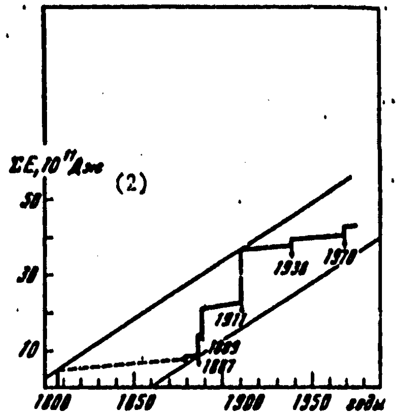

Figure 77. Benioff graph for Northern Tyan'-Shan'

Key:
1. years; 2. joules

Let us consider the graphs of the recurrence rate of earthquakes for different times of instrument observations (Fig 76). The period from 1951 to 1961 is marked by increased activity by comparison with the later times. During this period the activity A_{10} reduced to an area of 1000 km^2 and the time interval of 1 year had a value of 0.2 for an angular coefficient of the slope of the graph $\gamma=0.47$. The next time interval of 1961-1967 has $A_{10}=0.1$, and the slope of the graph $\gamma=0.55$. The increase in the slope is connected with general attenuation of the activity for the 1962-1965 period. During this period the number of earthquakes of energy classes 9 and 10 was minimal for the entire observation time. The later time interval of 1968-1972 (not presented in Fig 76) is similar with respect to level of activity to the preceding one, $\gamma=0.5$ [55, 56]. A comparison of the graphs with the radiotelemetric system data (RTS) of the observations in recent years indicates that the graph of the recurrence rate 4 turned out to be somewhat higher with respect to activity level, $A_{10}=0.13$, and the angular coefficient of the graph $\gamma=0.46$, which is connected with general weak increase in activity of Northern Tyan'-Shan' in recent years. It is significant that the weak earthquakes of sixth to seventh energy class are indicated with a common behavior of the recurrence rate graphs in the preceding years. This fact justifies the study of the characteristics of the region with respect to weak seismicity, and the relation of the weak earthquakes to the stronger ones (K=10-12) can indicate the nature of the activation of the region in the future.

The graph for the isolation of seismic energy of the region of Northern Tyan'-Shan' is presented in Fig 77. On construction of it, the assumption was made that during the periods of weakening of the seismic activity of the region the course of the energy release differed little from that observed by the instrument data for the period since 1929; the energy of the seismic shock of 1807 was approximately the same as the earthquake of 1887. From the graph it is possible to draw the conclusion that the relative quiet in the seismic activity observed in recent years must be replaced in the near future by significantly growing activity. The available time reserve must be spent on the development of more detailed geophysical and seismological operations in order to predict the time of a possible strong shock. One of the phases of this work is the radiotelemetric recording system.

§2. Seismic Characteristics of Alma-Ata

The Alma-Ata test area is in a seismically active territory which has been studied by seismologists for a long time. The most complete information on the seismic conditions of the entire region and also the Alma-Ata seismically active region for the period from 1951 to 1967 were obtained as a result of the work of the complex seismological expedition of the Earth Physics Institute of the USSR Academy of Sciences for the period from 1966 to 1972 -- the Iliyskaya expedition, and in recent years, the Institute of Geology and Geophysics of the Kazakh SSR Academy of Sciences. The specific nature of the observations of the test area of highly sensitive (even in the territory of the city) automatic stations with radiotelemetric multichannel recording and a united time service insured more complete recording of the weak shocks and higher accuracy of determination of the position of the centers of the local earthquakes in this area (±1-2 km) at the same time as in the preceding papers the accuracy of determining the position of the epicenters and the depths of the centers, as a rule, did not exceed ±3 to 5 km. This made it possible to study the time-space laws of the distribution of the weak local earthquakes in a very local region adjacent directly to the city of Alma-Ata which is impossible to do by the regional network observations.

Let us proceed with the discussion of the results obtained by the observation of the seismic conditions for the period from June 1972 to July 1976. When studying the seismic regime, in addition to determining the spatial position of the earthquake centers (the construction of the epicenters) estimates were also made of the mean recurrence rate of the earthquakes and its variations in time for the area as a whole.

Epicenter Maps. The maps of the epicenters reflect the spatial position of the centers in the investigated region. In order to construct maps of the epicenters under the conditions of the test area, the fixed energy class of earthquakes is representative, for the epicenter distribution does not depend on the location of the stations for it. The epicenters of the fifth energy class earthquakes are basically constructed by the two southern stations of Talgar and Ozero; for them t_{S-P} usually is 3-5 seconds. These earthquakes characterize the seismic conditions in a radius of 25-30 km of the Talgar and Ozero stations.

The depths of the centers are reckoned from the reduction line (see Fig 41, a). Their gradation on the epicenter maps is given every 10 km; on the depth maps it is given every 5 km. The maps of the epicenters are presented both with respect to years and for the entire observation period. The center depth map was compiled separately.

Over the extent of the entire period of instrument observation from 1929 to 1967 according to the data from the complex seismological expedition and from 1966 to 1971 according to the research data of the Iliyskaya expedition with the Zemlya type equipment [3, 50, 54, 55], the Zailiyskiy and Kungey Alatau region appeared to have the same seismic activity. Fig 78 shows a map of the epicenters of the nearby earthquakes of the Alma-Ata seismically active zone for 1966 to 1971 from reference [54]. The territory that we investigated is outlined on it. The results of these studies are of interest as directly preceding our observations in the radiotelemetric test area.

As follows from investigation of Figures 78 and 79, the epicenters of the earthquakes in the investigated territory are distributed highly nonuniformly. The greatest density of the epicenters of all the energy classes on both maps is observed south of the test area. This is the central part of the Zailiyskiy and Kungey Alatau Ridges.

A line running through the sections with increased density of epicenters according to the 12-year observations of the complex seismological expedition (1956-1967) and also the belts of high seismic activity according to the data of reference [3] is plotted on Fig 79. According to our data, it is possible to realize a more detailed breakdown of the region of high seismic activity and locate the individual sections of concentration of the earthquake centers. We have provisionally isolated three zones of high seismic activity. Let us call them the "western" zone, the "central" zone and the "eastern" zone.

The "western" zone of concentration of epicenters extended in the form of a strip with a width not exceeding 20 km in the southwesterly direction from Alma-Ata is more clearly outlined (it is also noted in Fig 78). The earthquakes are observed here in a wide range of energy classes, including K=9, 10 and 11. The western zone in the southwest ends with the epicenter of the strongest earthquake during the entire observation time in the test area with K=11.5 on 4 January 1975. The direction of the strike of the strip forms a small angle with the direction of strike of the Alma-Ata and Zailiyskiy zones of deep fractures (Fig 79).

The second zone -- the central zone -- is separated from the first section by reduced seismicity; this is a section of maximum concentration of epicenters of all energy classes. It is located to the south and southeast of the stations of the test area and it is associated with the central part of the Zailiyskiy and the Kungey Alatau Ridges. The zone does not have a clearly expressed direction of strike. In the south it is surrounded by

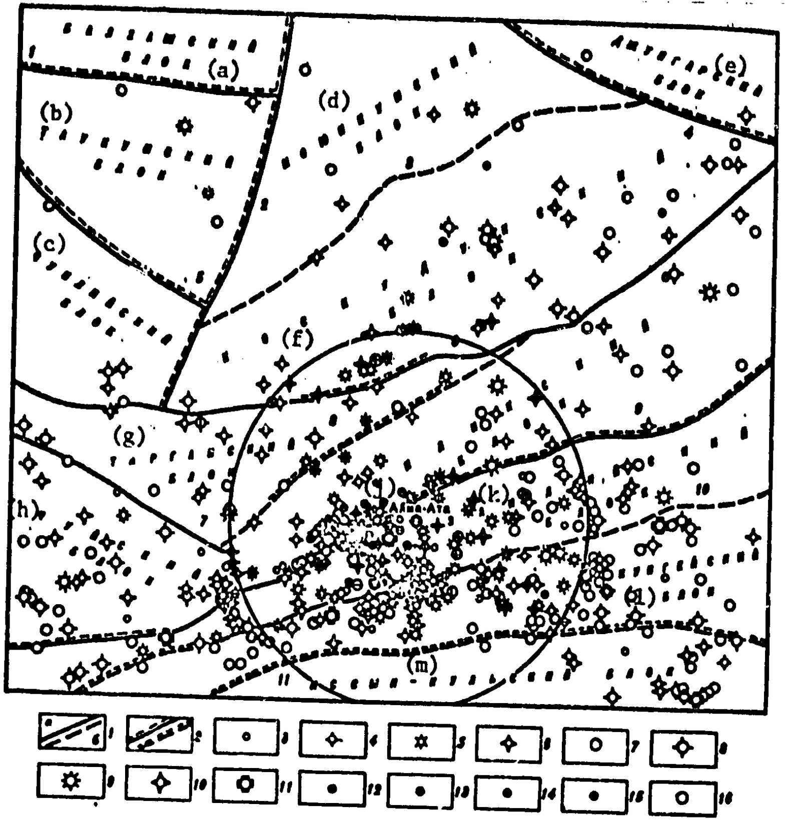

Figure 78. Schematic of the epicenters of nearby earthquakes of the Alma-Ata seismically active region for 1966-1971 [54]

Provisional notation: 1 -- deep fracture zones penetrating into the mantle (a) and into the basaltic layer (b); 2 -- deep fracture zones renewed in alpine time; 3-10 -- epicenters of earthquakes of the following energy classes: 3 -- fourth, 4 -- fifth, 5 -- sixth, 6 -- seventh, 7 -- eighth, 8 -- ninth, 9 -- tenth, 10 -- eleventh; 11 -- epicenter of the disastrous earthquake; 12-16 -- location of hypocenters with respect to depth in km; 12 -- to 10, 13 -- 11-20, 14 -- 20-30, 15 -- more than 30, 16 -- depth not determined.

The fracture zones (the numbers in the figure) are as follows: 1 -- Taukumskaya, 2 -- Central Kazakhstan, 3 -- Bakpatinskaya, 4 -- Yuzhno-Dzhungarskaya, 5 -- Sarykumskaya, 6 -- Altyn-Emel'skaya, 7 -- Dzhalair-Naymanskaya, 8 -- Chemolganskaya, 9 -- Severo-Tyan'-Shan'skaya, 10 -- Chiliko-Keminskaya, 11 -- Severo -Issyk-Kul'skaya.

[See key on following page]

[Key to Fig 78]:

a. Balkhash block; b. Taukunskiy block; c. Chuiliyskiy block; d. Moyunkunskiy block; e. Duzhungarskiy block; f. Koskudukskiy block; g. Targalskiy block; h. Chilikskiy block; i. Chuyskiy block; j. Alma-Ata; k. Zailiyskiy block; l. Kungeyskiy block; m. Issyk-Kul'skiy block

a region of quite sharp reduction in seismicity (at a distance of 40 to 45 km south of Ozero station) although the earthquakes with K>6 would have to be recorded by the Ozero, Alma-Ata, and Talgar stations. To the east the density of the epicenters decreases gradually, and the outline of the zone is blurred. On the whole the strike of the zone close to latitudinal which matches with the strike of the mountain ridges in the general scheme of the tectonic structure is noted.

The section with three zones of deep fractures joined is characterized by the greatest activity: Severo-Tyan'-Shan'skaya from the west and the Kemino-Chilik and Tyupskaya from the east. Within the boundaries of the zone there are two centers of disastrous earthquakes in the past: at the southwest extremity, the most serious disaster in the world, the Kebin earthquake of 1911 (M=8.7), in the central part of the zone, the Vernenskoye earthquake (M=7.2). The zone spreads to the east, and the epicenter concentration increases.

The third zone of clustering of the epicenters is located on the eastern edge of the region of investigation. It separates the strips of relatively low activity which are less clear in the southeasterly direction from the "central" zone. The position of the epicenter concentration belt agrees generally speaking with the zone of high seismic activity isolated in reference [3]; it is true that the epicenters are shifted somewhat to the east. The density of the epicenters in the zone is not very high. It increases in the southern part of the zone in the eastern spurs of the Zailiyskiy Alatau. In this zone the eighth energy class earthquakes are concentrated to a higher degree than all the rest (especially in the south). This is partially connected with the remoteness of the zone from the station network.

When investigating the summary map of the epicenters (Fig 79) the complete absence of centers north of Alma-Ata and Zailiyskaya fracture zones is noticeable, indeed even in the central part of the zone. This fact was not noted earlier (see, for example, the map in Fig 78). The high accuracy of the construction provided by the radiotelemetric recording made it possible to locate both the regions of accumulation of centers and the aseismic regions.

Activity of Individual Seismic Zones in Time. The annual maps for 1973, 1974, and 1975 and the semiannual maps for 1972 and 1976 give qualitative representations of the variation in activity of the investigated region on the whole and individual zones of it in time. From Fig 80 it follows that the migration of the centers in time and in space is significant. This was also noted in a number of other papers [3, 54, 55]. The activity of the zones is manifested differently in time.

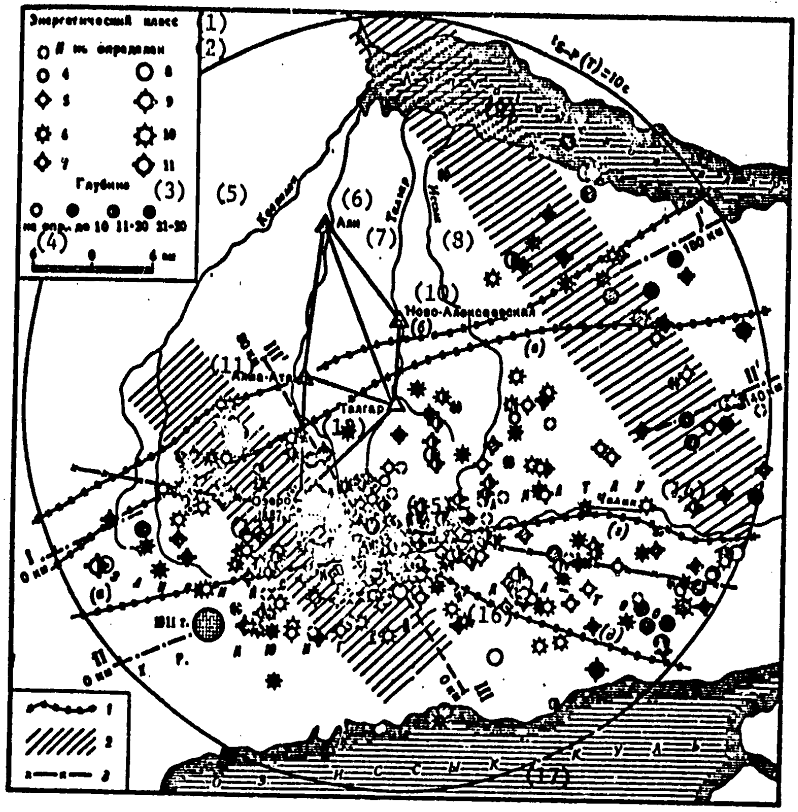

Figure 79. Summary map of the epicenter according to the observation data in the Alma-Ata test area for the period from 1 June 1972 to 1 July 1976.

Provisional notation: 1 -- deep fracture zones: Severo-Tyan'-Shan'skaya (a), Alma-Atinskaya (b), Zailiyskaya (c), Kemino-Chilikskaya (d), Tyupskaya (e); 2 -- zones of high seismic activity according to the data of [3]; 3 -- line passing through the sections with increased density of epicenters for 1956-1967 according to the data of the complex seismological expedition; I-I', II-II', III-III' -- axes of the strips for which the time-space laws of the earthquake distribution were analyzed.

Key:

1. Energy class; 2, K not determined; 3, depth; 4, not determined to 10 11-20 21-30; 5, Kaskelen; 6, Ali; 7, Talgar; 8, Issyk;
9. Kalchagay reservoir; 10, Novo-Alekseyevskaya; 11, Alma-Ata;
12. Talgar; 13, Ozero; 14, Chilik; 15, Zailiyskiy Alatau Ridge;
16. Kyungey-Ala-Too Ridge; 17, Lake Issyk-Kul'.

In the second half of 1972 (Fig 80, a) the seismic activity is low. The accumulations of the centers are observed in three areas: southwest of Alma-Ata -- the greatest concentration in the "western" zone; south of Alma-Ata, in the area of the "central" zone where two earthquakes of energy class 9 were recorded in direct proximity to the city, one of them was felt as a force 3 to 4 earthquake, and in the eastern spurs of Kyungey-Ala-Too Ridge where the accumulation of epicenters is associated with the Tyupskaya deep fracture zone. An earthquake with K=9 was recorded here. In the eastern zone only individual earthquakes were observed, one of them with energy class 10 on 4 November 1972.

In 1973 (Fig 80, b) the seismic activity of the area increased significantly basically as a result of the weak earthquakes of the sixth energy class and lower. The number of earthquakes of energy class 9-10 decreased from 8 in 1972 to 3 in 1973.

The seismic activity in the "western" zone and in the vicinity of the Tyupskaya fracture zone was reduced significantly. South of Alma-Ata, no earthquakes were observed. Then the "central" zone of Zailiyskiy and Kyungey Alatau became active. The high concentration of epicenters here encompassed a large territory of latitudinal strike. Two energy class 9 earthquakes occurred. A separate group of centers appeared east of the Talgar station (by 25 to 30 km).

Finally, the seismic activity of the eastern zone increased, in the northern part of which an earthquake occurred on 24 January with K=10, the only one in 1973.

In 1974 (Fig 80, c) high seismic activity remained in the region, but the internal structure of the epicenter distribution changed. Again the western zone became active. An earthquake of energy class 10 occurred here on 6 May. Near Alma-Ata a small accumulation of centers of weak earthquakes was observed ($K \leq 6$). The concentration of the centers in the central zone did not decrease. Only the configuration of the area of high seismic activity changed somewhat -- it moved toward Alma-Ata (close to Ozero station), growing in the southwestern and northeastern directions where it encompassed a group of epicenters to the southeast of the Talgar station. In the central seismically active zone an earthquake occurred on 27 April with K=10, one out of three in this year. The "eastern" zone became active in the south. An accumulation of centers with K=8-10 was observed here (an earthquake with K=10 occurred on 31 December) characterized by shallow depths of occurrence.

By the epicenter map for 1975 (Fig 80, d) it is possible to determine some decrease in seismic activity in the "central" zone and in the southern part of the "eastern" zone. The activity of the "western" zone remained. On the southwest end, at the very beginning of the year (4 January), an earthquake of energy class 11 occurred (K=11.5). Two months later in the opposite, northeastern edge of the "western" zone an earthquake was recorded with K=9, one out of three in that year, and then an earthquake with K=8.

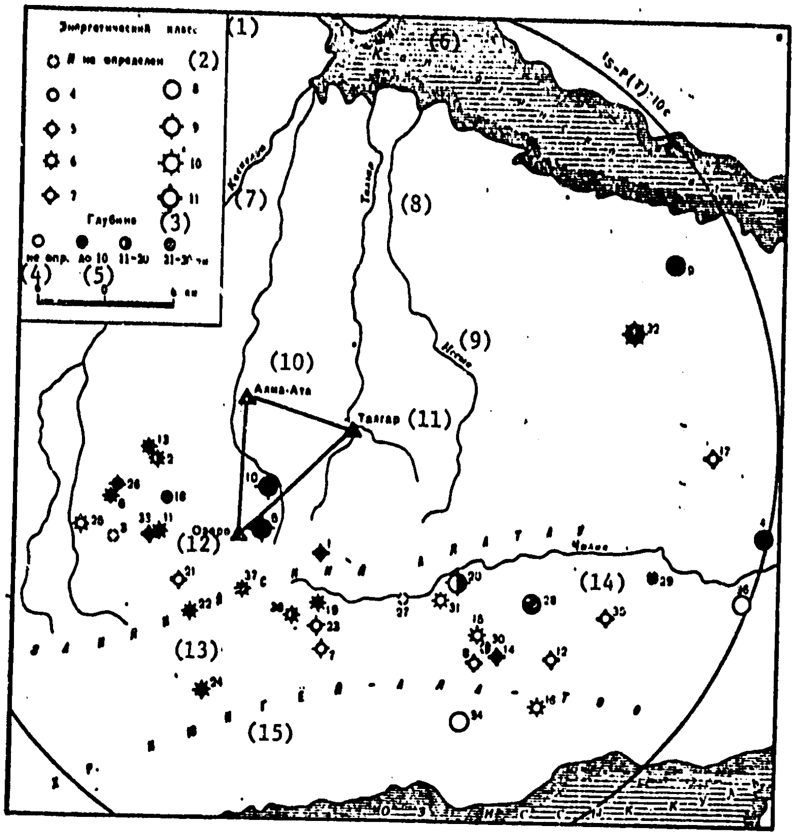

Figure 80. Maps of the epicenters for the period of 1 June to 31 December 1972 (a), for 1973 (b), 1974 (c), 1975 (d), for the period from 1 January to 1 July 1976 (e)

Key:

1. energy class
2. K not defined
3. depth
4. not defined
5. to 10
6. Kapchagay reservoir
7. Kaskelen
8. Talgar
9. Issyk
10. Alma-Ata
11. Talgar
12. Ozero
13. Zailiyskiy Alatau
14. Chilik
15. Kyungey-Ala-Too Ridge

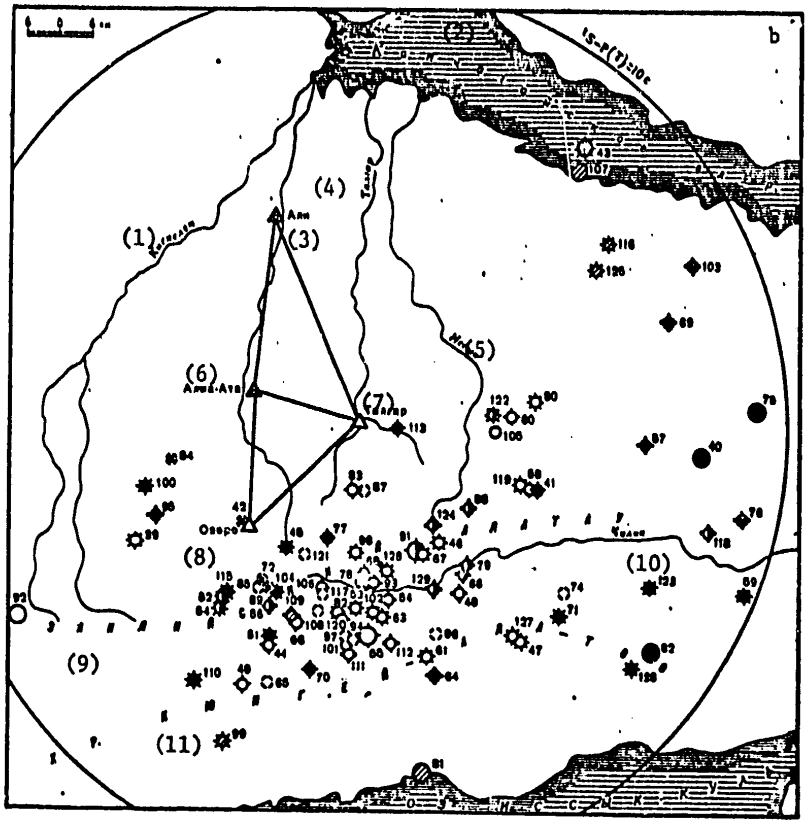

Figure 80 [continued]. The numbers near the epicenters are the order numbers of the earthquakes in the catalog (Appendix I)

Key:

1. Kaskelen
2. Kapchagay reservoir
3. Ali
4. Talgar
5. Issyk
6. Alma-Ata
7. Talgar
8. Ozero
9. Zailiyskiy Alatau
10. Chilik
11. Kyungey-Ala-Too Ridge

In the central zone the configuration of the area with maximum density of the epicenters again changed -- it extended in the latitudinal direction. The group of epicenters in the eastern part of this zone between the Zailiyskiy and the Kyungey Alatau Ridges was singled out where at the end of the year two earthquakes of energy class 9 occurred. A small group of epicenters has been observed in the northern part of the zone near Talgar station.

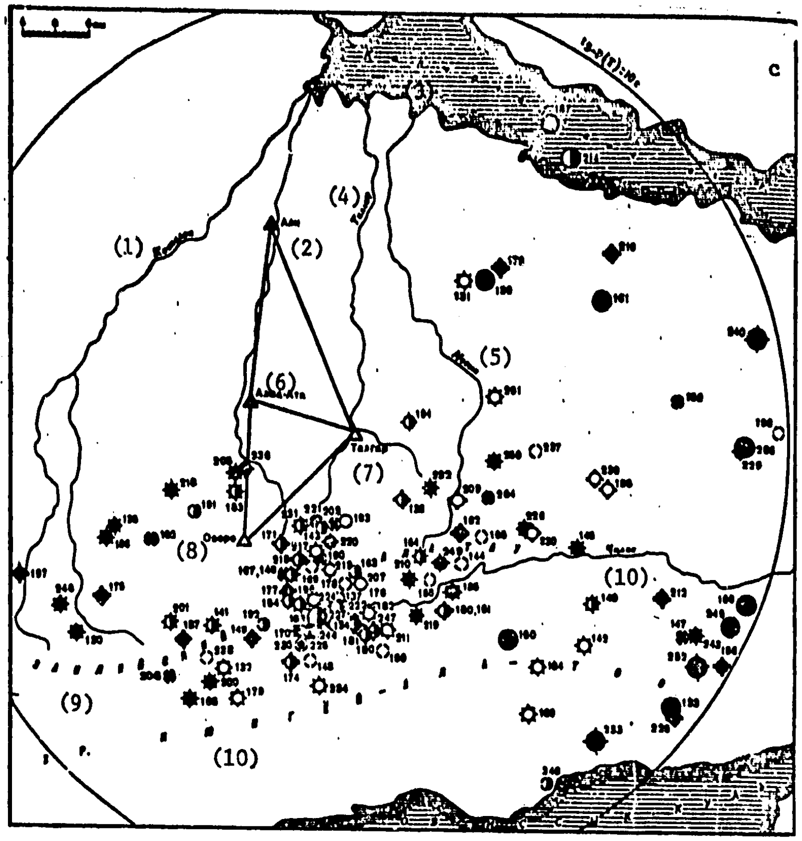

Figure 80, c [continued].

Key:

1. Kaskelen
2. Ali
3. Kapchagay reservoir
4. Talgar
5. Issyk
6. Alma-Ata
7. Talgar
8. Ozero
9. Zailiyskiy Alatau
10. Kyungey-Ala-Too Ridge
11. Chilik

The seismicity of the "eastern" zone, in contrast to the preceding year, is very weakly exhibited, including in the active southern part.

During the first half of 1976 (Fig 80, e) a clear drop in seismic activity is observed. Although the map was compiled by the observations for only the first half of the year, the decrease in activity is obvious. This is especially noticeable in the area with the usual maximum density of the epicenters -- to the south of the test area,

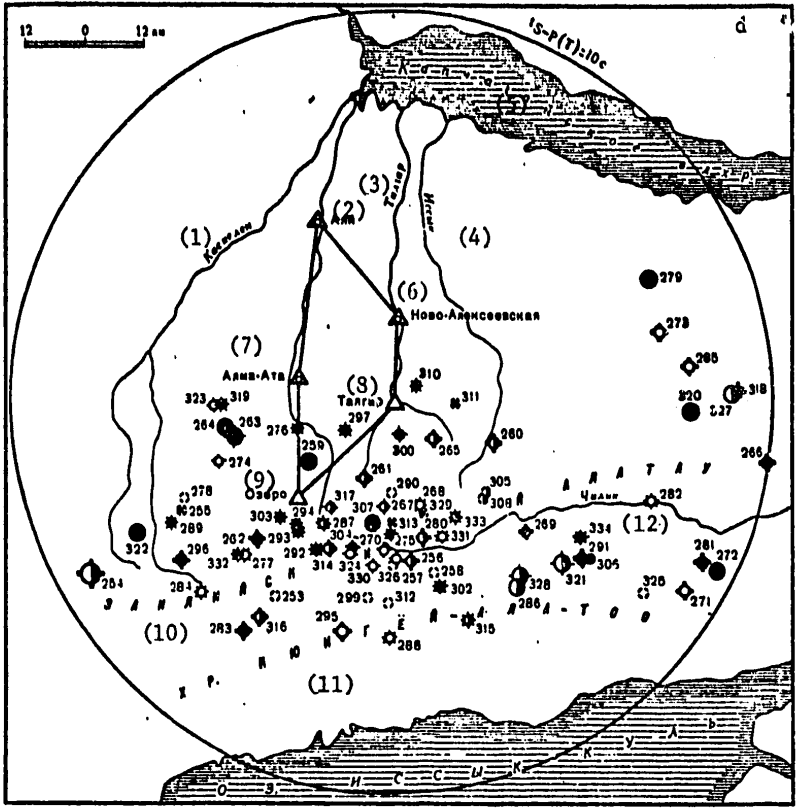

Figure 80, d [continued]

Key:

1. Kaskelen
2. Ali
3. Talgar
4. Issyk
5. Kapchagay reservoir
6. Novo-Alekseyevskaya
7. Alma-Ata
8. Talgar
9. Ozero
10. Zailiyskiy Alatau
11. Kyungey-Ala-Too Ridge
12. Chilik

Out of the highly active broad central zones (according to the observations of 1973-1975) a small chain of epicenters remained in the headwaters of the Chilik River in 1976. The "western" zone was represented by four earthquakes on the northeastern limb.

The strongest of the earthquakes recorded during this 6-months period included one with K=9 and two with K=8 -- they were concentrated in the

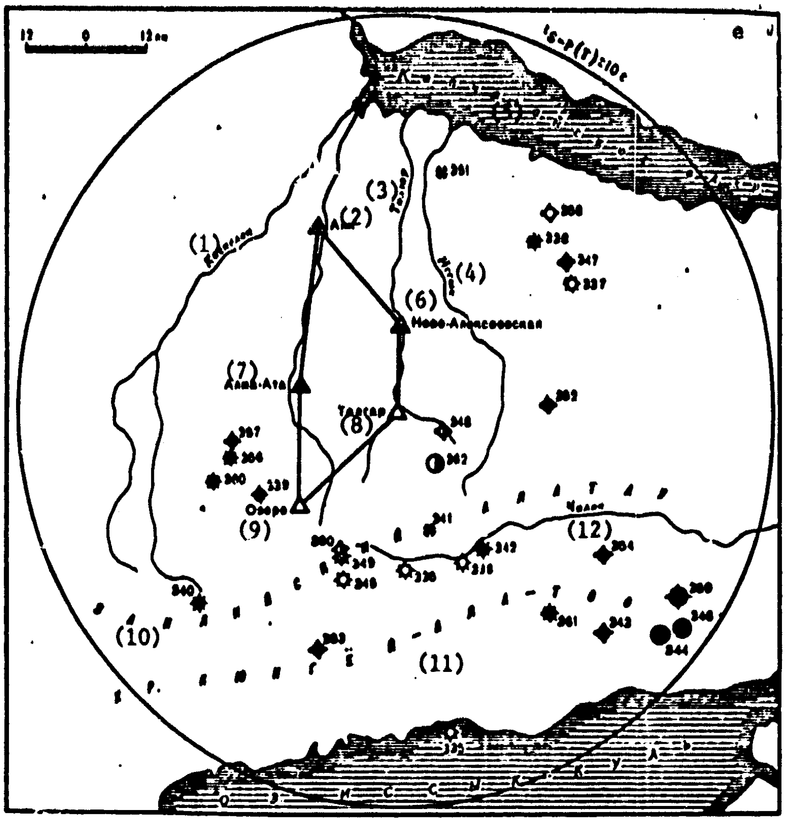

Figure 80, e [continued]

Key:

1. Keskelen
2. Ali
3. Talgar
4. Issyk
5. Kapchagay reservoir
6. Novo-Alekseyevskaya
7. Alma-Ata
8. Talgar
9. Ozero
10. Zailiyskiy Alatau
11. Kyungey-Ala-Too Ridge
12. Chilik

southern part of the "eastern" zone. A small group of epicenters was located by itself in this zone northeast of the Novo-Alekseyevskaya station. An analogous group was observed in 1974.

Time-Space Graphs. To supplement the annual maps of the epicenters let us consider the sequence of earthquakes of different energies and time within the limits of the limited sections of the investigated area. Three strips were selected about 12 km wide each -- two along the direction of strike of the northern zones of the fractures and the mountain ridges (I-I' and II-II'), and one across the strike, encompassing the region of maximum concentration of the epicenters (III-III'). The longitudinal axes of these strips are shown in Fig 79. The earthquake, the epicenters of which fell into the strips, belong to the axial line.

The Belt I-I' (Fig 81) stretches along the Alma-Ata and the Zailiyskaya fracture zone. Its seismic activity is very nonuniform. The "western" zone of increased activity isolated by us was encompassed by this strip and extended from 0 to 60 km (to Alma-Ata). The seismic conditions of the western zone were analyzed in time by the annual epicenter maps. Let us give attention to the fact that the strong earthquake of energy class 11 in the westernmost end of the zone (0-20 km) where there were very few earthquakes was essentially smaller than in the eastern half (20-40 km). It occurred against a background of almost complete seismic quiet and was not accompanied by subsequent shocks. The center of the earthquake is 15 km from the center of the disastrous Kebin earthquake of 1911.

The central part of the fracture zone, as has already been noted, is in practice aseismic. The northeast end of the strip (110-150 km) encompasses the northern part of the "eastern" zone. The comparatively high seismicity was observed here only at the end of 1973 and the beginning of 1974.

Belt II-II', which is similar with respect to strike to belt I-I', encompasses the Zailiyskiy Alatau Ridge and the north slopes of the Kyungey-Ala-Too Ridge, that is, it passes through the section of the "central" zone (20-100 km) with greatest density of the epicenters. As is obvious from Fig 81, over the extent of 3 years of observations the central part of the zone (40-60 km) is characterized by increased seismic activity and the maximum comes in 1973 and 1974. A tenth class earthquake occurred here which was preceded by some increase in activity and then quiet directly before the earthquake. There were few subsequent shocks. The level of activity was high in the central part, decreases sharply to the southwest and northeast where individual, rare earthquakes are observed. The western edge of the belt (0-20 km) looks in general aseismic (although the Kebin earthquake was located here) and it reflects the weak activity of the west end of the Alatau ridges during the entire period of the instrument observations since 1951.

The time-space graph of the seismic conditions in strip III-III' clearly illustrates the displacement of the centers for the 1972-1975 period from the southeast to the northwest.

Center Depth Map. By the data of the preceding studies [3, 30, 31] the earthquakes with K<9 for the most part have depths within the limits of the first 5 km from the earth's surface. It is noted that with low accuracy of determining the depth, in the best case ±5 km, the majority of the earthquakes of Zailiyskiy and Kyungey Alatau have depths of 10-15 km; the deeper centers are a rare phenomenon. The relation of the depth of centers to the energy class of the earthquakes is discussed in reference [3] where attention is given to the fact that the centers of the weak earthquakes of energy classes 4-7 are in the "granite" layer (to 22-25 km); the earthquakes with centers in the lower part of the earth's crust have the highest energy corresponding to classes 7-10. In reference [54] it is noted that in the investigated region all of the centers are located within the limits of the earth's crust. Some 80% are associated with the "granite" layer. It was discovered that the centers concentrated at different hypsometric levels are characterized by their own distribution in plan view.

The center depth map (Fig 82) constructed by the RTS station is of special interest, for in practice all of the epicenters of the "western" and "central" zones and the majority of them are removed from the Ozero or Talgar stations by no more than 40 km. The neutral arrangement of the stations and the earthquake centers with high accuracy of taking the time of arrival of the P and S waves under the conditions of multichannel radiotelemetric recording insured high accuracy of determining the depths of the centers (within the limits of ±1-2 km) of these zones. For the more remote centers of the "eastern" zone the accuracy of determining the depths drops to ±5 km.

Our data also indicate that all of the centers are within the limits of the earth's crust. According to the available data on earthquakes with K<10 no relation was detected between the strength of the earthquake and the depth of the center. No differences were observed in orientation of the centers associated with the different depth intervals in plan view. At the same time the relation of the depths of the centers to the location of the epicenters within the limits of the investigated small territory was established for the first time.

An explicit predominance of shallow centers within the limits of the first 5 kilometers from the surface is characteristic of the "western" zone. (The depth of the center of an earthquake with K=11.5 is, however, 20 km.)

General submersion of the centers in the direction from the southwest to the northeast is observed in the "central" zone. Separation of the "central" zone into three sections is noted, within the limits of each of which the depths of the centers vary little.

The first section is located 15-20 km south of Ozero station and it is characterized by shallow depths H=(-3) to 5 km; H increases occasionally to 10 km.[1] The second section is adjacent to the Ozero station on the southeast and is extended in the same direction. Here depths of centers

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[1] Here and hereafter we are talking about depths reckoned from the reduction line.

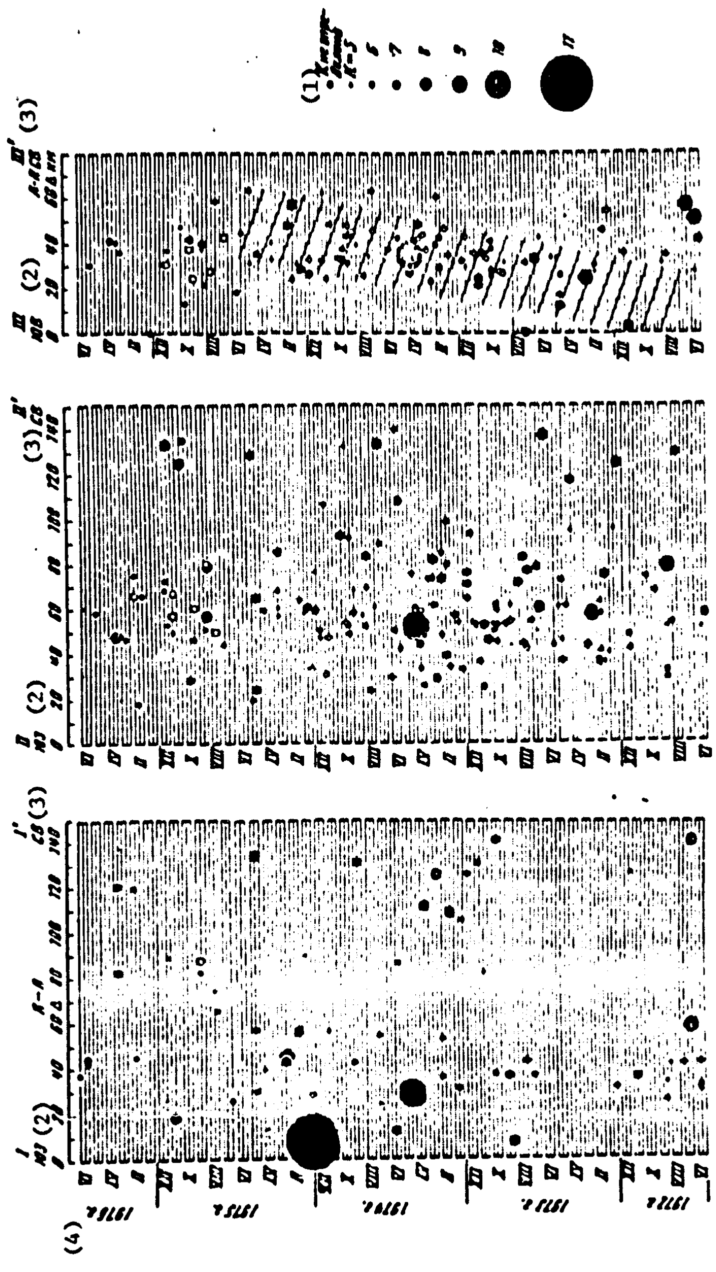

Figure 81. Time-space graphs of the seismic conditions along the I-I', II-II' and III-III' lines (see Fig 79)

Key:
1. K not determined; 2. south; 3. north; 4. years

of 11-15 km predominate. Between these sections there is a narrow belt of earthquake centers characterized by great spottiness of the distribution of the depth -- from 5 to 20 km. The depths of earthquake centers nearest Alma-Ata with energy class 8 and 9 usually are zero. For one earthquake $H=9$ km. The third section is in the eastern part of the zone, the depths of centers here are 15-20 km, and up to 30 km is encountered.

In the "eastern" zone in the north, along with the shallow centers, centers with a depth of up to 30-35 km are observed; in the southern part of the zone the depths are, as a rule, zero.

It was of interest to analyze the center distribution with respect to depths in the vertical plane П-П'. In Fig 83 where this distribution is presented, the submersion in the northeasterly direction of the centers of all earthquakes located both in the strip 12 km wide and in a wider strip essentially encompassing all of the earthquakes of the "central" zone is clearly obvious.

Thus, our observations, which have high accuracy of determining the epicenters of the earthquakes made it possible to break down the seismically active region of Zailiyskiy and Kyungey Alatau into several zones characterized by defined distribution laws of the depths of centers. Against a background of described pictures of the epicenters and depths of centers it is of interest to consider certain laws encompassing all of the recorded earthquakes, including those the centers of which cannot be plotted on the map.

Earthquake Distribution with Respect to t_{S-P} and in Time. According to the observation data for the highly sensitive test area beginning in 1972 first an increase in the number of recorded local earthquakes with $t_{S-P} \leq 10$ sec is observed (1972, 127; 1973, 156; 1974, 217), and in 1975 their number is reduced to 183. These changes occur basically as a result of the earthquakes of energy classes 5 to 7; the annual number of eighth class earthquakes almost does not change in this case, and the annual number of ninth energy class earthquakes decreases. A few -- 5 to 6% -- weak shocks ($K<5$) are recorded. As for the stronger earthquakes ($K>8$), their contribution to the total number of recorded shocks also does not exceed 5-8%. Thus, more than 85% of all of the earthquakes recorded by the stations of the Alma-Ata test area belong to a quite narrow range of energy classes $K=5-7$, that is, just those energy classes which are not fully recorded by the regional network of Kazakhstan.

It was of interest to analyze how the centers of the local earthquakes are distributed as a function of t_{S-P}. For the Talgar station this distribution averaged over the years within the different t_{S-P} intervals is shown in Fig 84, a, and the total distribution for 4 years, in Fig 84, b. It is obvious that the annual number of earthquakes with $t_{S-P}=0-3$ sec does not on the average exceed 10% (N with $t_{S-P}<2$ sec is only 2-3%), and in the range of 3-6 seconds it is about 50% of the total number of recorded earthquakes. The greatest variation of the number of earthquakes in different years is observed in the range of $t_{S-P}=2-4$ and $4-6$ seconds where N varies within the limits of 15-20% at the same time as the annual mean N in other t_{S-P} intervals is more stable, and its variation does not exceed 5-8%. According to the annual distribution graphs it is also obvious that the value of t_{S-P} for the majority of earthquakes decreases from 1972 to 1975. Whereas in 1972 the maximum N came for $t_{S-P}=4-6$ sec, in 1973 it was 4-5 sec, and in 1974 and 1975, in the range of $t_{S-P}=3-5$ sec.

The migration of the earthquakes is clearly illustrated in Fig 84, c, where the annual changes in the relative number of earthquakes recorded by the Talgar station within the range of $t_{S-P}=3-5$ and 4-6 seconds are presented: from 1972 to 1975 the number of the former increases, and the latter decreases.

The southernmost and most sensitive station of Ozero in the test area turns out to be closest to the area with maximum density of the epicenters. It is of interest to analyze the distribution with respect to t_{S-P} of all the earthquakes recorded by the station and to compare it with the distribution of the earthquakes for which the position of the center was determined. This comparison was made in 1974 and 1975 (Fig 85). It turned out that in the range of $t_{S-P}=1-4$ sec (that is, within a radius of 30 km of the Ozero station) there are 10 to 15% more earthquakes than plotted on the epicenter map at the same time as in other ranges of t_{S-P} the growth in number of earthquakes is insignificant and more uniform. A comparison of the distributions of the earthquakes not recorded on the epicenter map, depending on t_{S-P} for the two stations of Talgar and Ozero is presented in Fig 86, a. For the Talgar station all of the earthquakes, the epicenters of which were not determined, are distributed by the values of t_{S-P} more uniformly than for the Ozero station, and in direct proximity to the station ($t_{S-P}=1-3$ seconds) their number even decreases somewhat. Thus, the complete processing of the information with respect to the Talgar station should not essentially change the distribution picture of the centers of local earthquakes presented on the epicenter map.

In order to characterize the seismic activity in time for all of the recorded earthquakes, graphs were constructed for the 10-day number of earthquakes as a function of time (Fig 86, b; Fig 87), and by the epicenter maps, the time-space graphs were constructed characterizing the variation in time of the seismic activity in individual sections (see Fig 81).

Let us discuss the investigation of the first type of graph. What is the distribution in time of the earthquakes recorded only by the Ozero station and not figuring into the epicenter maps? The graph of the 10-day variation of the number of such earthquakes with time in the various ranges of t_{S-P} for 1974 and 1975 is shown in Fig 86, b. It is not excluded that among the earthquakes with $t_{S-P}=2-3$ seconds weak explosions from the vicinity of Medeo could appear which are not recorded by more remote stations (for example, during August-October 1975). The nonuniformity of the distribution of the earthquakes in time -- the periods of increased activity

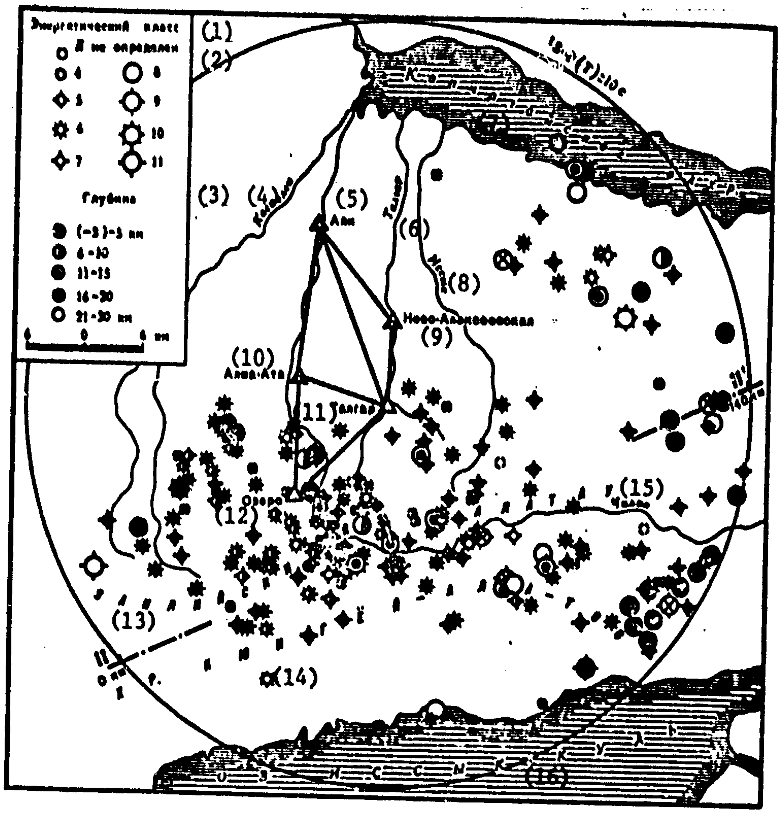

Figure 82. Depth map of Earthquake Center recorded in 1972-1976. The reduction level (H=0) at the depth of the basement under the Alma-Ata station is 4.2 km.

Key:

1. energy class
2. K not determined
3. depth
4. Kaskelen
5. Ali
6. Talgar
7. Kapchagay reservoir
8. Issyk
9. Novo-Alekseyevskaya
10. Alma-Ata
11. Talgar
12. Ozero
13. Zailiyskiy Alatau
14. Kyungey-Ala-Too Ridge
15. Chilik
16. Lake Issyk-Kul'

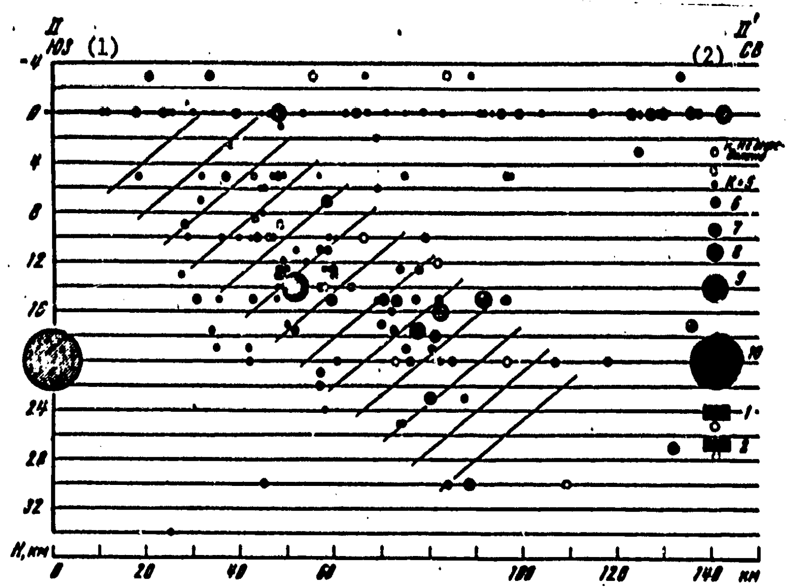

Figure 83. Distribution of centers with respect to depth in the vertical plane along the II-II' direction. The epicenters located within the limits of 6 km (1) and 20 km (2) on both sides of the II-II' line are taken into account. The reduction level is 4.2 km.

Key:

1. southwest
2. northeast

are replaced by almost complete quiet -- attracts attention. The sharp increase in the number of earthquakes within a radius of 15 km of Ozero station (t_{S-P}=1-2 seconds) is observed in September-October 1974 which is correlated with the observation data at the Talgar station (see Fig 87). In 1975 the same increase in August-September is noted, but basically as a result of more remote earthquakes (t_{S-P}=2-3 seconds). For the rest of the time the 10-day number of earthquakes does not exceed two.

For the Talgar station the dependence of the 10-day number of all recorded earthquakes on time is presented in Fig 87. In order to reflect the distribution of these earthquakes with respect to t_{S-P} schematically, they are broken down into three groups (zones); t_{S-P} is less than 4 sec., that is within a radius of 30 km of Talgar; in the range from 4 to 6 sec (30-45 km) and from 6 to 10 sec (45-80 km). This gradation of the earthquakes is caused by the maximum migration of the centers in the range of t_{S-P}=2-4 and 4-6 sec.

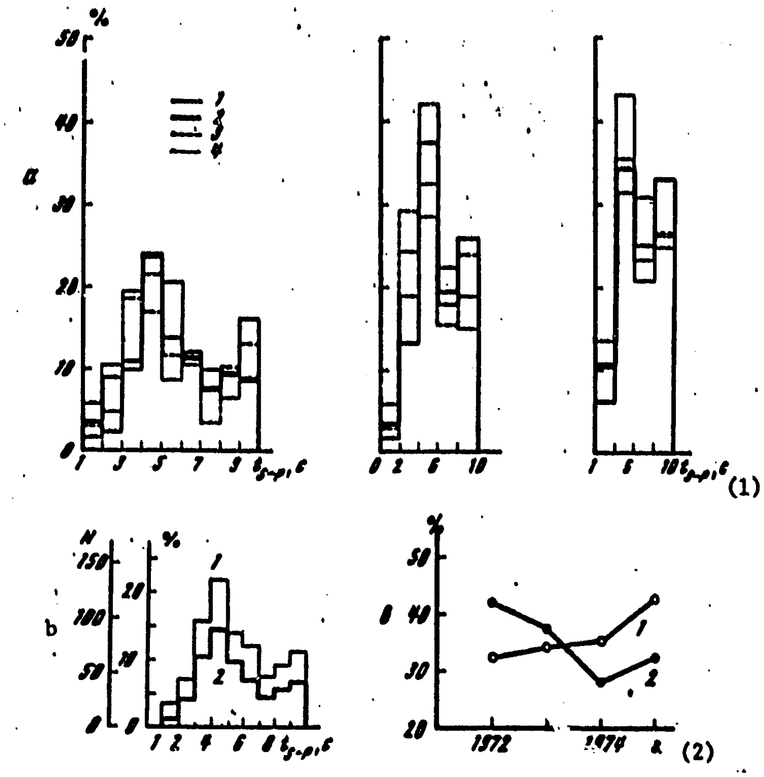

Figure 84. Distribution of the number of earthquakes as a function of t_{S-P} at the Talgar station.
a -- in different observation years (1 -- 1972, N=121; 2 -- 1973, N=165; 3 -- 1974, N=189; 4 -- 1975, N=139);
b -- total (N=635) from 1 June 1972 to 1 July 1976:
1 -- recorded, 2 -- plotted on the map; c -- angle variations in the relative number of recorded earthquakes (1 -- t_{S-P}=3-5 sec, 2 -- t_{S-P}=4-6 sec)

Key:

1. seconds
2. years

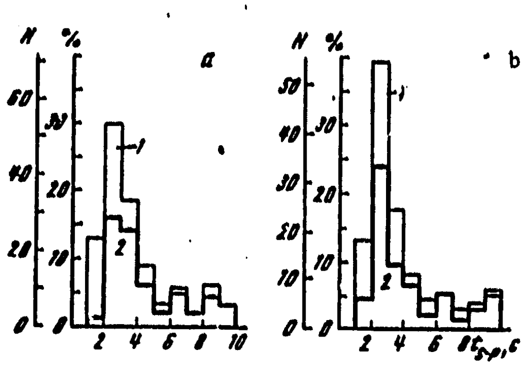

Figure 85. Distribution of the number of recorded earthquakes (1) and those plotted on the map (2) as a function of t_{S-P} at Ozero station for 1974, N=162 (a), and 1975, N=139 (b)

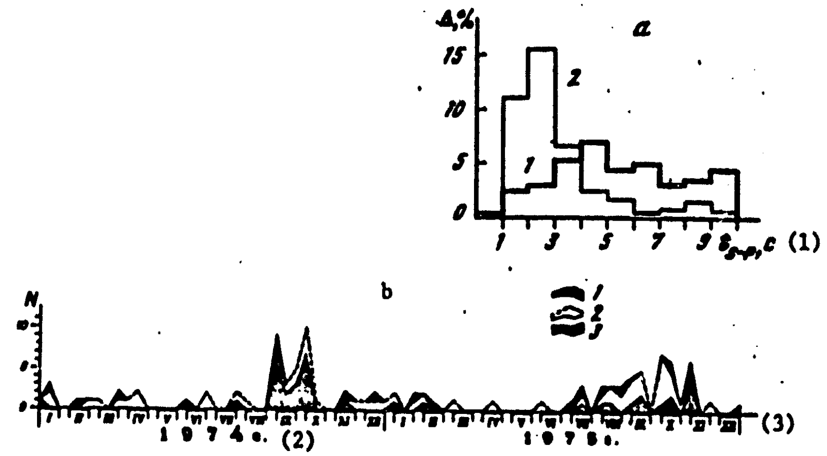

Figure 86. Distribution of the number of earthquakes not plotted on the map Δ for the Talgar station (1) from 1 June 1972 to 1 July 1976 and Ozero station (2) for 1974-1975, as a function of t_{S-P} (a) and a 10-day variation in time of the number N of earthquakes not plotted on the map and recorded by the Ozero station (b) in the range of values of t_{S-P}=1-2 (1), 2-3 (2) and 3-4 sec (3)

Key: 1. seconds; 2, year; 3. month

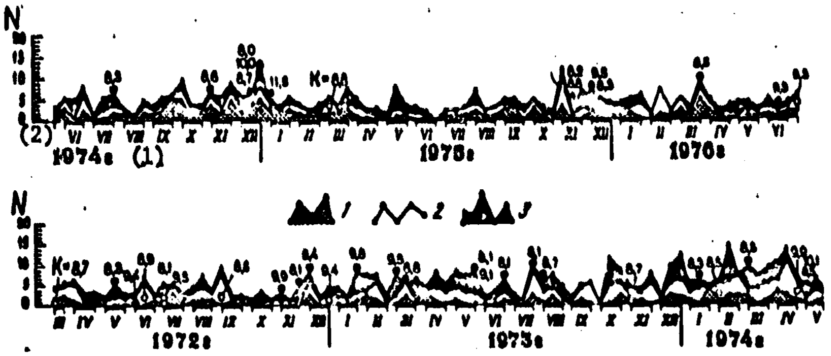

Figure 87. Distribution of earthquakes recorded by the Talgar station from March 1972 to July 1976 in the range of values of $t_{S-P}\leq 4$ (1), $4<t_{S-P}<6$ (2), $t_{S-P}\geq 6$ sec (3)

Key:

1. year
2. month

A study is made of the 10-day variations of the total number of earthquakes for the entire period of centralized radiotelemetric recording from 10 March 1972 to 1 July 1976 (Fig 87). Attention is attracted to the nonuniformity of the distribution of the earthquakes in time. The periods of almost complete quiet from September to November 1972, from June to July 1975, weak activity from May to August 1974, from August to October 1975 and from April to June 1976 and increased activity from October 1973 to April 1974 are observed. No explicitly expressed cyclicity is noted in the manifestation of seismicity (in [3] the presence of a 2-month cyclicity is noted). The periods of increased activity of different duration (5-8 months) are replaced by shorter (2-4 months) intervals of quiet. The predominant time intervals between peaks on curve 3, that is, for the entire region, amount to 70-80 days on the average, more rarely 50-60 or 100-140 days. The seismic conditions of the equally removed zones is not always synchronous: the increase in number of earthquakes in one zone is frequently accompanied by a decrease in the other. For example, the increase in the overall seismic activity during periods from March to September 1972 and from December 1974 to March 1975 are observed as a result of the near zone, during the period from November 1972 to May 1973 as a result of the far zone, and from October 1974 the number of earthquakes increases in both zones. The seismic conditions of the nearest zone (no more than 30 km from Talgar station) are expressed most clearly. Beginning with the end of 1973 a fluctuating but unswerving growth in the number of earthquakes is observed here, reaching a maximum during the period from September to December 1974. The number of earthquakes in the other zones dropped off. This shift of the epicenters closer to Talgar in 1974 was noted when analyzing the earthquake distribution with respect to t_{S-P} (Fig 84, a, c). After the earthquake in January 1975 with K=11.5, a sharp decrease in activity is observed in the near zone.

The shift of the epicenters of the earthquakes of all energy classes from the southeast to the northwest during the period of 1973-1974 is clearly obvious on the time-space graph of the seismic conditions for a strip 12 km wide (see Fig 81, the axis of the III-III' strip) running from the southeast to the northwest along the zone of highest seismic activity. The time-space graphs of the seismic conditions are projections of the epicenters of the earthquakes located within the limits of the strip on the map of the epicenters, on the line running through the middle of this strip. From 81 it is obvious that during the period from the beginning of 1973 to the middle of 1975 explicit migration of the centers in the northwestern direction takes place. In 1975, this law is violated which possibly is connected with the January earthquake in 1975.

In order to discover the relation of the strong and weak earthquakes in Fig 87 in the corresponding zone times are noted (by 10-day periods) for the occurrence of earthquakes of no less than energy class 8. The majority of them are in the far zone. In 70% of the cases association of these earthquakes with the times of increased activity of the weaker shocks is observed. This fact can also be accidental, for the coincidence is observed only in 50% of the cases for the earthquakes of energy class 9 or higher. Judging by the graphs (Fig 87), the earthquakes higher than energy class 8 are observed more frequently in groups of two to five, that is, they are concentrated in limited time interval sometimes lasting 1 to 2 months; then comes a period of absence or them or a sharp individual manifestation. The centers of the earthquakes grouped in time are not associated with the same region.

Recurrence Rate of the Earthquakes. One of the basic characteristics of the seismic regime is the recurrence rate of the earthquakes. The parameters of the recurrence rate graph which is a relation between the logarithm of the energy of the earthquakes (the energy class) and the logarithm of the number of earthquakes for one energy class constitute a quantitative characteristic. The level of the straight line on the graph of $\lg N = f(K)$ averaging the experimental points for the energy class preliminary for the given region determines the seismic activity A on the given energy level. The slope of the graph γ characterizes the ratio of the weak and strong earthquakes.

The graph of the recurrence rate was compiled for the region as a whole for the 1972-1975 period. Table 15 shows the data on the number of earthquakes of different energies by years; the values of K were taken from the bulletins of the Talgar station of the complex seismological expedition. Inasmuch as not all of the investigated earthquakes turned out to be classified with respect to K and about 15% were not recorded as the Talgar station of the complex seismological expedition in general, numbers are presented in parentheses in the table which include the skipped earthquakes for which K was determined by the duration of the recordings.

Table 15

Признак группы	5	6	7	8	9	10	11
1972 г.	18	42	34	9	7	1	-
1973 г.	26	67	31	9	2	1	-
1974 г.	27	65	31	9	2	3	-
1975 г.	36	48	27	9	3	-	1
Всего за 1972-1975 гг.	107 (190)	222 (284)	123 (127)	36	14	5	1
В среднем за год	26,75 (47,5)	55,5 (71,0)	30,75 (31,8)	9	3,5	1,25	0,25
В среднем за месяц	2,23 (3,96)	4,63 (5,90)	2,56 (2,65)	0,75	0,27	0,10	0,02
N^*	0,267 (0,475)	0,555 (0,710)	0,306 (0,318)	0,090	0,035	0,0125	0,0025

Key:
1. Group attribute
2. year
3. Total for 1972-1975
4. On the average for the year
5. Monthly average

In the last row of the table the normalized density of the recurrence rate of the earthquakes N^* is presented. It is equal to the number of earthquakes reduced to 100 km^2 of area (or a volume of $2 \cdot 10^3$ km^3) and a time interval of 1 year. The area occupied by the epicenters (the northwestern sector where centers were not observed is excluded in the area of the circle) is about 10000 km^2. The weak earthquakes for which $K<5$ are incompletely recorded by the Talgar station. In order that the southern stations of Talgar and Ozero record earthquakes with $K<5$, their centers must be located no farther than 25-30 km from these stations.

The number of earthquakes with $K=5$, as is obvious from Table 15, is low. Consequently, the earthquakes of energy class 5 must be considered the representative for the entire investigated territory.

The graphs of the recurrence rate of the earthquakes for the investigated regions by years and the summary graph for 4 years are presented in Fig 88. The values of N^* for energy classes 5 to 7 are taken considering the earthquakes for which class K is defined by the duration of the recording (Table 15). As is obvious from Fig 88, b, the sixth energy class of earthquakes can be considered representative for the investigated area.

On the annual graphs of the recurrence rate (Fig 88, a) significant dispersion of the points is observed basically for the large values of $K=9-11$, lowering the reliability of the averaging and determining the angular coefficient γ. The value of γ is determined more reliably by the summary graph of the recurrence rate for 4 years (Fig 88, b).

The seismic activity for the Alma-Ata region based on the 4-year observations is A_6=0.70. The angular coefficient of the recurrence rate graph γ=0.46. The mean value of γ for the vicinity of Alma-Ata determined for the entire period of instrument observations according to the data of the complex seismological expedition also is 0.46. In the papers of the complex seismological expedition it is noted that both for the entire region of Zailiyskiy and Kyungey Alatau and for the more local Alma-Ata region, a systematic increase in value of γ is observed. For the entire region it is characterized by the following figures: 1929-1950 -- γ=0.3; 1951-1960 -- γ=0.46; 1961-1967 -- γ=0.58.

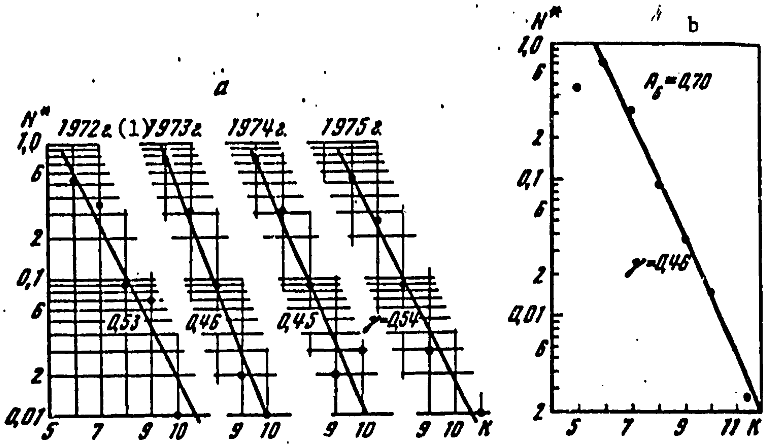

Figure 88. Graphs of the recurrence rate of earthquakes for the Alma-Ata region by year (a) and summary graphs for 4 years (b)

Key:

1. year

For Alma-Ata the especially intense growth of γ occurred during the 1961-1967 period, reaching values of 0.54.

This agrees with the data of reference [55], where the variation of γ is analyzed for the Alma-Ata region for the period of 1959-1970. Thus, in 1953 the value of γ was 0,28 and to 1959 it varied within the limits of 0.47-0.39. From 1959 to 1966 γ increases from 0.39 to 0.67; in subsequent years (1966-1969) the value of γ decreases to 0.39, and in 1970 it again increases to 0.49. In reference [56] information is presented on the variation of γ for the 1966-1974 period preceding the work in the test area. During this time the value of the coefficient of the slope angle varied from 0.40 to 0.67. For 3 years before the Sarykamyshskoye earthquake (5 June 1970, K=15) the value of γ reached a maximum, and then it began to decrease sharply to a value of 0,47 in 1970 which is close to average value of γ with respect to our observations for the period from 1972 to 1975.

§3. Azimuthal Deviations of the Seismic Beams of Distant Earthquakes

In the practice of seismic studies, the azimuth of the source usually is determined by the direction of the seismic beam of the first longitudinal wave. Here it is proposed that the azimuth of the direction of approach of the wave coincides with the azimuth of the epicenter. This condition which is satisfied in uniform or axisymmetric media is far from always adhered to in real media. On passage of waves through inclined boundaries and nonuniformities the seismic beams change direction in space [14, 48]. The laws of variation of the directions of the beams in the case of refraction are investigated, for example, in reference [18].

In order to determine the direction of approach of the wave, either the kinematic or dynamic characteristics of the waves can be used [14, 19]. In the former case the direction of approach is determined in general form by the direction of the field gradient vector (or an individual element of it). For this purpose area observations are required, a special case of which are the observations with respect to two mutually perpendicular profiles.Then the azimuth of the beam is determined by the formula

$$\omega = \text{arc tg } (V^*_X/V^*_Y),$$

where V^*_X and V^*_Y are the apparent velocities with respect to perpendicular direction.

When using the data on the dynamics, the azimuth of the beam is found by observations at one point along the direction of motion of the particles in the first longitudinal wave. In the region close to the wave front, the azimuths determined by both procedures must be equal. In the nonuniform media they theoretically can differ somewhat. It is natural that the calculation of the azimuth by the data from area observations is the most representative and accurate.

Thus, the accuracy of determining the direction of the epicenter is caused primarily by whether the beam azimuth coincides with the azimuth of the direction of the epicenter, that is, the presence or absence of azimuthal deviations. The magnitude of the azimuthal deviations depends on many factors (the ratio of the velocities above and under the refracting interface), the slope angle of the interface and orientation of it in space with respect to the plane of incidence of the wave, and so on). It is difficult to predict the azimuthal deviations theoretically. Accordingly, we have used the observation data from the Alma-Ata radiotelemetric test area to obtain experimental data on the azimuthal deviations of seismic beams of distant earthquakes. In this item a study has been made of the problems of procedure and accuracy of determining the azimuth of the epicenters, and the azimuthal deviations are discovered.

Procedure for Determining Azimuths. The azimuths of the epicenters of the distant earthquakes were determined by the differences in time of arrival of the first longitudinal waves at the three stations. In order to determine the azimuth it is convenient to use nomograms similar to those described in §2 of Chapter IV. The nomogram was calculated for the case of a plane front where the epicentral distance exceeds by 10 times or more the maximum distance between the test area stations. The Mir-1 computer was used to calculate the field of the difference in time of arrival of the seismic waves at three stations for a wave with an apparent velocity of $V^*=8.0$ km/sec. For other values of V^* the recalculation is made by multiplying by the coefficient $m=V^*/8.0$. The azimuths are selected every 10°. The nomograms were calculated for three triangles of stations: Talgar-Ozero-Ali, Talgar-Ozero-Alma-Ata, Talgar-Ali-Alma-Ata.

Examples of the nomogram are shown in Fig 89. The configuration of the isolines on the nomograms for each triangle is determined by the position of the observation stations. The experimental points are located with respect to the entire field. Their position on the plane of the nomogram depends on the azimuth of approach of the waves and the angle of exit of the beam which is related to the magnitude of the apparent velocity V^* by the known Bendorf equation $\cos e=V_0/V^*$, where V_0 is the velocity at the observation point. Inasmuch as the earthquakes were investigated in a very wide range of epicentral distances, from R=600 to 1200 km (Pamir, Afghanistan, China) and to R=15000 to 17000 km (Mexico, Chile, Argentina), the values of the angles of exit varied within broad limits causing great dispersion of the point. In order to consider this fact, the nomograms were supplemented by isolines calculated for the different values of V^* (5.9, 10, 12, 15, 20, 30, 40, 60 km/sec).

An example of this type of template for the triangle of stations Talgar-Ozero-Ali is presented in Fig 90. The lines of the different azimuths are straight lines or converging at the center of the template. The experimental points are plotted in Fig 90, and areas are described to which they belong. By the figure it is obvious that the points corresponding to the nearby regions -- Afghanistan, Pamir and China -- are grouped near the isolines at $V^*=7$-8 km/sec. As the epicentral distance increases, the points are shifted toward the center of the template, toward the large values of V^*: Japan, Kamchatka -- $V^*=10$-12 km/sec; the Philippines, Indonesia -- great dispersion of the points, $V^*=12$-30 km/sec; Mexico, Chile -- $V^*=30$-60 km/sec. By the nomogram not only is the azimuth of the direction of approach of the wave determined, but also its apparent velocity or angle of exit e.

The differences in times of arrival of the first longitudinal wave at the stations are plotted on the axes: 1 -- Talgar-Alma-Ata ($t_T-t_{A-A}=\Delta t_1$) and Talgar-Ozero ($t_T-t_O=\Delta t_2$); 2 -- Talgar-Alma-Ata (Δt_1) and Talgar-Ali ($t_T-t_A=\Delta t_3$), 3 -- Talgar-Ali (Δt_3) and Talgar-Ozero (Δt_2). The theoretical and experimental data for each triangle of stations are illustrated by their own symbols, circular and fine respectively.

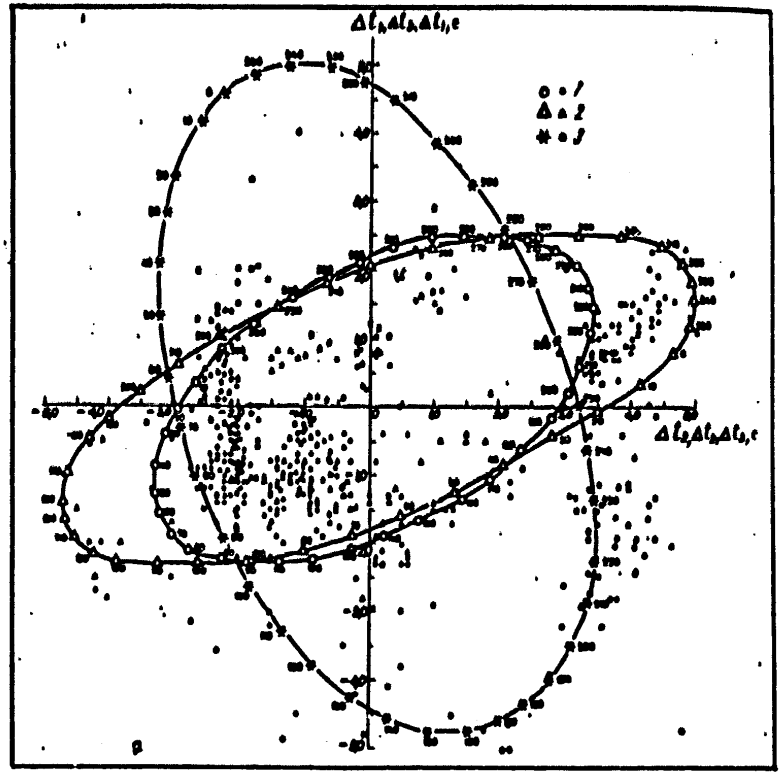

Figure 89. Nomogram for determining the azimuth of the directions to the epicenters of distant earthquakes for $V^*=8.0$ km/sec

By the azimuthal deviations we mean the difference in azimuths of the epicenters determined by the test area data and over the globe. This deviation will be positive if the experimentally determined azimuth exceeds the actual value.

Estimating the Accuracy of Determination of the Azimuth to the Source. The error in determining the azimuth of approach of the waves is made up of the errors of two types -- instrument errors and station erros -- which depend on the direction of approach of the wave, that is, on the azimuth a and angle of exit e, For the distant earthquakes the predominant observed values of V^* are included within the limits of 8-20 km/sec. The errors are determined also by the mutual location in space of the observation stations, and they do not coincide with the different triangles of stations. In each specific case this permits selection of the best triangle of stations from the point of least errors to determine a.

Let us estimate the values of the possible instrument and station errors when determining azimuth to the source.

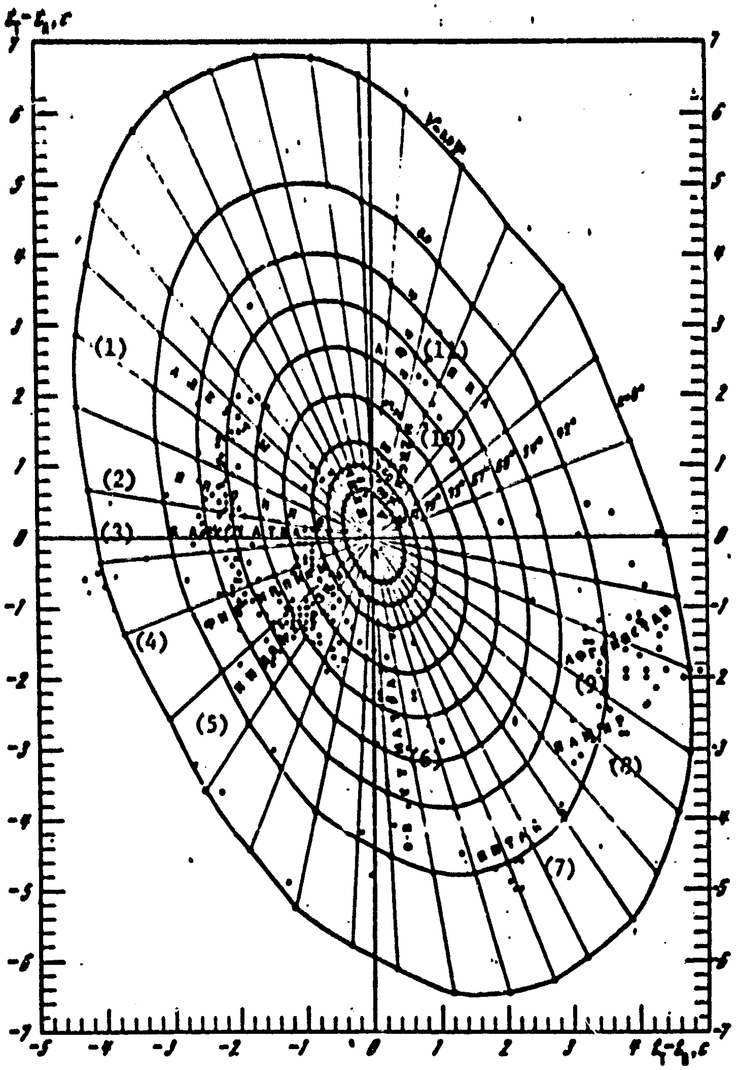

Figure 90. Nomograms for determining the azimuth of earthquakes by the triangle of stations Talgar-Ozero-Ali

Key:

1. Aleutians; 2. Japan; 3. Kamchatka; 4. Philippines; 5. Indonesia; 6. Sumatra; 7. China; 8. Pamir; 9. Afghanistan; 10. Mexico; 11. Africa

Instrument Errors. The errors connected with the time service belong to the $\Delta a_{instrument}$. For centralized radiotelemetric recording with a united time service these errors reduce only to errors in reckoning the time difference on the seismogram and depend on the scanning rate and the predominant oscillation frequencies. In our case this error does not exceed ±0.1-0.2 seconds.

Depending on the azimuth of the source, $\Delta a_{instrument}$ were calculated for two values of the apparent velocity $V^*=8$ and 20 km/sec ($e=48$ and 17°). The error in reckoning the difference in time of arrival of the waves at two stations was taken as a maximum at ±0.2 seconds. The values of the least and greatest instrument errors of $\pm\Delta a_{instrument}$ (in degrees) for the large triangle of stations Talgar-Ozero-Ali are presented in Table 16. For fixed values of V* the maximum and minimum errors differ by 1.5-2 times. With an increase in V* the error $\Delta a_{instrument}$ increases (according to the data in Table 16, by 2-3 times).

For the large triangle Talgar-Ozero-Ali $\Delta a_{instrument}$ is half that for the triangle Talgar-Ozero-Alma-Ata.

Table 16

V*, km/sec	Azimuth from the Talgar station	
	50-90, 230-310°	160-210, 350-30°
8	2-3	5-6
20	6-9	12-14

Station Errors. In contrast to the instrument errors which are of a random nature and determine the width of the fiducial interval, the station corrections are systematic. The station deviations are caused by a different position of the stations in space and geological structure in the vicinity of the stations. As has already been mentioned, the stations in the first area are under the conditions of sharp variation in relief of the day surface -- the automation difference between Ozero and Alma-Ata stations reaches 3400 meters, and between Ozero and Talgar, 1760 meters. The Ozero, Talgar and Ali stations are located on bedrock, and Alma-Ata and Novo-Alekseyevskaya on sediment.

The depth of the basement under the Alma-Ata station equal to 4200 meters was selected as the reference level for the depths. The errors δt in the time delay Δt considering the capacity of the station system depend on the apparent velocity. Inasmuch as the corrections are not introduced into the absolute travel times, the values of δt are the difference in travel times of the waves to the different stations of the test area in the section above the reduction level. For large values of V* ($e=90°$) the difference in paths of the waves is close to the difference in heights; with a decrease in V* it increases and the correction for the relief increases correspondingly.

The graphs of the corrections for the relief δt_1, δt_2, δt_3 introduced into the observed time differences Δt_1, Δt_2, Δt_3 for the three triangles of stations depending on V* are depicted in Fig 91. The corrections for the relief are maximal for the difference $\Delta t_2 = t_T - t_0$, and they are +0.3 seconds or more; the corrections are minimal for $\Delta t_1 = t_T - t_{A-A}$ and they are equal to about -0.1 second. To values of V*=10 km/sec the corrections δt vary little with variation of V*. For smaller values of the apparent velocity the increase in δt becomes sharper.

The station azimuth corrections Δa_{st} were calculated by the templates of the nomogram type shown in Fig 90. The station azimuthal corrections, just as the instrument corrections, for the triangle of stations Talgar-Ozero-Ali are half those for the triangle Talgar-Ozero-Alma-Ata, the area of which is half as large.

Let us consider Δa_{st} (Fig 92) for the large triangle Talgar-Ozero-Ali. In the azimuth range of 40-220° the corrections are negative; in the range of 220-40°, positive. On the azimuth of 40 and 220° the corrections for relief are 0. The maximum corrections for relief come for azimuth ranges of 100-150 and 290-320°, and they are 7-9° for V*=8 km/sec and 13-15° for V*=20 km/sec. The minimum corrections are observed in the directions of 30-50° and 210-230°. With an increase in V* from 8 to 20 km/sec Δa_{st} increases by 1.5-2 times.

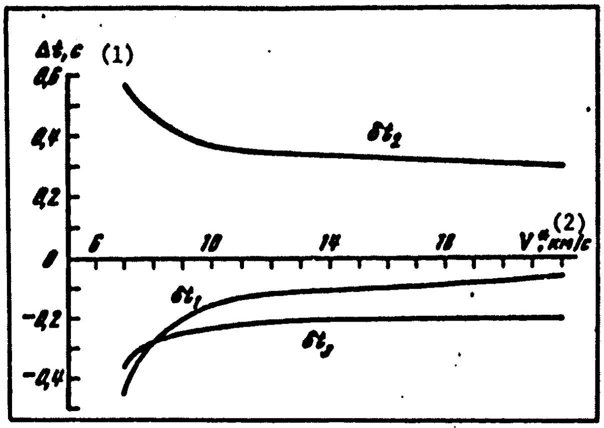

Figure 91. Graphs of the corrections for relief as a function of V*

Key:

1. seconds
2. km/sec

When processing the recordings with respect to the nomograms (Fig 90), the azimuth of the approach of the wave a_1 and the apparent velocity are determined for which the time correction for the relief δt is found for each Δt by Fig 91. Then for each pair of stations a new azimuth a_2 is determined considering the correction for the relief. This permits calculation of the azimuthal deviations without considering the relief $\Delta a_1 = a_1 - a$ and considering the relief $\Delta a_2 = a_2 - a$ (a is the azimuth with respect to the globe).

The azimuthal deviations defined by the differences in times of arrival at the Ali, Ozero and Talgar stations for five earthquakes in 1973 are presented in Table 17. The values at the introduction of the corrections for the relief essentially decrease the azimuthal deviations Δa_2, and they turned out to be within the limits of instrument errors.

Thus, if the observations of the group of stations are made under the conditions of complex relief of the day surface and the geological structure, then without considering the latter when determining the azimuth of the source, significant errors can be permitted. For the Alma-Ata radiotelemetric test area they reach ±15-20°.

Azimuthal Deviations of Directions to the Source. For processing, recordings of distant earthquakes ($R > 400$-500 km) were selected which have been recorded during the 1972-1974 period and which had sufficiently clear arrivals of first wave insuring accuracy of determining Δt no lower than ±0.2 seconds. The majority of the earthquakes were recorded by the slaved recording system where the accuracy of determining Δt was ±0.10-0.05 seconds.

The majority of the processed 366 recordings of distant earthquakes are grouped with respect to defined regions, each of which characterizes the predominant values of V^* (see Fig 90). The observed values of the apparent velocity lie within very broad limits (from 6.5 to 60 km/sec), the angle of arrival e varies from 25 to 85°. The predominant values of V^* are 10-30 km/sec ($e = 55$-$80°$). The representativeness of the regions is not identical. The maximum number of recordings were obtained from the regions of Indonesia, the Philippines, Japan and the Kamchatka-Japanese zone; the minimum number, from the areas of Chile, Argentina, Peru and Mexico. The processing results are illustrated in summary graphs of the azimuthal deviations as a function of azimuths of the epicenters (Fig 92). The curves for the maximum instrument errors for two values of V^* are depicted on the same graphs. The azimuthal deviations are of interest, the magnitude of which stably go beyond the limits of possible errors.

Let us consider the azimuthal deviations defined by the Talgar-Ozero-Ali triangle (Fig 92). The values of Δa_1 and Δa_2 for the earthquakes are plotted on the graphs from the provisionally isolated five sectors located in different directions.

Table 17

Дата (1)	Время суток, ч, мин (2)	Район (3)	Эпицентральное расстояние, 10^3 км (4)	V^*, км/с (5)
20. XII	21,01	Юго-восточнее о-ва Хонсю (6)	5,5	11,6
20. XI	2,38	Иран (7)	2,3	13,4
14. XII	9,16	Каспийское море (8)	2,3	16,0
10. XI	8,45	Море Банда, Индонезия (9)	7,6	26,0
29. XII	7,38	Боливия–Чили (10)	16	32,0

Key:

1. Date
2. Time of day, hours, minutes
3. Region
4. Epicentral distance, 10^3 km
5. V^*, km/sec
6. Southeastern Honshu Island
7. Iran
8. Caspian Sea
9. More Banda, Indonesia
10. Bolivia-Chile

1. The Kamchatka-Japanese sector (azimuth 50-80°) corresponds to the range of small instrument and station errors. The introduction of corrections for the relief insignificantly change the position of the experimental points, but it grouped them more compactly. The small, but stable negative azimuthal deviations on the order of 5° are still observed after introduction of corrections for the relief.

2. The Indonesian sector includes azimuths to the epicenters of 90-140°. For this sector a maximum number of recordings were obtained, and significant scattering of the experimental points is observed. The large corrections for the relief in the sector essentially diminish the dispersion of the points. The azimuthal deviations of the beams in the sector of the azimuth 90-130° are stable. They are negative and they amount to 10°, that is, they coincide with respect to sign with the Δa for the Kamchatka-Japanese sector, but they exceed it by 2 times with respect to magnitude.

3. The Chinese sector contains azimuths of 110-190°. The number of observation points is small, and the centers are near; therefore the values of V^* are small. The large time corrections for the relief δt which can turn out to be somewhat high and the azimuth range correspond to the maximum Δa_{st}. The introduction of the corrections for the relief shifts the points beyond the limits of possible errors; the values of the azimuthal deviations become positive and equal to 5-10°. The results of estimating Δa for the earthquakes from this sector are not very convincing.

4. The Hindukush sector is the azimuth of 210-220°. In this very narrow sector of directions there are many observation points which are piled together. The corrections for the relief are in practice zero. Stable positive azimuthal deviations of 10-15° are observed. The most reliable results are obtained in this sector.

Table 17 [continued]

Азимут,° (1)			δt, c		$\Delta a_{ст}$	Азимутальные отклонения,° (2)		$\Delta a_{инстр}$,° (3)
a	a_1	a_2	$t_T - t_0$	$t_T - t_A$		Δa_1	Δa_2	
79	66	72	0,34	−0,22	6	−13	−7	±8
246	253	250	0,33	−0,21	−3	7	4	±4
277	289	280	0,32	−0,21	−9	12	5	±4
120	98	117	0,30	−0,20	19	−22	−3	±9
302	318	298	0,30	−0,20	−20	16	−4	±8

Key:

1. azimuth, °
2. azimuthal deviations, °
3. Δa_{instr}

5. The Latin American sector (azimuths 30–350°) has few data and great dispersion of the experimental points -- Δa=±30°. The corrections for the relief are large; their introduction has decreased the dispersion of the points somewhat. All of this and also the large values of V* reduce the accuracy of determining Δa. However, on the whole it is possible nevertheless to say that the positive signs of azimuthal deviations predominate, the magnitude of which is difficult to estimate.

Thus, the experimental observations of the distant earthquakes by a group of stations in the Alma-Ata test area revealed stable deviations of the directions of propagation of the first longitudinal waves from the azimuth to the epicenters caused apparently by nonuniformities on the path of the beams. The values of the size of the deviations are different for beams and different azimuths. The accumulation of this information is of great interest from the point of view of studying the nonuniformities of the medium. The development of the procedure for such observations under complex conditions of the ground relief and also the discovery of azimuthal deviations as a function of the epicentral distance are of interest. This analysis has not been specially performed. It is only possible to give attention to the fact that two such regions as Indonesia and China, which are in the same azimuth sector but at different distances from the observation point, are characterized by azimuthal deviations of the seismic beams of different sign.

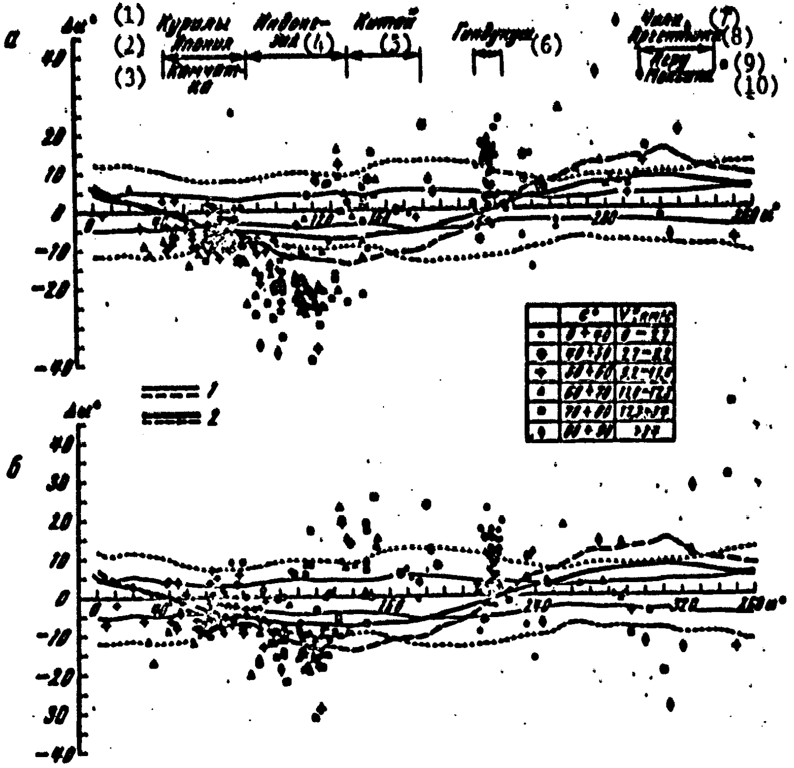

Figure 92. Azimuthal deviations as a function of the azimuth of the epicenters without considering (a) and considering (b) the station corrections
The maximum instrument errors (1) and the corrections for the relief (2) were calculated for two values of the apparent velocity -- 8 km/sec (the side lines) and 20 km/sec (the dotted lines).

Key:
1. Kurils
2. Japan
3. Kamchatka
4. Indonesia
5. China
6. Hindukush
7. Chile
8. Argentina
9. Peru
10. Mexico

§4. Directions of Future Research

The investigated results of the highly sensitive observations with radiotelemetric recording indicate that the general nature of the seismic picture obtained in the Alma-Ata highly sensitive test area and by the ordinary network of stations turns out to be approximately identical. This makes it possible to make a number of remarks with respect to further improvement of the highly sensitive operations with the radiotelemetric recording system.

First of all, it is necessary to note that under the conditions of fixed series of sedimentary deposits with a high level of microseismic interference in the vicinity of a large city the seismic observations in deep wells are the only means of recording earthquakes of weaker energy classes which increases the representativeness of the seismogeological data for a comparatively low level of overall seismic background. The possibility of using the weaker shocks to characterize the seismic conditions in time is the most important result of the research.

One of the basic problems of the development of seismological studies in the regions of probable occurrence of strong seismic events is the use of instrument observations to predict the time of occurrence of strong earthquakes. In order to expand the forecasting possibilities in the investigated area the first step is the expansion of the observation system, first to the east, and then to the west, and then south. Beginning with the noise level of the area, the new eastern and western stations must be located in especially drilled wells. The development of observations in the south is possible under the condition of using low-power and economical radio communications channels, the operation of which is insured by the autonomous power supply. The improvement of the entire radiotelemetric observation system, as a minimum, requires the organization of two or three stations in the west, one in the east and two or three in the south. The experience in operation of the RTS indicates that after expanding the entire observation system it will be possible basically to do away with the application of ordinary seismic stations and at the same time significantly simplify the entire organization of the seismological work in Northern Tyan'-Shan'.

It is necessary to convert from the vertical seismographs to the observation system with tricomponent instruments. This observation system will permit more reliable study of the variation of the ratio of the velocities of the longitudinal and transverse waves in Alma-Ata seismically active region. The expansion of the pass band of the seismic channels in the direction of the low frequencies will permit us to study the spectral composition of the seismic recordings, including at the times of scattering of the voltage at the earthquake center.

These characteristics can be used for forecasting strong earthquakes. The system of observations must also provide the possibility of reliable determination of the mechanism of thecente.s. The experience of such studies in the Garmskiy Rayon of Tadzhik SSR indicates that during the period of preparation of strong earthquakes, a change takes place in the mechanism of the centers of the weak shocks. It is significant that the centralized recordings can insure reliable determination of the difference in path of the seismic waves through the zone of the prepared strong shock. The available data indicate that this characteristic can also be of a forecasting nature.

Thus, the centralized high-frequency recording of earthquakes can insure significant expansion of the seismological data obtained as applied to the problem of predicting strong earthquakes. The effectiveness of the prediction studies can be increased as a result of the use of large stations not only for studying the seismological observations, but also as a result of the organization of observations of other geophysical and geochemical attributes in the same wells. In particular, in the wells observations can be made of the acoustic noise, threshold pressure in the deep water-saturated horizon, the parameters of the geochemical regime of groundwater using automated geochemical analyzers. The expansion of the range of observed parameters will require the application of more multichannel radiotelemetric systems respectively. This system can be created at the present time by the industrially manufactured Konteyner [Container] station.

In order to increase the operativeness of the forecasting observations it is necessary in the near future to organize the input of all of the information to the computer and insure its automatic processing.

The areas of subsequent experiments noted here will depend in the future on a number of technical possibilities, but the prospectiveness of such experiments is quite obvious.

Thus, as a result of the 4-year operation of the radiotelemetric test area a study is made of the seismic characteristics of Alma-Ata for the period from 1 June 1972 to 1 July 1976. The basic peculiarities of the regime are as follows.

1. The seismic activity for the Alma-Ata area is $A_6=0.7$, and the angular coefficient of the repetition rate graph $\gamma=0.46$.

2. The seismically active region of Zailiyskiy and Kungey Alatau known by the data from the preceding studies is broken down into several zones characterized by defined laws of the seismic regime. The activity of the different zones is exhibited differently in time. The highest activity is associated with the section where the three zones of deep faults join -- Northern Tyan'-Shan' with the west, Kemino-Chilik and Tyupskaya with the east -- located 25-30 km in the southeasterly direction from Alma-Ata.

3. Significant migration of the centers occurs in time and in space.

4. There are sectors of the azimuths to the distant earthquakes for which the stable deviations of the directions of propagation of the first longitudinal waves are characteristic. For the Japanese-Kamchatka sector negative azimuthal deviations of 5° are observed; for the Indonesian sector, negative deviations of 10°; for the Hindukush sector, positive azimuthal deviations of 10-15°.

The experience that we have accumulated indicates the expediency of further work in the following areas:

a) Expansion of the geophysical research and creation of equipment for such observations in wells;

b) The development of multiplexing equipment for the radiometric recording channels and the use of series, economic radio relay systems;

c) The development of the method of studying the set of physical parameters;

d) The study of the polarization of seismic waves, in particular transverse waves.

CONCLUSIONS

The most significant difficulty with the detailed study of the seismic characteristics of large industrial centers located in seismically dangerous regions is the high level of interference connected with the vital activity of the city. The basic requirements on the procedure are insurance of highly sensitive observations and high accuracy of determining the centers of local earthquakes. These, to a great extent, contradictory, requirements correspond to the developed procedure based on seismological observations in deep wells permitting a sharp increase in useful sensitivity of the equipment under the conditions of high ground noise level, and in centralized multichannel recording with a united type service significantly raising the accuracy of all of the constructions.

The effectiveness of the seismic observations in the wells arises from the fact that the noise level decreases more rapidly with depth than the useful signal. The gain in useful sensitivity during observations in wells for different regions is different, and it depends primarily on the noise level on the day surface. The higher the ground noise level, the higher the gain in sensitivity. At shallow depths (to 100 meters) in loose sedimentary rock the gain is determined primarily by the absence of the interference of wind origin which is not felt at depths of 40-50 m. A large gain can be obtained for observations in shallow wells discovering the basement. Here even at a depth of 30 to 40 meters with a very high level of ground noise sensitivity can be realized which is close to the sensitivity of the ground stations located under favorable conditions. At average depths (to 500-600 meters) the gain is determined by a sharp decrease in noise level in the upper part of the section and also stability of the noise. Under high noise level conditions the observations in loose sedimentary series at depths of several hundreds of meters can give a significant gain.

The observations at greater depths (2000-3000 meters) in practice in all cases permit us to obtain sensitivity which is close to the sensitivity for ground observations under favorable conditions. However, the difficulties of working at great depth under the conditions of high temperatures and pressure justify such observations only in cases where there is no free choice of the investigation point. In particular, this pertains to the study of the seismic characteristics of large industrial centers.

The 4-year experiment in the operation of the test area of automated highly sensitive deep well and ground stations created in the vicinity of Alma-Ata with centralized multichannel radiotelemetric recording confirmed the effectiveness of such observations systems for studying the seismic regime of large industrial centers. Such systems are characterized by high useful sensitivity of the stations, high accuracy of the constructions, operativeness of processing permitting determination of the position of the centers one to two minutes after the beginning of the earthquake and also economicalness of the operations based on the automatic mode of operation of the stations. A total of three specialists service a test area of five stations.

Under the conditions of seismic quiet characteristic of the north slopes of the Zailiyskiy Alatau, the automated stations of the test area recorded about 700 local earthquakes in 4 years with $t_{S-P} \leq 10$ sec and about 300 explosions. More than 85% of the local earthquakes recorded by the test area stations belong to energy classes 5 to 7 which are not representative for the regional network of stations. The weakest earthquakes recorded only by Ozero station belong to energy class 2. The strong effect of the observation conditions on the structure of the seismograms is felt. The effect of the day surface relief and also the nonuniformity of the upper part of the section have the greatest significance. When studying the seismic characteristics of the city it is necessary on the recordings to discover the local explosions and exclude them from the subsequent processing of the local earthquakes. The explosions in the vicinity of Medeo differ from the local earthquakes with respect to shape of the recording and lower frequency composition.

The procedure for processing the multichannel seismograms from centralized radiotelemetric recording considering the spatial arrangement of the test area stations insures determination of the centers of the local earthquakes with an accuracy of ±1-2 km in plan view and with respect to depth.

This makes it possible to recommend the development equipment and the observation procedure to study the seismic characteristics of large industrial centers or other local sections in seismically dangerous areas and to solve various problems of seismology.

BILIOGRAPHY

1. Aksenovich, G. I.; Belov, B. G.; Kristev, Yu. G., et al. "Recorders with Visible Ink Recording," EKSPERIMENTAL'NAYA SEYSMOLOGIYA [Experimental Seismology], Moscow, Nauka, 1971.

2. Aksenovich, G. I.; Gal'perin, Ye. I.; Gal'perina, R. M., et al. "Study of the Laws of Decrease in Background of Seismic Interference with Depth in the Cities of Alma-Ata and Tashkent," IZV. AN SSSR. FIZIKA ZEMLI [News of the USSR Academy of Sciences, Earth Physics], No 11, 1972.

3. Al'ter, S. M.; Kunin, N. Ya.; Lysyakov, L. M., et al. "Results and Further Direction of Complex and Geophysical Studies of Seismically Dangerous Areas such as Alma-Ata," ZEMNAYA KORA SEYSMOOPASNYKH ZON. [The Earth's Crust in Seismically Dangerous Zones], No 11, Moscow, Nauka, 1973.

4. Andreyev, S. S. "Methods of Interpreting Nearby Earthquakes," TRUDY IFZ AN SSSR [Works of the Earth Physics Institute of the USSR Academy of Sciences], No 25, 1962, p 192.

5. APPARATURA I METODIKA SEYSMICHESKIKH NABLYUDENIY V SSSR [Equipment and Methods of Seismic Observations in the USSR], Moscow, Nauka, 1974.

6. Aptikayev, F. F. SEYSMICHESKIYE KOLEBANIYA PRI ZEMLETRYASENIYKH I VZRYVAKH [Seismic Oscillations During Earthquakes and Explosions], Moscow, Nauka, 1969.

7. Bogdanovich, K. I.; Klark, N. M.; Korol'kov, B. Ya.; Mushketov, D. I. "The Earthquake in the Northern Tyan'-Shan' Chains on 22 December 1910 (4 January 1911)," TRUDY GEOLOGICHESKOGO KOMITETA (NOVAYA SERIYA) [Works of the Geological Committee (New Series)], No 89, 1914.

8. Bune, V. I.; Czovskiy, M. V.; Zapol'skiy, K. K., et al. "Methods of Detailed Study of Seismicity," TRUDY IFZ AN SSSR [Works of the Earth Physics Institute of the USSR Academy of Sciences], No 9, 1960, p 176.

9. Vvedenskaya, N. A. "Problem of Using Instrument Data on Strong Earthquakes of Central Asia During Seismic Regionalization," TRUDY IFZ AN SSSR, No 17, 1961, p 184.

10. Vil'gel'mzon, P. I. KEMINO-CHUYSKOYE ZEMLETRYAYENIYE 21 YUNYA 1938 [Kemino-Chu Earthquake of 21 June 1938], Alma-Ata, 1947.

11. Vostrikov, G. A. "Estimating the Seismic Event of Local Earthquakes by the Tail Section of the Seismogram," DAN SSSR [Reports of the USSR Academy of Sciences], No 2, 1975, p 220.

12. Vyrupayeva, G. P.; Degtyareva, L. A.; Kalmykova, N. A. "Earthquakes of Northern Tyan'-Shan'," ZEMLETRYASENIYA V SSSR V 1969 [Earthquakes in the USSR in 1969], Moscow, Nauka, 1973.

13. Vyrupayeva, G. P.; Degryareva, L. A.; Kalmykova, N. A. "Earthquakes of Northern Tyan'-Shan'," ZEMLETRYASENIYA V SSSR V 1970 [Earthquakes in the USSR in 1970], Moscow, Nauka, 1974.

14. Gal'perin, Ye. I. "Azimuthal Deviations of Seismic Beams," IZV. AN SSSR. SER. GEOFIZ. [News of the USSR Academy of Sciences, Geophysics Series], No 11, 1956.

15. Gal'perin, Ye. I. VERTIKAL'NOYE SEYSMICHESKOYE PROFILIROVANIYE [Vertical Seismic Profiling], Moscow, Nedra, 1971.

16. Gal'perin, Ye. I. POLYARIZATSIONNYY METOD SEYSMICHESKIKH ISSLEDOVANIYA [Polarization Method of Seismic Research], Moscow, Nauka, 1977.

17. Gal'perin, Ye. I.: Vorovskiy, L. M.; Gal'perina, R. M. "Seismological Observations in the Wells and the Possibilities of Increasing the Useful Sensitivity of Equipment," IZV. AN SSSR. FIZIKA ZEMLI [News of the USSR Academy of Sciences, Earth Physics], No 2, 1976.

18. Gal'perin, Ye. I.; Frolova, A. V. "Variation of Direction of Seismic Beams on Refraction on an Intermediate Interface," PRIKL. GEOFIZ. [Applied Geophysics], No 48, 1966.

19. Gamburtsev, G. A. "Determination of the Azimuth to the Epicenter when Recording Local Earthquakes," DAN SSSR, No 2, 1952, p 87.

20. Gamburtsev, G. A. "High Frequency Seismometry," DAN SSSR, No 5, 1953, p 88.

21. Gamburtsev, G. A. "Correlation Methods of Studying Earthquakes," DAN SSSR, No 4, 1953, p 92.

22. Gamburtsev, G. A. "Deep-Well Seismic Sounding of the Earth's Crust," TRUDY GEOFIZ. IN-TA AN SSSR [Works of the Geophysics Institute of the USSR Academy of Sciences], No 25, 1954, p 152.

23. Gamburtsev, G. A.; Gal'perin, Ye. I. "Procedure for Working by the Correlation Method of Studying Earthquakes," IZV. AN SSSR. SER. GEOFIZ [News of the USSR Academy of Sciences. Geophysics Series], No 1, 1954.

24. Gamburtsev, G. A.; Veytsman, P. S.; Tulina, Yu. V. "Structure of the Earth's Crust in the Vicinity of Northern Tyan'-Shan' by the Data from Deep Seismic Sounding," DAN SSSR, No 1, 1955, p 105.

25. Gamburtsev, G. A.; Veytsman, P. S.; Davydova, N. I.; Tulina, Yu. V. "Deep Seismic Sounding of the Earth's Crust in Northern Tyan'-Shan'," BYUL. SOVETA PO SEYSMOLOGII [Bulletin of the Council on Seismology], No 3, 1957.

26. Gamburtsev, G. A.; Veytsman, P. S. "Peculiarities of the Structure of the Earth's Crust in the Vicinity of Northern Tyan'-Shan' by the Data from Deep Seismic Sounding and Comparison with the Geology, Seismology and Gravimetry Data," BYUL. SOVETA PO SEYSMOLOGII, No 3, 1957.

27. Gamburtsev, G. A. "Some New Methods of Seismological Studies," IZV. AN SSSR. SER. GEOFIZ. [News of the USSR Academy of Sciences, Geophysics Series], No 12, 1957.

28. Gamburtsev, G. A.; Gal'perin, Ye. I. "Results of Studying Weak Local Earthquakes in the Southwestern Part of Turkmenia by the Correlation Method," TRUDY G.A. GAMBURTSEVA [Works of G. A. Gamburtsev], Moscow, IZD-VO AN SSSR, 1960.

29. Gamburtsev, G. A.; Gal'perin, Ye. I. "Experiment in Studying Weak Local Earthquakes of the Khait Epicentral Zone of the Tadzhik SSR," TRUDY G. A. GAMBURTSEVA, Moscow, Izd-vo AN SSSR, 1960.

30. Gorbunova, I. V. "Detailed Study of the Seismicity of Northern Tyan'-Shan'," TRUDY IFZ AN SSSR [Works of the Earth Physics Institute of the USSR Academy of Sciences], No 25, 1962, p 192.

31. Gorbunova, I. V. "Study of the Seismic Characteristics of Dzhungaria and Northern Tyan'-Shan'," TRUDY IFZ AN SSSR, No 32, 1964, p 199.

32. Gostev, M. A. "Calibration and Control of Seismic Stations by the Electrodynamic Method," TRUDY IFZ AN SSSR, No 25, 1962, p 192.

33. Zapol'skiy, K. K. "ChISS Frequency-Selective Seismic Stations," EKSPERIMENTAL'NAYA SEYSMOLOGIYA [Experimental Seismology], Moscow, Nauka, 1971.

34. Zapol'skiy, K. K.; Solov'yeva, R. P. "Spectral Characteristics of a Strong Earthquake in Alaska on 28 March 1964 and Its Aftershocks," EKSPERIMENTAL'NAYA SEYSMOLOGIYA, Moscow, Nauka, 1971.

35. Zapol'skiy, K. K. "Spectral Analysis of Seismic Waves of Weak Local Earthquakes," EKSPERIMENTAL'NAYA SEYSMOLOGIYA, Moscow, Nauka, 1971.

36. Zapol'skiy, K. K.; Nersesov, I. L.; Rautiyan, T. G.; Khalturin, V. I. "Physical Principles of the Magnitude Classification of Earthquakes," MAGNITUDA I ENERGETICHESKAYA KLASSIFIKHATSIYA ZEMLETRYASENIY [Magnitude and Energy Classification of Earthquakes], Vol 1, Moscow, Nauka, 1974.

37. Katrenko, V. G. "Method of Analyzing Seismic Information," SEYSMICHESKIYE PRIBORY [Seismic Instruments], No 6, Moscow, Nauka, 1972.

38. Katrenko, V. G.; Ulomov, V. I.; Gal'perin, Ye. I., et al. "Seismological Observations in a Deep Well Located in Tashkent," NOVYYE DANNYYE PO SEYSMOLOGII I SEYSMOGEOLOGII UZBEKISTANA [New Data on Seismology and Seismogeology of Uzbekistan], Tashkent, Fan, 1974.

39. Malamud, A. S. "Relation Between the Energy of Earthquakes and the Duration of the Recording," SBORNIK STATEY PO SEYSMOLOGII. TRUDY IN-TA SEYSMOSTOYKOGO STROITEL'STVA I SEYSMOLOGII [Collection of Articles on Seismology. Workers of the Institute of Earthquakeproof Construction and Seismology], Vol 10, Dushanbe, 1962.

40. Mikhaylova, R. S. "Study of the Seismic Characteristics of the Local Zone Using a Highly Sensitive Seismograph," SEYSMICHESKIY REZHIM. MATERIALY I VSESOYUZNOGO SIMPOZIUMA 12-17 DEKABRYA 1966 [Seismic Characteristics. Materials of the 1st All-Union Symposium on 12-17 December 1966], Dushanbe, Donish, 1969.

41. Mushketov, I. V. "Vernenskoye Earthquake of 28 May (9 June) 1887," TRUDY GEOLOGICHESKOGO KOMITETA [Works of the Geological Committee], No 1, 1890.

42. Mushketov, I. V. "Chilean Earthquake of 30 June (12 July) 1889," MATERIALY DLYA IZUCHENIYA ZEMLETRYASENIY ROSSII [Materials for Studying the Earthquakes of Russia], Vol 1, 1891.

43. Mushketov, I. V.; Orlov, A. P. KATALOG ZEMLETRYASENIY ROSSIYSKOY IMPERII [Catalog of Earthquakes of the Russian Empire], St. Petersburg, 1893.

44. Nersesov, I. L.; Nikolayev, A. V. "Problem of the Dependence of the Predominant Frequencies During Explosions on the Size of the Charge," TRUDY IFZ AN SSSR, No 25, 1962, p 192.

45. Nersesov, I. L.; Tokmulin, M. Kh. "Graphical Method of Selecting Frequency Characteristics," TRUDY IFZ AN SSSR, No 32, 1964, p 199.

46. Nersesov, I. L.; Gal'perin, Ye. I.; Vorovskiy, L. M.; Gal'perina, R. M. "Alma-Ata Seismological High-Frequency Radio Temperature Test Area," IZV. AN SSSR [News of the USSR Academy of Sciences, Earth Physics], No 7, [illegible]4.

47. Nersesov, I. L.; Kurochkina, R. I. "Earthquakes of Northern Tyan'-Shan'," ZEMLETRYASENIYA V SSSR V 1968 [Earthquakes of the USSR in 1968], Moscow, Nauka, 1972.

48. Nikolayev, A. V. SEYSMIKA NEODNORODNYKH I MUTNYKH SRED. [Seismic Characteristics of Nonuniform and Turbid Media], Moscow, Nedra, 1973.

49. Pavlova, I. N. "Dynamic Peculiarities of the Aleutian Earthquake of 4 February 1965 and Its Aftershocks According to the Recordings of the Frequency-Selective Seismic Station," EKSPERIMENTAL'NAYA SEYSMOLOGIYA [Experimental Seismology], Moscow, Nauka, 1971.

50. Pevzner, L. A.; Popov, K. A.; Pushkarev, I. K., et al. "Geophysics Research During Microregionalization of the City of Alma-Ata," GEOFIZICHESKIYE POLYA I SEYSMICHNOST' [Geophysical Fields and Seismicity], Moscow, Nauka, 1975.

51. Pomerantseva, I. V. "Isolation and Correlation of PS Waves Recorded by the Zemlya Stations," TEORETICHESKIYE I EKSPERIMENTAL'NYYE ISSLEDOVANIYA OBMENNYKH VOLN ZEMLETRYASENIYA [Theoretical and Experimental Studies of the Exchange Waves of Earthquakes], Moscow, VNII Geofizika, 1973.

52. Riznichenko, Yu. V. "Methods of Mass Determination of the Coordinates of the Centers of Nearby Earthquakes and the Velocities of Seismic Waves in the Area Where the Centers Are Located," IZV. AN SSSR. SER. GEOFIZ. [News of the USSR Academy of Sciences, Geophysics Series], No 4, 1958.

53. Rozova, Ye. A. "Earthquakes of Central Asia," TRUDY SEYSMOLOGICH. IN-TA AN SSSR [Works of the Seismological Institute of the USSR Academy of Sciences], No 123, 1947.

54. Urazayev, B. M.; Akishev, T. A.; Antonenko, A. N., et al. "Results of the Forecasting Work at the Alma-Ata Geophysics Test Area," POISKI PREDVESTNIKOV ZEMLETRYASENIY. MEZHDUNAR. SIMPOZ. 27.05-3.06.74 [Search for Earthquake Predictors, International Symposium 27 May to 3 June 1974], Tashkent, Fan, 1976.

55. Urazayev, B. M.; Antonenko, E. M.; Ospanov, A. B. "Seismotectonic Special Geophysical and Seismological Studies in Alma-Ata Seismically Active Regions," SEYSMICHESKOYE MIKRORAYONIROVANIYE [Seismic Microregionalization], Alma-Ata, Nauka, 1976.

56. Urazayev, B. M.; Ospanov, A. B.; Latypov, Zh. A., et al. "Earthquakes of Northern Tyan'-Shan'," ZEMLETRYASENIYA V SSSR V 1972 [Earthquakes of the USSR in 1972], Moscow, Nauka, 1976.

57. Fedoseyenko, N. Ye. "Electrodynamic Seismograph," USSR author's certificate, kl. 42 s., No 475581, OTKRYTIYA IZOBRETENIYA, OBRAZTSY I TOVARNYYE ZNAKI [Discoveries, Inventions, Models and Trademarks], No 24, 1975.

58. Khalturin, V. I. "Procedure for Estimating the Spectral Composition of Seismic Oscillations by the Recordings of a Frequency Selective Station (ChISS)," TRUDY IFZ AN SSSR, No 25, 1962.

59. Shnirman, G. L.; Razorenov, A. A.; Agafonov, A. G. "System for Remote Control of Seismic Instruments in Wells," GEOFIZICHESKAYA APPARATURA [Geophysics Equipment], No 59, Leningrad, Nedra, 1976.

60. Afamaty, K. "Microseism in Frequency Range 1-200 cps," BULL. EARTHQUAKE RES. INST., Tokyo Univ., No 39, 1961.

61. Brune, J. N.; Allen, C. K. "A Microearthquake Survey of the San Andreas Fault System in Southern California," BULL.SEISMOL. SOC. AMERICA, No 2, 1967, p 57.

62. Crampin, S.; Willmore, P. L. "Small Earthquakes Observed with Local Seismometer Networks," PHILOS. TRANS. ROY. SOC., LONDON A, 1973, No 1239, p 274.

63. Crosson, R. S. "Small Earthquakes Structure and Tectonic of the Puget Sound Region," BULL. SEISMOL. SOC. AMERICA, No 5, 1972, p 62.

64. Douse, E. I. "Rayleigh Waves in Short Period Seismic Noise," BULL. SEISMOL. SOC. AMERICA, No 4, 1954, p 54.

65. Douse, E. I. "Signal and Noise in Deep Wells," GEOPHYSICS, No 5, 1964, p 29.

66. Douse, E. I. "Noise Attenuation in Shallow Holes," BULL. SEISMOL. SOC. AMERICA, No 3, 1966, p 56.

67. Douse, E. I. "Short Period Seismic Noise," BULL. SEISMOL. SOC. AMERICA, No 1, 1967, p 57.

68. Eaton, J. P.; O'Neill, M. E.; Murdock, J. N. "Aftershocks of the 1966 Parkfield-Cholame, California Earthquake," BULL. SEISMOL. SOC. AMERICAN, No 4, 1970, p 60.

69. Gupta, I. N, "Standing Wave Phenomena in Short-Period Seismic Noise," GEOPHYSICS, No 6, 1965, p 30.

70. Takano, K.; Hagiwaka, T. "Observation of Microearthquakes with a Deep-Well Seismometer," BULL. EARTHQUAKE. RES. INST., Tokyo Univ., 1968, p 46.

71. Levin, F. K.; Lynn, R. D. "Deep-Hole Geophone Studies," GEOPHYSICS, No 4, 1958, p 23.

72. Roden, R. B. "Horizontal and Vertical Arrays for Teleseismic Signal Enhancement," GEOPHYSICS, No 4, 1965, p 30.

73. Roden, R. B. "Seismic Experiment with Vertical Arrives," GEOPHYSICS, No 2, 1968, p 33.

74. Sax, R. L.; Hartenberger, R. A. "Theoretical Prediction of Seismic Noise in a Deep Borehole," GEOPHYSICS, No 5, 1964, p 29.

75. Sax, R. L.; Hartenberger, R. A. "Seismic Noise Attenuation in Unconsolidated Material," GEOPHYSICS, No 4, 1964, p 30.

76. "Second Phase of Earthquake Prediction Program in Tokyo Area," TECHNOCRAT, No 3, 1976, p 9.

77. Takano, K.; Hagiwaka, T. "Preliminary Observation of Microearthquakes with a Deep Well Seismometer," BULL. EARTHQUAKE RES. INST., Tokyo Univ., No 3, 1966, p 44.

78. Hirono, T.; Shyehiro, S.; Furuta, M.; Koide, K. "Noise Attenuation in Shallow Holes," PAPL METEOROL. AND GEOPHYS., No 2, 1954, p 19.

79. Hirono, T.; Shyehiro, S.; Furuta, M.; Koide, K. PAP METEOROL. AND GEOPHYS., No 2, 1961, p 20.

80. Tatel, H. E.; Tuve, M. A. "Seismic Observation at One Kilometer Depth," Contributions in Geophysics in Honor of Beno Gutenberg, Vol 1, London, 1959.

81. Ward, P. L. "Comparison with Data from a Network of Stations and Small Tripartite Arrays on Kilanea, Hawaii," BULL. SEISMOL. SOC. AMERICA, No 2, 1973, p 63.

82. Zoltana, A. D. "Surface Wave Components in Microseism," BULL. SEISMOL. SOC. AMERICA, No 2, 1969, p 54.

APPENDIX I. BULLETIN OF LOCAL EARTHQUAKES RECORDED BY RADIOTELEMETRIC SYSTEM FROM 1 JUNE 1972 TO 1 JULY 1976 FOR WHICH EPICENTERS ARE CONSTRUCTED

Номер землетрясения	Дата	Из бюллетеня станции Т (КСЭ) (a)			Количество станций РТС+региональной сети	H, км
		Время, ч.мин.с	t_{S-P}, с	K		
1	2	3	4	5	6	7
1	9.VI.72 г.(b)	18. 6.52,2	4,4	7,5	3	22
2	11.VI.72 г.	21.30.20,8	4,1	5,6	3+Ч*	12
3	12.VI.72 г.	17.56.14,1	–	–	2	–
4	13.VI.72 г.	0.18.30,0	5,0	8,9	2+К	0
5	13.VI.72 г.	17.31.36,1	9,9	7,7	3+К, Ч(c)	0
6	14.VI.72 г.	1.54.00,0	5,3	6,4	3	7
7	19.VI.72 г.	6. 2.43,2	–	5,2	2	–
8	4.VII.72 г.	3.42.25,4	6,0	6,8	2	–
9	4.VII.72 г.	10.50.30,1	5,8	8,1	2+К, Ч	10
10	6.VII.72 г.	0.46.12,7	2,0	9,5	3	0
11	19.VII.72 г.	18.22.58,3	4,6	6,1	3	5
12	22.VII.72 г.	3.53.26,9	7,9	6,9	2	–
13	29.VII.72 г.	17.15.44,6	4,4	6,4	3	5
14	7.VIII.72 г.	12.32.59,3	5,6	6,9	3+К, Ч	10
15	7.VIII.72 г.	12.35.12,2	5,8	6,2	2	–
16	13.VIII.72 г.	6.10.31,2	7,2	5,8	2	–
17	15.VIII.72 г.	1.34.21,5	8,4	6,9	2	–
18	22.VIII.72 г.	21.57.41,4**	–	–	3	20
19	28.VIII.72 г.	23,20.22,2	4,5	6,1	2	–
20	3.IX.72 г.	6.30.24,4	5,6	8,6	3	17,5
21	4.IX.72 г.	14.39.40,9	5,8	7,5	2	–
22	5.IX.72 г.	13.34.23,3	5,5	6,4	3	5
23	7.IX.72 г.	20.59.19,9	4,8	5,1	2	–
24	8.IX.72 г.	22.19.30,5	5,8	6,4	3	10
25	8.IX.72 г.	23.29.37,2	6,0	5,9	2	–
26	10.IX.72 г.	8.20.26,5	4,5	5,4	3	10
27	8.X.72 г.	4.38.53,1	3,8	–	2	–
28	14.X.72 г.	2.59.40,2	7,2	7,6	3	30
29	16.X.72 г.	21.25. 8,6*	9,2	–	3	30
30	16.X.72 г.	21.41.32,7**	6,5	–	3	20
31	24.X.72 г.	8.15.34,6	4,7	6,0	2	–
32	4.XI.72 г.	6.38.38,3	8,6	9,9	3	30
33	20.XI.72 г.	15. 6. 0,3	9,1	6,7	3	10
34	21.XI.72 г.	7.48.16,3	7,4	9,1	2	–
35	23.XI.72 г.	7.39.34,7	8,0	6,6	2	–
36	3.XII.72 г.	22.17. 9,8	10,0	8,4	2	–
37	8.XII.72 г.	1. 8. 6,3	5,7	6,3	3	19
38	10.XII.72 г.	12.36.44,2	4,8	6,0	3	14
39	8.I.73 г.	5.17.17,7	6,2	6,4	2	–
40	9.I.73 г.	18. 0.57,1	9,0	7,9	2+К	0
41	18.I.73 г.	5.32.46,8	4,8	5,2	2+К, Ч	0
42	19.I.73 г.	1.13.59,3	2,6	–	3	8.5

**, * see end of table, page 246

Key: 1. Earthquake number; 2. date; 3. time, hours, minutes, seconds; 4. t_{S-P}, seconds; 5. K 6. number of RTS stations plus the regional network;
(a) from the station bulletin T (Complex Seismological Expedition)
(b) day, month, year (c) Ch

Appendix I, continued

1	2	3	4	5	6	7
43	24.I.73 г.	7.37.22,1	7,4	9,5	3	0
44	28.I.73 г.	2.32.22,8	5,5	5,1	2	-
45	29.I.73 г.	3.17. 5,0	4,5	6,4	3	5
46	1.II.73 г.	23.10.49,8	7,0	6,0	2	-
47	4.II.73 г.	11.17.20,2	6,6	6,5	2	-
48	5.II.73 г.	2.51.24,8	9,5	7,4	2	-
49	5.II.73 г.	4.31.34,7	6,0	5,5	2	-
51	15.II.73 г.	14.43.41,9	5,9	6,5	3	10
52	15.II.73 г.	14.48.15,5	5,8	6,0	3	15
53	18.II.73 г.	22.47.40,8	4,3	5,9	2	-
54	19.II.73 г.	23.59.15,0	4,1	5,2	2	-
55	5.III.73 г.	10.49.51,0	9,9	9,5	2	-
56	11.III.73 г.	16.13.34,9	5,8	6,8	3	15
57	22.IV.73 г.	2.37.44,1	6,7	7,0	2+К	0
58	29.IV.73 г.	23.46.59,4	4,5	5,2	2	-
59	1.V.73 г.	16.38.26,1	10,0	6,5	3+К, Ч	9
60	2.V.73 г.	3.11.43,6	3,4	5,8	2	-
61	3.V.73 г.	17.49.13,9	5,8	6,3	2	-
62	5.V.73 г.	17. 8.18,0	8,6	7,6	3+К, Ч	0
63	6.V.73 г.	2.17.43,0	4,9	6,2	2	-
64	10.V.73 г.	15.12.45,4	5,7	6,8	2+К, Ч	0
65	12.V.73 г.	12.24.19,7	6,0	-	2	-
66	13.V.73 г.	6.27.53,8	4,5	5,3	2	-
67	19.V.73 г.	10.35.49,4	4,5	5,9	2	-
68	23.V.73 г.	20.32. 3,0	4,2	5,3	4	10
69	30.V.73 г.	2.12. 3,5	7,7	7,4	4	0
70	31.V.73 г.	21.38.14,2	5,1	5,1	3+1	0
71	1.VI.73 г.	10.24.43,8	6,9	5,8	2+К	-3
72	5.VI.73 г.	22.48.53,8**	-	-	3	5
74	15.VI.73 г.	18.41.11,6	6,0	-	2	-
75	26.VI.73 г.	16.28.40,7	9,3	8,1	3+К, Ч	0
76	28.VI.73 г.	23.49.44,2	9,6	7,4	3+К, Ч	5
77	29.VI.73 г.	6. 1. 3,1	-	5,1	3	5
78	8.VII.73 г.	10.15. 4,6	3,8	7,6	4	15
79	13.VII.73 г.	3.51.51,3	4,7	7,5	4	15
80	23.VII.73 г.	22.25.46,8	4,3	5,6	2	-
81	25.VII.73 г.	9.34.46,5	9,4	8,1	4	30
82	25.VII.73 г.	21.40.29,5	4,2	5,7	2	-
83	3.VIII.73 г.	7.42.54,5	1,9	5,4	2	-
84	6.VIII.73 г.	23.24.49,0**	6,0	-	4	-3
85	7.VIII.73 г.	23.44. 1,3	4,3	-	2	-
86	10.VIII.73 г.	21.27.57,1	5,1	7,2	3	20
87	17.VIII.73 г.	4.35.58,3**	-	-	2	-
88	17.VIII.73 г.	23.50.54,0	5,6	6,6	3	15
89	19.VIII.73 г.	18.59.10,1**	-	-	3	10
91	27.VIII.73 г.	10.55.56,1	4,0	7,7	4	15
92	10.IX.73 г.	11.03.39,2	9,0	7,7	2	-
93	14.IX.73 г.	21.14.20,9	4,0	5,3	2	-
94	16.IX.73 г.	22.13.30,4	-	-	2	-
95	17.IX.73 г.	15.31.15,2	5,5	6,9	3	0
96	22.IX.73 г.	18.54.16,3	5,5	-	2	-
97	23.IX.73 г.	11.15.27,0	5,1	-	2	-
98	11.X.73 г.	23, 7.40,6	4,5	5,6	2	-
99	13.X.73 г.	7. 5.24,9	8,0	6,2	4	35

Appendix I, continued

1	2	3	4	5	6	7
100	14.X.73r.	7.28.16,5	4,7	6,0	3	5
101	15.X.73r.	7. 4.48,2	5,0	5,8	2	-
102	15.X.73r.	15.17.30,7	9,7	6,2	2	-
103	17.X.73r.	23.40.39,4	8,8	6,8	3+4	0
104	19.X.73r.	9.48.52,4	4,5	5,9	3	6
105	28.X.73r.	14.32.45,8	3,0	4,5	2	-
106	29.X.73r.	18.14.37,8	4,2	5,3	2	-
107	29.X.73r.	22.24. 5,2	9,1	7,6	3	30
108	30.X.73r.	21.15.51,4**	4,4	-	2	-
109	1.XI.73r.	7.19.14,8	6,5	6,8	3	31
110	12.XI.73r.	4.33.55,0	6,8	6,4	3	0
111	13.XI.73r.	7.34.55,1	5,3	6,8	2	-
112	19.XI.73r.	21.33. 2,2	5,0	7,3	2	-
113	19.XI.73r.	23.51.21,9	1,3	5,0	3	5
114	26.XI.73r.	12.21.31,4	4,2	5,6	3	19
115	26.XI.73r.	12.24.10,0	5,0	5,8	3	10
116	27.XI.73r.	22.45.49,4	8,2	6,4	3	30
117	30.XI.73r.	21.47.11,3	4,0	-	2	-
118	9.XII.73r.	17.41.18,5	9,1	7,4	3	20
119	15.XII.73r.	6.44.12,5	4,0	5,7	2	-
120	19.XII.73r.	3.15.11,5	4,4	5,5	2	-
121	19.XII.73r.	7.54.43,2**	3,3	-	2	-
122	21.XII.73r.	23.30.12,5	4,2	6,3	3	15
123	23.XII.73r.	21.33.15,5	5,0	5,7	3	0
124	24.XII.73r.	16.22.47,3	4,5	6,7	4	19
125	24.XII.73r.	23.38. 3,3	8,0	6,4	3	35
126	26.XII.73r.	21.50.51,4	4,5	6,4	3	0
127	28.XII.73r.	12.59.51,8	6,0	6,0	2	-
128	31.XII.73r.	7.36. 1,9	3,5	5,7	2	-
129	31.XII.73r.	17.41.21,9	5,0	7,3	3	17
130	2.I.74r.	23.25.29,3	2,2	6,0	4	0
131	7.I.74r.	10.14.35,9	4,5	6,5	2	-
132	8.I.74r.	4.36.44,9	6,0	5,7	2	-
133	14.I.74r.	7.51. 7,2	9,5	8,3	4	0
134	19.I.74r.	4. 1. 3,2	5,3	5,3	2	-
135	20.I.74r.	8.45.53,2**	5,4	6,1	3	5
137	23.I.74r.	23. 1.16,5**	3,7	-	2	-
138	28.I.74r.	22.55.49,0	3,2	7,3	3	17,5
139	3.II.74r.	14.14. 3,1	5,7	8,5	4	25
140	6.II.74r.	20.37.11,9	6,2	5,6	4	15
141	8.II.74r.	18.59.36,4	5,6	6,5	4	17,5
142	8.II.74r.	23,30.37,3	6,8	5,6	2	-
143	9.II.74r.	23.45.35,5	3,5	-	3	14
144	11.II.74r.	10.55.17,6**	-	-	2	-
145	15.II.74r.	5.34.21,9	5,9	6,1	4	5
146	16.II.74r.	10.44.25,3	4,3	6,1	3	13
147	16.II.74r.	11.23.22,3**	8,6	-	2+4	0
148	17.II.74r.	12.34.21,5**	4,4	-	2	-
149	20.II.74r.	4. 5.29,4	5,5	7,4	4	0
150	23.II.74r.	7.21.48,4	3,0	5,5	3	16
151	23.II.74r.	7.22.27,2	5,0	7,1	3	16
152	24.II.74r.	21.25.22,9**	5,2	-	3	-3
153	26.II.74r.	8.40. 1,7	4,5	6,0	3	19

Appendix I, continued

1	2	3	4	5	6	7
154	26.II.74 г.	9.48.34,9	4.7	5,6	3	15
155	28.II.74 г.	5.18.46,5**	–	–	2	–
156	2.III.74 г.	20.31.13,7	9,8	7,0	3	0
157	6.III.74 г.	0.42.36,9	6,3	7,4	4	9
158	6.III.74 г.	1.19. 6,5*	7,6	–	4	0
159	6.III.74 г.	23. 5.48,4**	4,9	–	2	–
160	7.III.74 г.	1,56. 0,2	7,0	7,9	3	25
161	7.III.74 г.	20.48. 0,5	7,0	8,5	4	15
162	12.III.74 г.	22.29.39,4	4,5	7,0	3	19
163	15.III.74 г.	22. 8.48,6**	4,2	–	3	20
164	18.III.74 г.	5.57..1,5	4,0	6,3	3	15
165	21.III.74 г.	1.11. 9,7	–	–	2	–
166	22.III.74 г.	9.49.35,9	9,8	7,7	4	0
167	29.III.74 г.	12.46.45,3**	3,0	–	3	9
168	2.IV.74 г.	18.19.17,7	7,0	6,4	4	0
169	2.IV.74 г.	22.20.25,9**	3,1	–	2	–
170	7.IV.74 г.	18.27.39,1	4,6	6,5	3	5
171	7.IV.74 г.	21. 1.56,6	3,9	6,7	4	12,5
172	10.IV.74 г.	5.35.23,9	5,0	6,9	3	0
174	15.IV.74 г.	0.36.54,1	5,6	6,7	4	10
175	15.IV.74 г.	19. 4.38,8	6,9	7,2	4	0
176	17.IV.74 г.	21.35.18,0	4,0	5,8	2	–
177	18.IV.74 г.	3.34.41,9	4,0	5,8	4	5
178	18.IV.74 г.	4.15.48,9**	3,4	–	2	2
179	19.IV.74 г.	4.40. 1,5	6,5	5,8	2	–
180	25.IV.74 г.	22.21.34,4	5,0	6,8	4	14
181	27.IV.74 г.	7.11.21,2	4,7	7,4	4	11
182	27.IV.74 г.	7.36. 6,5	4,5	6,5	4	12,5
183	27.IV.74 г.	10.56.47,0	4,7	9,9	4	14
184	28.IV.74 г.	13.42.19,2	6,6	6,3	2	–
185	4.V.74 г.	23.21.15,0	5,5	5,9	3	25
186	6.V.74 г.	21.51.38,4	6,5	10,1	4	–3
187	9.V.74 г.	12. 1. 2,5	2,1	8,5	4	0
188	16.V.74 г.	6.36.37,1**	–	–	2	–
189	20.V.74 г.	23.42.46,5	7,3	6,2	2	–
190	30.V.74 г.	20.18.32,0	3,7	–	4	–3
191	31.V.74 г.	21.46.20,3	–	–	3	15
192	1.VI.74 г.	16.45. 9,4**	5,7	–	3	20
193	4.VI.74 г.	6.27.59,1	2,0	4,2	2	–
194	5.VI.74 г.	3.11. 4,5	2,3	6,5	3	11
195	7.VI.74 г.	14.36.55,4	5,8	7,0	2	–
196	13.VI.74 г.	11.37.18,6	3,0	5,7	3	12
197	19.VI.74 г.	0.27.25,7	8,3	6,8	4	0
198	20.VI.74 г.	7.46.16,1**	6,5	–	2	–
200	26.VI.74 г.	9. 2.52,7	6,6	6,1	4	0
201	12.VII.74 г.	22.38.42,0	5,7	5,8	3	13
202	25.VII.74 г.	19.14.27,1**	5,5	–	4	10
203	22.VII.74 г.	18.19.59,2	4,5	–	4	13
204	23.VII.74 г.	3.44.27,5	4,9	–	3	23
205	24.VII.74 г.	21.44.16,0	7,5	6,3	3	23,5
206	24.VII.74 г.	21.54.31,8	9,5	8,3	4	25
207	10.VIII.74 г.	5.59.33,8	3,5	4,9	2	–

Appendix I, continued

1	2	3	4	5	6	7
208	14.VIII.74 r.	23.15.41,6**	6,8	–	4	0
209	23.VIII.74 r.	6.21.23,5	2,2	6,6	2	–
210	23.VIII.74 r.	3.40.40,3	5,5	5,7	3	2
211	23.VIII.74 r.	12.39.36,0	5,0	6,0	2	–
212	23.VIII.74 r.	16. 6. 7,0	8,5	6,6	4	20
213	5.IX.74 r.	9.57.40,0	2,5	4,6	2	–
214	13.IX.74 r.	8.38.23,6	8,0	7,7	4	15
215	18.IX.74 r.	3. 5.28,6	4,0	6,2	3	17,5
216	18.IX.74 r.	7.52.45,0	8,5	7,2	3	30
217	20.IX.74 r.	7. 2.47,5	3,5	6,0	2	–
218	22.IX.74 r.	7.28.06,7	3,8	6,0	3	5
219	25.IX.74 r.	4.41.50,8	4,2	6,4	4	0
220	25.IX.74 r.	9.58.14,5	3,2	5,8	3	24
221	27.IX.74 r.	11. 2.59,0	4,0	–	4	21
222	29.IX.74 r.	8. 0.36,0	4,0	–	2	–
224	1.X.74 r.	17. 1.52,2	3,9	6,5	2	–
225	5.X.74 r.	8. 0.35,4	4,5	5,8	3	1
226	10.X.74 r.	2.17.44,6	4,7	6,3	3	0
227	13.X.74 r.	6.38.49,2	3,8	–	2	–
228	14.X.74 r.	16.38.43,5	9,5	7,2	3	0
229	15.X.74 r.	2.56.22,9**	9,0	–	4	0
230	23.X.74 r.	2.30.21,5	8,9	6,8	2	–
231	2.XI.74 r.	4. 8.43,5	3,1	6,5	4	12
232	2.XI.74 r.	10.40.17,5	2,2	6,0	4	0
233	4.XI.74 r.	19. 1. 1,4	9,0	8,6	4	0
234	20.XI.74 r.	0.28. 8,0	5,7	6,0	2	–
235	23.XI.74 r.	9.15.28,0	4,6	–	3	10
236	23.XI.74 r.	22.13.43,5	3,0	5,5	3	10
237	27.XI.74 r.	7.19.45,1**	3,5	–	2	–
238	2.XII.74 r.	10.45.48,5	10	–	2	–
239	9.XII.74 r.	14.12.22,0	5,5	6,9	2	–
240	12.XII.74 r.	15.29.13,0	9,3	8,7	4	0
243	18.XII.74 r.	6.23.11,7	7,0	6,4	3	0
244	21.XII.74 r.	9.30.32,5	–	–	2	–
245	22.XII.74 r.	3.45.36,0	9,2	8,0	4	0
246	22.XII.74 r.	21.39.26,1	7,5	6,2	4	0
247	27.XII.74 r.	1. 9. 7,3	4,7	7,2	4	11
248	30.XII.74 r.	4.22.25,4	–	–	3	15
249	30.XII.74 r.	7.23. 7,0	3,0	5,5	3	0
250	30.XII.74 r.	7.45.10,7	3,7	6,2	4	0
251	30.XII.74 r.	15.29.16,2	3,5	6,3	2	–
252	31.XII.74 r.	14.22.51,3	10	10	4	20
253	4.I.75 r.	5. 9.36,1**	–	–	2	–
254	4.I.75 r.	21.47.46,7	9,8	11,5	3	20
255	5.I.75 r.	2.39. 7,8	–	–	3	5
256	13.I.75 r.	20.33.11,0	5,0	6,6	4	12,5
257	13.I.75 r.	6.29.28,1	3,9	5,0	2	–
258	9.II.75 r.	7.13.12,0	–	–	2	–
259	10.II.75 r.	19.45.54,3	3,3	7,6	5	9
260	16.II.75 r.	7.55.24,8	5,0	7,0	3	20
261	21.II.75 r.	8.18.49,5	4,0	7,3	4	12,5
262	1.III.75 r.	12.15.13,8	5,8	6,7	4	3
263	3.III.75 r.	7.56. 7,8	4,7	8,8	3	0

Appendix I, continued

1	2	3	4	5	6	7
264	6.III.75r.	9.59.18,4	4,8	7,6	4	0
265	10.III.75r.	10.28.16,2	2,8	7,3	4	12,5
266	14.III.75r.	17.56.37,9	10	6,9	3	-3
267	23.III.75r.	5.43.47,0	2,8	5,3	4	12,5
268	23.III.75r.	8.43.13,0	4,2	5,7	2	-
269	25.III.75r.	0.56.47,7	7,4	6,8	3	30
270	26.III.75r.	0.47.17,3	4,0	5,3	3	-
271	29.III.75r.	8. 6.39,0	9,8	7,4	2	-
272	29.III.75r.	13.43.07,9	9,1	7,7	4	0
273	3.IV.75r.	3.13.31,7	7,3	7,5	2	-
274	27.IV.75r.	18. 4.31,5	5,0	5,5	2	-
275	28.IV.75r.	20. 3.13,5	4,7	6,5	4	10
276	11.V.75r.	3. 4.27,9	3,9	6,1	3	4
277	12.V.75r.	6.25.35,4	3,9	5,6	2	-
278	12.V.75r.	10.47.23,6**	3,7	-	2	-
279	13.V.75r.	17.29.49,4	7,9	7,9	4	0
280	15.V.75r.	12.45.52,4	4,4	6,8	3	14
281	16.V.75r.	1.45.20,5	8,7	7,3	3	0
282	16.V.75r.	15.43.33,4	8,8	6,4	2	-
283	19.V.75r.	11.31.58,9	6,8	7,0	3	0
284	24.V.75r.	8. 2.52,9	6,8	6,3	2	-
285	30.V.75r.	23.23.17,5	8,0	6,8	2	-
286	1.VI.75r.	3.10.55,3	6,4	7,8	3	18
287	10.VI.75r.	0.26. 6,2	4,1	6,5	3	17
288	18.VI.75r.	18.38.40,7	6,0	5,7	2	-
289	4.VII.75r.	4.45.22,2	6,8	6,5	4	5
290	11.VII.75r.	5.58.29,5	2,3	-	2	-
291	20.VII.75r.	4.57.46,9	6,2	7,1	3	0
292	25.VII.75r.	17.11.14,8	-	5,6	3	0
293	28.VII.75r.	10.53.44,2	4,4	6,4	3	6
294	2.VIII.75r.	10.53.24,9	4,4	5,8	3	8
295	5.VIII.75r.	15. 1.29,9	6,0	7,0	2	-
296	6.VIII.75r.	0.29.38,0	7,0	7,2	4	-3
297	9.VIII.75r.	5.36. 5,2	1,4	6,2	4	-3
299	15.VIII.75r.	0.43.15,6	5,0	-	2	-
300	19.VIII.75r.	13.46.20,5	1,4	5,5	5	0
302	27.VIII.75r.	16. 4.40,6	4,0	5,7	3	-3
303	30.VIII.75r.	23.18.20,6	4,5	5,8	3	10
304	6.IX.75r.	7.35.26,3	3,8	5,0	3	0
305	6.IX.75r.	5.10. 3,6	4,5	-	3	20
306	6.IX.75r.	23.39.31,8	7,2	-	4	20
307	7.IX.75r.	23.12.37,3	3,3	7,6	4	7
308	17.IX.75r.	19.32.45,6	5,6	-	5	12
310	18.IX.75r.	22.21.43,2	1,1	5,7	4	2
311	23.IX.75r.	7. 9.34,3	-	-	3	-3
312	24.IX.75r.	6.16.53,5	5,1	-	2	-
313	1.X.75r.	6. 0. 3,5	2,8	-	3	0
314	9.X.75r.	10.19.35,2	4,2	6,7	3	12
315	16.X.75r.	5.54.58,0	6,0	6,3	3	15
316	17.X.75r.	0.47. 5,4	7,7	7,1	4	15
317	26.X.75r.	18.49.49,2	4,3	5,0	5	14
318	30.X.75r.	16.22.26,8	9,0	7,0	3	0
319	2.XI.75r.	6.49.46,6	4,7	5,6	4	-3

1	2	3	4	5	6	7
320	8.XI.75r.	7.58.22,7	7,8	7,7	3	0
321	13.XI.75r.	7. 1.51,3	6,5	8,8	4	15
322	14.XI.75r.	1.39.42,6	7,1	8,2	3	-3
323	20.XI.75r.	22.40. 1,9	4,7	5,3	2	-
324	22.XI.75r.	21.54.54,3	4,0	5,4	2	-
325	24.XI.75r.	20.59. 8,1	8,1	-	2	-
326	30.XI.75r.	18. 9.34,9	4,1	-	2	-
327	2.XII.75r.	6.41.51,6	9,4	8,3	4	17
328	3.XII.75r.	15.19. 8,8	6,1	9,5	3	16
329	6.XII.75r.	3.47.15,3	3,5	-	4	6
330	9.XII.75r.	14.31.38,3	4,2	5,0	2	-
331	12.XII.75r.	23.56.53,7	3,6	5,7	2	-
332	19.XII.75r.	21. 5.14,7	5,8	5,6	4	7
333	19.XII.75r.	21.44.10,2	5,0	6,5	3	25
334	20.XII.75r.	3.55,26,5	6,1	6,3	4	5
335	2.I.76r.	3.56.58,4	9,7	5,8		0
336	1.II.76r.	0. 8.46,4	4,2	6,4		-
337	14.II.76r.	10.10.20,6	5,5	6,5		0
338	16.II.76r.	8.28.21,8	5,5	6,3		0
339	10.II.76r.	12.41. 8,6	4,4	5,9		2,5
340	[illegible].II.76r.	12.15. 7,8	4,6	5,6		5
341	[illegible].II.76r.	21. 9.41,8	3,1	-	4	10
342	6.II.76r.	4. 4.48,3	4,7	6,4	4	5
34[illegible]	[illegible].III.76r.	3.33.34,4	7,8	7,2	3	0
344	[illegible]III.76r.	17.40.37,4	8,0	7,9	5	0
345	[illegible]I.76r.	11.38.49,4	4,0	5,7	2	-
346	[illegible].76r.	20. 8.12,5	9,1	8,5	3	0,5
347	[illegible]I.76r.	14.54.56,1	6,3	7,2	3	-3
348	[illegible]I.76r.	19.49.41,5	2,9	6,7	5	12,5
349	2[illegible].II.76r.	1. 0.[illegible]	4,5	6,2	3	12,5
350	2.IV.76r.	13.19.00,7	4,2	7,5	5	12
351	12.IV.76r.	2.22.52,1	6,1	-	3	0
352	30.IV.76r.	7.36.46,8	4,1	6,6	3	0
353	4.V.76r.	2.20.55,8	6,3	7,5	4	5
354	15.V.76r.	3.28.14,0	7,0	7,0	3	15
355	27.V.76r.	17.49.56,7	4,0	6,3	2	-
356	1.VI.76r.	17.12.49,3	4,8	6,3	4	6
357	1.VI.76r.	17.13.52,0	5,0	7,4	4	5
358	5.VI.76r.	5. 3.55,6	6,4	7,3	3	0
359	20.VI.76r.	20.27.51,2	8,7	9,3	4	0
360	21.VI.76r.	20.51.11,8	4,7	5,9	3	10
361	27.VI.76r.	12.21.15,5	6,8	5,8	3	0
362	28.VI.76r.	21.48.11,3	3,0	7,8	4	15

Notes. The depth of the basement under the Alma-Ata station of 4.2 km is taken as the reduction level H=0.

*The Kurmenty (K) and Chilik (Ch) stations of the regional network are indicated, the data of which were used to find the coordinates of the system.

**The earthquakes not recorded by the complex seismological expedition station. The time was taken by the T(RTS) station.

APPENDIX II. BULLETIN OF NEARBY INDUSTRIAL EXPLOSIONS RECORDED BY THE RADIOTELEMETRIC SYSTEM FROM 1 JUNE 1972 to 1 JULY 1976

№	Дата	Время*, ч.мин.с	K	Место взрыва
1	2	3	4	5
1	3.VI.72 г.	0. 1.32,5	7,9	Medeo
2	15.VI.72 г.	6.31.49,7	5,5	"
3	19.VI.72 г.	11.50.57,9	4,9	"
4	5.VII.72 г.	12.37	7,1	"
5	6.VII.72 г.	11.54.46,4	5,9	"
6	11.VII.72 г.	1.14. 1,4	-	"
7	15.VII.72 г.	0. 1.32,6	-	"
8	30.VII.72 г.	0.0. 10,8	5,5	"
9	1.IX.72 г.	11.38.49,1	7,5	Kotur-Bulak
10	18.IX.72 г.	12.22.22,9	5,5	Medeo
11	20.IX.72 г.	10. 3.30,9	6,4	Kotur-Bulak
12	22.IX.72 г.	9.54.05,2	4,4	Medeo
13	8.X.72 г.	15.14.19,0	5,5	Kotur-Bulak
14	3.XI.72 г.	10. 0. 3,2	7,3	"
15	2.XII.72 г.	10.29. 6,2	6,9	"
16	13.I.73 г.	8.51. 8,4	5,7	"
17	31.I.73 г.	10.50.49,2	7,3	"
18	5.II.73 г.	5.53,36,5	5,3	Medeo
19	23.II.73 г.	6.38.45,2	7,6	Kotur-Bulak
20	11.VI.73 г.	9. 5.43,5	-	Medeo
21	5.VII.73 г.	14.40.11,3	7,5	Kotur-Bulak
22	19.VII.73 г.	0.13.47,8	7,4	Issyk
23	19.VII.73 г.	10.27.31,0	6,6	Kotur-Bulak
24	29.VII.73 г.	22.12.49,0	6,3	Kapchagay
25	31.VII.73 г.	11.18.06,2	-	Medeo
26	4.VIII.73 г.	8,29,52,3	7,3	Kapchagay
27	8.VIII.73 г.	16.25. 8,3	6,8	"
28	10.VIII.73 г.	10.37. 8,5	7,3	"
29	18.VIII.73 г.	20.37.51,8	-	North of Alma-Ata
30	4.IX.73 г.	9.11.50,8	5,5	Kotur-Bulak
31	5.IX.73 г.	8.40.28,4	-	Chilik
32	20.IX.73 г.	11. 2.54,2	6,5	Kapchagay
33	25.IX.73 г.	10. 1.19,2	5,5	Kotur-Bulak
34	4.X.73 г.	11. 7.38,9	5,2	Medeo
35	5.X.73 г.	6.33.30,2	-	Kapchagay
36	6.X.73 г.	12.49. 8,0	5,9	Medeo
37	8.X.73 г.	11.50.29,6	5,7	Medeo
38	9.X.73 г.	11.28.27,7	6,0	"
39	10.X.73 г.	11.26.55,5	-	"
40	12.X.73 г.	11.48.45,9	5,6	"
41	14.X.73 г.	11.31.45,6	5,3	"
42	14.X.73 г.	11.31.54,8	6,4	"

Key: 1. date; 2. time, hours, minutes, seconds; 3. place of explosion; 4. day, month, year; 5. *at Talgar station

Appendix II, continued

1	2	3	4	5
43	16.X.73r.	3.23.20,7	-	Medeo
44	16.X.73r.	12.34.14,2	-	″
45	17.X.73r.	3.40. 5,5	-	″
46	19.X.73r.	11. 1.51,9	6,2	″
47	20.X.73r.	11.15.58,3	4,9	″
48	24.X.73r.	12.25. 9,4	-	″
49	25.X.73r.	6. 9.55,9	5,9	″
50	27.X.73r.	11.14.34,1	6,7	″
51	27.X.73r.	11.36.25,4	5,5	″
52	2.XI.73r.	11. 5.39,0	6,1	″
53	3.XI.73r.	6.22.18,3	8,7	″
54	3.XI.73r.	11.27.37,0	4,6	″
55	16.XI.73r.	11.38. 4,0	5,4	″
56	20.XI.73r.	5. 0.24,2	10,8	″
57	25.XI.73r.	10. 4.12,5	5,8	″
58	28.XI.73r.	11. 6.34,6	5,5	″
59	30.XI.73r.	11.16.52,5	6,3	″
60	30.XI.73r.	11.17.11,9	5,9	″
61	4.XII.73r.	10. 9.28,3	7,0	Kotur-Bulak
62	4.XII.73r.	11.57.30,5	5,7	Medeo
63	11.XII.73r.	11. 3.25,4	6,6	″
64	18.XII.73r.	11. 5.14,5	7,7	″
65	19.XII.73r.	18.57. 0,0	9,2	Kapchagay
66	25.XII.73r.	6.33.23,1	-	Medeo
67	26.XII.73r.	11.13.44,3	6,7	″
68	28.XII.73r.	7.34.57,4	-	″
69	29.XII.73r.	11.53.19,3	6,5	Kapchagay
70	7.I.74r.	11.31.24,0	6,4	″
71	8.I.74r.	5.10.01,4	5,7	Medeo
72	8.I.74r.	12. 2,57,1	-	″
73	9.I.74r.	11. 7.53,9	-	″
74	22.I.74r.	11. 9.27,4	-	″
73	23.I.74r.	8.44,11,0	4,9	″
76	25.I.74r.	6.10.15,0	-	″
77	25.I.74r.	11.39. 5,7	-	″
78	29.I.74r.	10.59. 3,6	-	Kapchagay
79	30.I.74r.	10.42.52.8	7,2	Kotur-Bulak
80	5.II.74r.	11.14.28,9	7,3	Medeo
81	7.II.74r.	11.17.42,3	5,5	″
82	9.II.74r.	1.37.41,0	7,0	″
83	12.II.74r.	11.13.14,1	5,1	″
84	12.II.74r.	11.35.14,1	6,3	Kapchagay
85	16.II.74r.	11.10. 7,3	5,7	Medeo
86	19.II.74r.	21.25.52,6	7,6	West of Alma-Ata
87	22.II.74r.	12.29. 7,5	7,0	Kotur-Bulak
88	23.II.74r.	9.29.16,7	6,2	Medeo
89	1.III.74r.	11.23.44,9	6,7	″
90	3.III.74r.	12. 8.57,4	-	″
91	4.III.74r.	11.22.54,9	7,2	″
92	12.III.74r.	12. 7.36,4	6,9	″
93	13.III.74r.	1. 5.24,9	4,8	″
94	22.III.74r.	5.47.28,8	6,6	Kapchagay

Appendix II, continued

1	2	3	4	5
95	23.III.74r.	9.42,32,9	-	Kotur-Bulak
96	30.III.74r.	13.30.11,0	6,0	Kapchagay
97	1.IV.74r.	13. 5.18;8	6,5	"
98	3.IV.74r.	11. 5.54,4	8,4	Medeo
99	6.IV.74r.	11.10. 8,5	5,9	"
100	11.IV.74r.	0.27.10,0	5,5	"
101	12.IV.74r.	11.37.49,1	-	"
102	16.IV.74r.	10.34.51,6	5,5	Kotur-Bulak
103	18.IV.74r.	11.16.48,4	-	Medeo
104	22.IV.74r.	11.45.28,9	6,7	Kapchagay
105	23.IV.74r.	11.11.46,3	5,5	Medeo
106	24.IV.74r.	12. 1.30,4	7,1	Kotur-Bulak
107	26.IV.74r.	11.26. 7,5	7,4	Medeo
108	28.IV.74r.	6.44.18,2	5,5	"
109	7.V.74r.	11.12. 2,2	5,8	"
110	8.V.74r.	11.19.29,8	6,5	Kapchagay
111	22.V.74r.	11.17.19,2	6,2	Medeo
112	29.V.74r.	11.21.29,4	6,6	"
113	29.V.74r.	12.10.14,9	-	Kapchagay
114	10.VI.74r.	11. 9.24,9	6,7	"
115	12.VI.74r.	11.16.54,6	5,8	Medeo
116	13.VI.74r.	11.18.36,2	6,8	"
117	22.VI.74r.	6.11.23,4	5,7	"
118	23.VI.74r.	8.35.14,4	5,8	"
119	29.VI.74r.	1. 0.33,7	6,5	"
120	30.VI.74r.	5.58.43,9	6,5	"
121	9.VII.74r.	11.36.24,4	6,7	"
122	13.VII.74r.	1. 0.12,5	6,7	"
123	13.VII.74r.	4. 0.15,0	-	Issyk-Kul'
124	18.VII.74r.	11.23. 3,4	-	Medeo
125	20.VII.74r.	11. 9.20,9		"
126	25.VII.74r.	0.28.19,6	6,7	"
127	6.VIII.74r.	0.26.30,0		"
128	9.VIII.74r.	0.46.31,4	8,5	Kotur-Bulak
129	11.VIII.74r.	0.25.23,5	6,8	Medeo
130	13.VIII.74r.	0.19. 0,0	7,8	"
131	24.VIII.74r.	0.43.19,6	7,1	"
132	27.VIII.74r.	11. 1.13,7	-	"
133	28.VIII.74r.	11. 6.44,2	6,1	"
134	2.IX.74r.	11. 6.27,2	6,1	"
135	3.IX.74r.	20,22. 2,7	7,7	Kapchagay
136	4.IX.74r.	11. 0.30,5	-	Medeo
137	7.IX.74r.	7. 6.34,7	7,9	"
138	1.X.74r.	11.29.23,6	-	"
139	6.X.74r.	0.52.46,0	7,9	"
140	19.X.74r.	10.57.41,0	6,0	"
141	22.X.74r.	11. 1. 8,3	5,5	"
142	30.X.74r.	11.57.40,2	7,4	"
143	2.XI.74r.	9.47. 4,0	5,7	Kotur-Bulak
144	3XI.74r.	9.20.36,7	5,9	Southeast of Ozero
145	12.XI.74r.	11.17.22,5	7,5	Medeo

Appendix II, continued

1	2	3	4	5
146	17.XI.74r.	8.57.40,7	8,1	Medeo
147	20.XI.74r.	22.43.46,8	7,9	Kapchagay
148	22.XI.74r.	10.22.20,5	6,9	"
149	22.XI.74r.	11. 5.40,9	-	
150	29.XI.74r.	7.33.48,0	8,7	Medeo
151	8.XII.74r.	10. 8. 2,3	9,1	Kapchagay
152	15.XII.74r.	8. 9. 0,0	7,9	North of Alma-Ata
153	15.XII.74r.	8.45.37,9	-	Medeo "
154	16.XII.74r.	10.30. 0,3	9,2	North of Alma-Ata
155	17.XII.74r.	7.21.31,4	-	Medeo
156	19.XII.74r.	11. 1.25,1	7,1	"
157	22.XII.74r.	6.33.21,2	7,4	"
158	20.XII.74r.	9.34.11,8	8,8	North of Alma-Ata
159	27.XII.74r.	8.52.39,5	7,0	Kapchagay
160	28.XII.74r.	10.49.49,4	-	Kotur-Bulak
161	31.XII.74r.	10.23.46,9	7,6	Medeo
162	9.I.75r.	7. 5.40,6	6,9	"
163	14.I.75r.	11. 7.04,1	7,5	"
164	20.I.75r.	10. 1.41,3	-	"
165	21.I.75r.	7. 6.02,7	5,7	"
166	26.I.75r.	9. 1.14,8	7,8	"
167	31.I.75r.	9.46.13,0	-	"
168	2.II.75r.	7.52.23,4	7,8	"
169	6.II.75r.	11. 0.20,3	6,4	"
170	8.II.75r.	7.46.21,0	6,6	"
171	10.II.75r.	11. 2. 9,6	5,6	"
172	11.II.75r.	11.18.58,3	5,2	"
173	16.II.75r.	2.02.34,8	6,5	"
174	20.II.75r.	6.35.26,0	-	"
175	21.II.75r.	11.23.50,6	7,6	"
176	1.III.75r.	11.33.54,2	6,6	"
177	10.III.75r.	11. 1.36,5	6,2	"
178	11.III.75r.	11. 7.45,3	7,6	Kotur-Bulak
179	12.III.75r.	8.56.15,8	7,3	Medeo
180	12.III.75r.	13. 3. 4,0	4,8	"
181	14.III.75r.	12.36.41,5	8,0	"
182	15.III.75r.	11.23.21,6	5,4	"
183	15.III.75r.	11.24.18,1	5,8	"
184	18.III.75r.	1.39.20,8	9,2	Kapchagay
185	23.III.75r.	8.10.51,2	8,4	Medeo
186	28.III.75r.	6.19.36,1	-	"
187	1.IV.75r.	6,32,42,2	6,4	"
188	4.IV.75r.	11.23.21,3	6,5	"
189	8.IV.75r.	12. 4. 6,0	-	Near Medeo
190	10.IV.75r.	7. 7.34,8	8,0	Medeo
191	15.IV.75r.	6.46. 6,7	6,2	"
192	15.IV.75r.	11.30,24,6	5,6	"
193	18.IV.75r.	7. 2.21,5	5,6	"
194	18.VI.75r.	7. 2.50,0	5,7	"

Appendix II, continued

1	2	3	4	5
195	19.IV.75r.	13.41.13,6	7,3	Kapchagay
196	20 IV.75r.	14.51.23,4	7,8	Medeo
197	23.IV.75r.	9.22.45,0	5,5	Kotur-Bulak
198	23.IV.75r.	11.14.55,3	5,7	Medeo
199	6.V.75r.	11. 6.35,1	7,5	"
200	12.V.75r.	11.39.46,9	6,3	"
201	18.V.75r.	3.38.53,1	8,6	"
202	22.V.75r.	12.18.14,0	6,1	"
203	23.V.75r.	11. 9.45,9	5,8	Kotur-Bulak
204	25.V.75r.	7.51.26,9	5,6	Medeo
205	31.V.75r.	10.38. 7,0	6,7	"
206	2.VI.75r.	11.48.29,0	6,0	Kotur-Bulak
207	3.VI.75r.	11.32.58,7	5,1	Medeo
208	8.VI.75r.	9.56.57,0	7,9	"
209	13.VI.75r.	6.11.13,3	7,0	"
210	14.VI.75r.	9.52.42,3	7,7	"
211	17.VI.75r.	6.37.34,4	7,6	"
212	22.VI.75r.	9.54.42,5	-	"
213	22.VI.75r.	9.56.52,6	-	"
214	27.VI.75r.	7. 5.44,4	7,3	"
215	1.VII.75r.	7. 8. 9,0	7,0	"
216	7.VII.75r.	11. 6.22,9	4,8	"
217	8.VII.75r.	11. 6.57,1	3,8	"
218	9.VII.75r.	7.26. 8,4	5,8	"
219	11.VII.75r.	20.43. 9,8	8,2	Kapchagay
220	12.VII.75r.	10.28.40,4	-	Kotur-Bulak
221	14.VII.75r.	7.08.24,3	5,7	Medeo
222	19.VII.75r.	11. 2.47,7	6,7	"
223	21.VII.75r.	11. 1.32,4	5,6	"
224	25.VII.75r.	4.26.47,1	6,4	Kotur-Bulak
225	27.VII.75r.	8.49.26,7	8,5	Medeo
226	30.VII.75r.	11.13.42,0	6,5	"
227	1.VIII.75r.	12.46.11,9	6,4	"
228	3.VIII.75r.	8.53.21,4	7,8	"
229	10.VIII.75r.	14.38.41,2	8,7	"
230	17.VIII.75r.	7.12.22,0	7,5	"
231	17.VIII.75r.	16.53. 8,2	6,6	"
232	23.VIII.75r.	9. 5.56,7	-	"
234	26.VIII.75r.	11.16.21,8	5,8	"
235	27.VIII.75r.	8.56.33,5	-	"
236	29.VIII.75r.	11. 9.27,9	6,5	"
237	30.VIII.75r.	4. 4.19,3	-	"
238	4.IX.75r.	8.42.88,6	-	"
239	5.IX.75r.	7.10.20,1	6,3	To the northeast of Alma-Ata
240	8.IX.75r.	12. 7.52,2	8,2	Medeo
241	16.IX.72r.	11.12.30,6	6,4	"
242	25.IX.75r	5.18.54,1	-	"
243	25.IX.75r.	11. 0.56,2	6,0	"
244	2.X.75r.	11.22.33,2	5,5	"
245	11.X.75r.	6.50.10,2	5,3	Kotur-Bulak

Appendix II, continued

1	2	3	4	5
246	11.X.75 r.	9.20. 0,7	6,0	Medeo
247	27.X.75 r.	11.18. 8,6	6,0	"
248	30.X.75 r.	18.24.16,3	7,7	To the northwest of Alma-Ata
249	31.X.75 r.	8.10. 8,5	–	Medeo
250	1.XI.75 r.	8.51.47,8	8,5	"
251	5.XI.75 r.	6.49.57,8	6,9	"
252	14.XI.75 r.	9.28.56,4	7,5	Kotur-Bulak
253	25.XI.75 r.	7.56.26,7	6,9	"
254	10.XII.75 r.	9.48.18,6	7,5	Medeo
255	11.XII.75 r.	6.33.13,8	7,6	"
256	22.XII.75 r.	9.45.28,1	7,5	Kotur-Bulak
257	23.XII.75 r.	10.56.46,2	6,6	Medeo
258	6.I.76 r.	20.33.15,8	5,6	"
259	10.I.76 r.	11.42.38,3	9,3	"
260	27.I.76 r.	20.15.10,5	6,9	Kapchagay
261	31.I.76 r.	7.12.35,7	7,1	Kotur-Bulak
262	31.I.76 r.	9.51.35,4	8,2	Medeo
263	10.II.76 r.	5.53.11,1	7,4	"
264	29.II.76 r.	6. 2.55,2	6,6	"
265	29.II.76 r.	11.52.15,7	3,3	"
266	9.III.76 r.	11. 9.46,3	6,4	"
267	24.III.76 r.	11. 2.52,8	5,7	Kotur-Bulak
268	24.III.76 r.	11.27.20,0	5,1	Medeo
269	26.III.76 r.	4.34. 2,0	8,3	"
270	6.IV.76 r.	11.16.39,8	6,5	"
271	9.IV.76 r.	6.38.30,3	7,0	"
272	21.IV.76 r.	11.20. 6,7	8,0	"
273	30.IV.76 r.	7.32.11,7	7,2	"
274	30.IV.76 r.	8.42.39,1	7,4	Kotur-Bulak
275	7.V.76 r.	6.52.26,2	8,0	Medeo
276	18.V.76 r.	11. 4.32,4	8,0	"
277	29.V.76 r.	10.44.42,0	7,9	"
278	2.VI.76 r.	11.30.37,0	–	Kotur-Bulak
279	9.VI.76 r.	8. 2.49,8	7,5	Medeo
280	11.VI.76 r.	11.19.45,5	7,2	"
281	18.VI.76 r.	11.27.35,6	6,7	"
282	24.VI.76 r.	11.26.22,8	5,1	"
283	29.VI.76 r.	6.11. 7,8	6,5	"

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DATE FILMED

April 10, 1979

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