EARTHQUAKE PREDICTION PROBLEMS IN THE USSR

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In the USSR, the problem of predicting the site, magnitude and time of earthquakes is an integral part of the general problem of mitigating the consequences of strong earthquakes, which also involves the prediction of seismic activity on the earth's surface as a result of strong underground shocks and seismic engineering and seismic zoning at various levels: general zoning, detailed zoning and microzoning.

In essence, seismic zoning is also a method of predicting strong earthquakes, but one which provides long-term assessments of the possible intensity and average recurrence of earthquakes in a given zone without regard to the precise site and time of their occurence. In predictions of the time of an earthquake, on the other hand, we try to monitor conditions in a seismic area continuously in order to determine those changes in geophysical fields which precede a strong shock and which can explain its location and time of occurrence.

At the same time, it should be emphasized that the methods of zoning and long-term prediction are based on the same data: recent tectonics, geomorphology, seismological data collected over the longest possible time interval, the nature of the mechanisms of earthquake foci, the spectral characteristics of seismic waves, etc., as well as on geodesic data. All this information is collected in respect of fairly large areas of substantially greater size than that of a single earthquake focus. For example, the new seismic zoning map of USSR territory (Fig.1) assesses not only the intensity but also the probability of occurrence of strong earthquakes in the Kamchatka area. This method of combining zoning maps with long-term assessment of seismic hazards will probably be applied in future in respect of all seismic areas in the Soviet Union.

Long-term prediction occupies a particularly important place in the over-all issue of earthquake prediction because it is through the development and perfecting of this technique that the State is increasingly able to take the most effective measures against the possible consequences of strong earthquakes by reinforcing weak buildings, choosing appropriate sites for new building developments, etc. and, no less important, channelling funds earmarked for earthquake-resistant construction towards the most economically advantageous projects. We should explain that by long-term prediction we mean the possibility of occurrence of a seismic event within a time interval ranging from a few decades to a few years.

However, important as the long-term prediction of strong earthquakes may be, the population's maximum security can be ensured only if the moment of occurrence of such an earthquake is accurately known. This is why in most countries efforts are directed precisely towards predicting the moment of an earthquake, that is to say, towards short-term prediction, of which, to be precise, there are several aspects: medium-term prediction, covering a few months, short-term prediction, covering a few weeks, and immediate prediction, covering a few days. Such categorization is, of course, artificial, but it does reflect to some extent the nature of the actual process preceding earthquakes, which involves an increasing number of different signs of the imminence of a seismic event.

The vast majority of scientists now believe that the origin of seismic events lies in deformation processes occurring in the earth's crust and in the upper mantle. These processes cannot be described from the point of view of the models of rock strata adopted in seismology, based as they are on a concept of the medium as a continuous whole. The absence at the present time of adequate mathematically founded models of rock strata means that the search for earthquake precursors must principally take the form of experimental study of subtle features of deformation processes in the earth's crust.

Modern prediction methods use geodetic and gravimetric data; levelling measurements on the coastlines of oceans and seas; direct deformation measurements from strain meters and tiltmeters of various kinds; measurements of the level of underground water and the rate of flow from springs and wells, including data on the rate of flow and pressure of oil wells situated in seismic regions; a whole range of geochemical studies of ground water and gases emitted by rock strata; and observations of various types of magnetic and electrical phenomena in the lithosphere and in the atmosphere. In recent years, increasing attention has been paid to biophysical phenomena as reflected in the abnormal behaviour of animals. In addition to all these observations, a broad range of work is being carried out in the field of seismicity (seismic regime, mechanisms of earthquake foci, spectral characteristics of seismic waves over a broad range of frequencies, etc.).

As a result of all the efforts made and on the basis principally of in situ observations, reliable evidence has been accumulated of the feasibility of predicting both strong and moderate earthquakes. An important result of the scientific and theoretical research has been the widespread acceptance of the theory, tacitly adopted by seismologists (and which, incidentally, is anything but trivial) of the similarity between earthquakes of different strength. This has opened the way to the use of rock bursts as a model for earthquakes, and to small-scale laboratory modelling. There have been a number of cases where empirical methods have been used successfully for preliminary reports.

The work of Chinese scientists has proved particularly effective in this respect. Several predictions have also been made in the USSR, in most cases prior to earthquakes of moderate strength.

In the USSR, prediction-related observations are carried out in Soviet Central Asia and Kazakhstan and in the Soviet Far East, Kamchatka and Sakhalin. Similar activities are now being organized in the Caucasus, the Crimea and Siberia. Initially, observations are made in the areas around the major cities and capitals of the Republics (Fig.2). The work is carried out by scientific institutes belonging to the Republics' academies of sciences and is co-ordinated by the Academy of Sciences of the USSR. In the Garm district of Tadzhikistan, a continuous prediction site has been established by the Institute of Earth Physics of the Academy of Sciences of the USSR.

Prediction successes and errors have shown clearly that earthquakes cannot be predicted without appropriate instruments. The present state of observations shows that there exists no one method of unequivocal prediction of earthquakes and that, as different methods of prediction may prove successful under different geological conditions and with different types of foci, a comprehensive set of observations is required. In decisions as to the imminence of a strong earthquake, thought must always be given to the question whether there exists an observation system in the area concerned.

Early experience of prediction reports has made it possible to work out a specific decision-making sequence. First, in each Republic, the responsibility for making predictions rests with that Republic's seismological or geophysical institute. Second, no one else in the Republic's territory may issue an independent conclusion concerning predictions. Should any

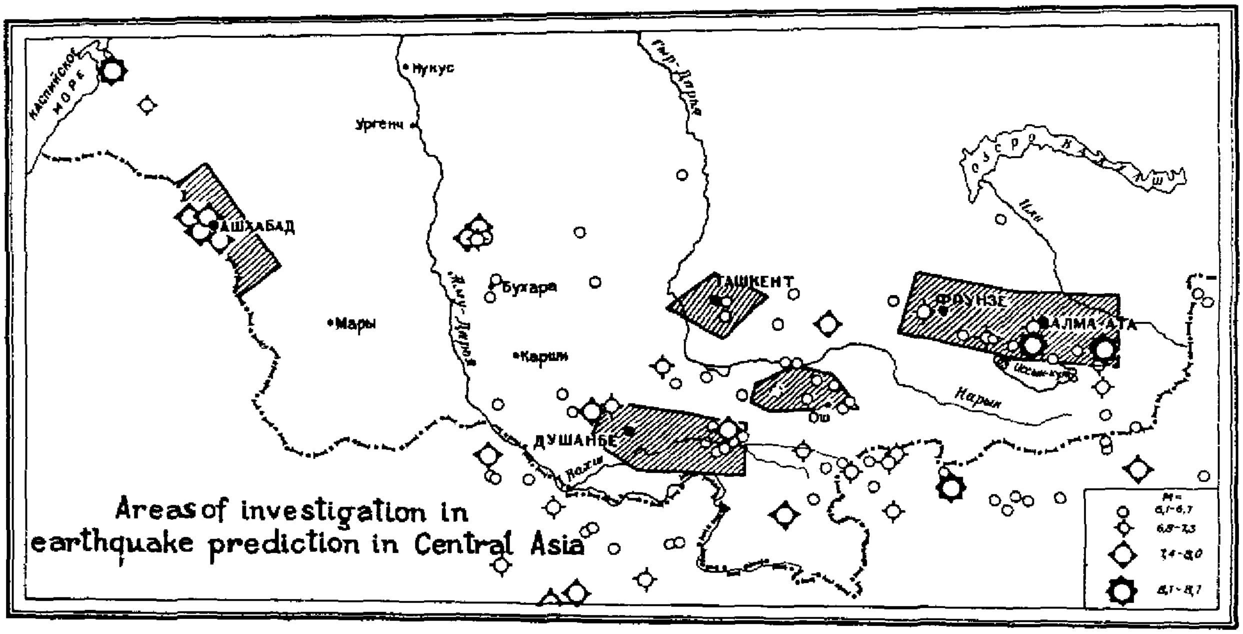

Fig.2. Prediction observation sites in Soviet Central Asia and Kazakhstan (3).

abnormal phenomena be detected, representatives of institutes not forming part of the Republic's own institute must transmit their data to the governing body of that institute for conclusion.

As a rule, each scientific institute responsibile for prediction has its own prediction commission, which generally meets once a week and examines the seismic situation as it has developed over the preceding week. A formal record is kept of the commission's meetings. Should any abnormal phenomena be detected, the commission may meet whenever necessary. Each commission's final decision must be taken collectively; where necessary, representatives of other establishments may be co-opted as consultants. A prediction report to the administrative authorities takes the form of an explanatory note to which all graphic material serving as a basis for the prediction is appended. The note must be approved by the governing body of the Republic's academy of sciences.

In the case of stronger earthquakes affecting the territories of several Republics, the procedure for the issuance of conclusions is the responsibility of regional prediction centres, which each monitor the territory of an entire geological region. The measures to be taken in such cases are now being drafted.

An examination of all the largest earthquakes that have occurred in Soviet Central Asia and Kazakhstan since 1970 shows (although in many cases this is only apparent in retrospect) that many of them were preceded by anomalous processes. For example, the earthquake that occurred on 5 June 1970 (magnitude 6.7) near Przhevalsk in Kirghizia (Fig.3) was preceded by considerable displacements of crustal blocks in the Alma-Ata district, anomalous tilts at the Turgen station and an area of quiescence in the epicentral region. No clear precursors were observed prior to the earthquake of 11 August 1974 on the border with China, although some anomalous deformations at Garm and Talgar may have been linked with the earthquake. Certain abnormal phenomena in seismic regime in the region of the future epicentre were observed more clearly.

Figures 4 and 5 show the changes that occurred before the earthquakes at Gazli on 8 April and 17 May 1976 (magnitude 6.8 and 6.3). Before these earthquakes there was an increase in micro-earthquake activity in the area of the future epicentre. A significant change was observed in the development of tilting, although to link these changes directly to the earthquake would be

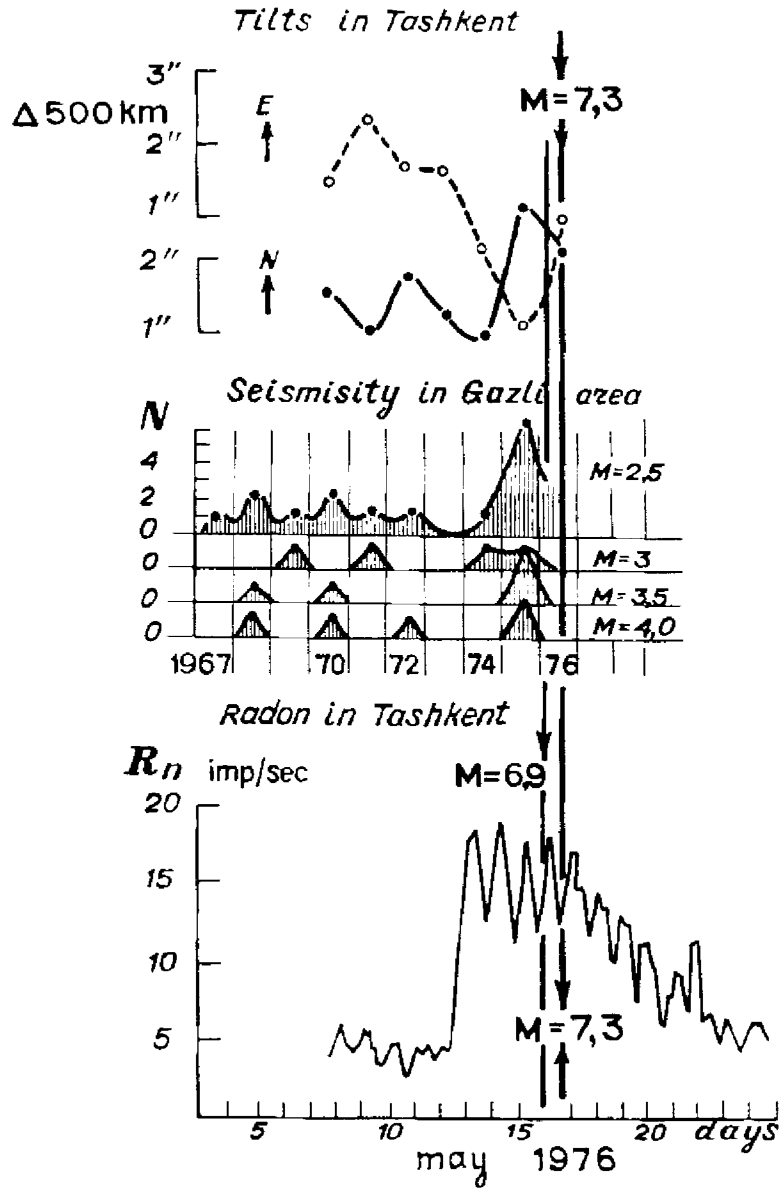

Fig.4. Precursors of earthquakes in Gazli, May 1976. M = 7.3. From top to bottom: tilts of the earth's surface at Tashkent station; seismicity in the Gazli area; radon content in the Tashkent gusher (= 500 km).

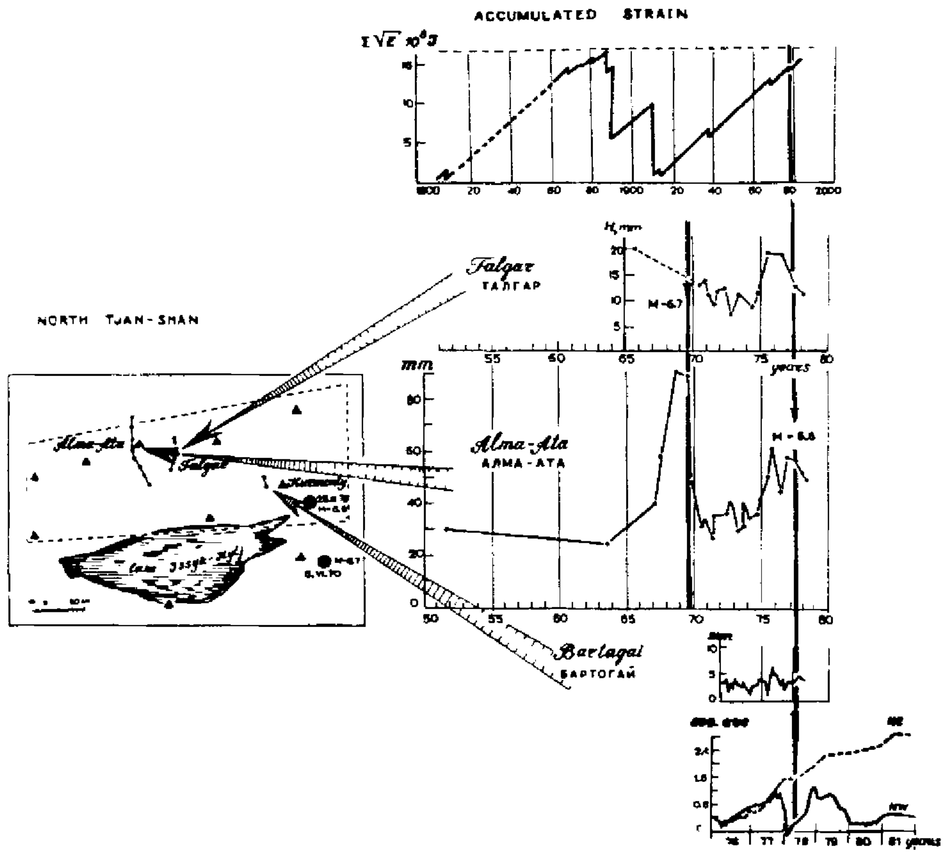

Fig.3. Precursors of 1970 and 1978 earthquakes in North Tyan-Shan. From top to bottom: accumulation of deformations; vertical displacements on the Talgar profile; vertical displacements on the Alma-Ata profile; vertical displacements in the epicentre area; changes in tilts at Turgen station (1).

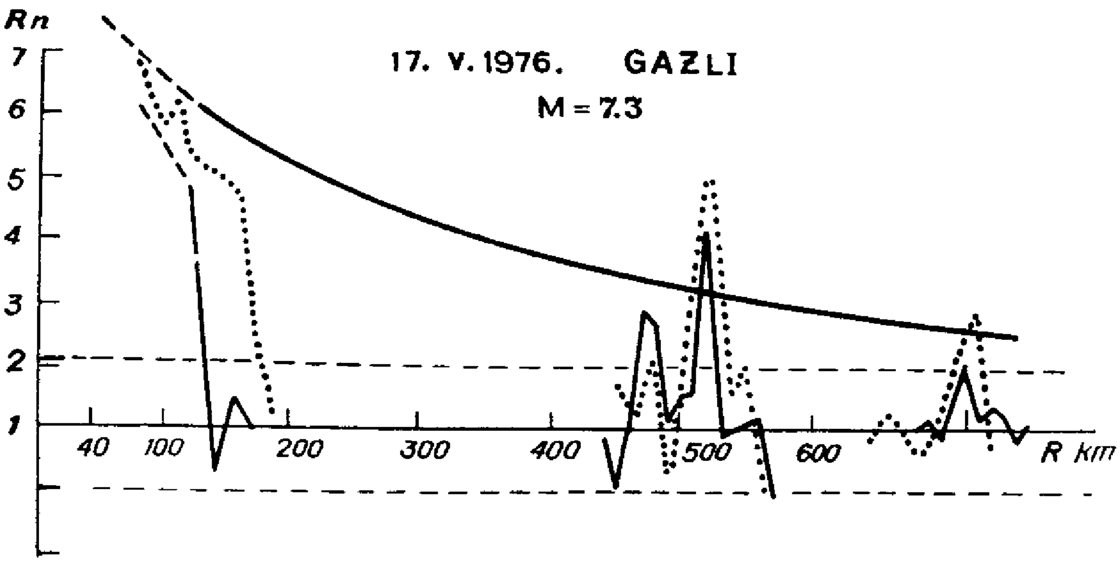

Fig.5. Variation in radon content with distance before the Gazli earthquake.

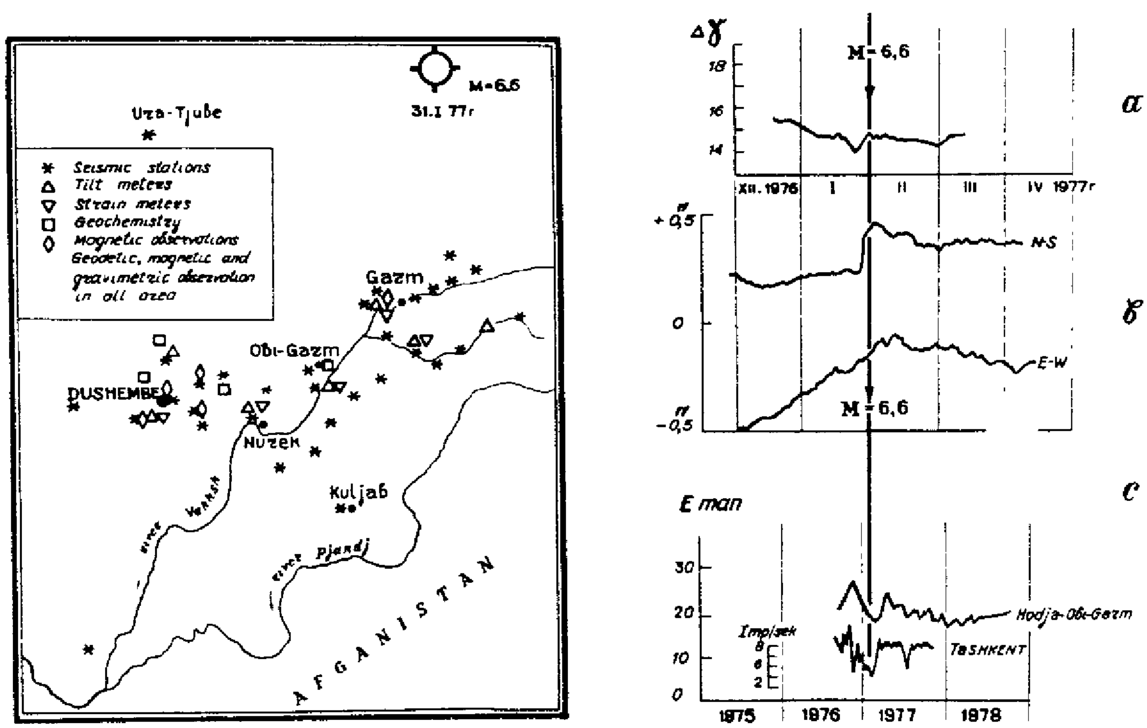

Fig.6. Precursors of earthquake in Isfar, 31 January 1977, M = 6.6. From top to bottom: magnetic anomaly at Garm; tilts of the earth's surface in the Dushanbe area; radon in gushers at Dushanbe and Tashkent.

difficult. Anomalies in the radon content appeared quite clearly at various distances up to 720 km. It was precisely on the basis of the radon anomaly in Tashkent that the second shock was predicted.

The earthquake of 31 January 1977 (magnitude 6.4) in the Isfara district occurred at an approximately equal distance from the Tadzhikistan and Uzbekistan observation sites (Fig.6). In this case, a small magnetic anomaly was recorded in the Garm area, changes in angular displacements were recorded in one of the tiltmeter components in the Dushanbe area and quite similar anomalies in radon content were recorded at the Khodzha-Obigarm and Tashkent stations. It should also be noted that, before this earthquake, the longitudinal and transverse wave velocity ratio in the area of the Garm observation site changed noticeably at all stations, the tendency being towards a general velocity increase. The impression is obtained that prior to the earthquake the whole district was in a state of increased compression.

The precursors of the Alaysky earthquake of 1 November 1978 (magnitude 6.6) (Fig.7) were observed mainly at stations of the Uzbek Academy of Sciences near Andizhan. Prior to the earthquake, small tremors ceased, a change occurred in the direction of movement on the levelling profile and a noticeable magnetic anomaly was observed between the Andizhan and Tashkent stations; three days before the shock, spring flow dropped sharply, stopping completely a day before the shock; some rather uncertain changes in radon, helium and carbon dioxide content were recorded. A warning in respect of this earthquake was issued seven hours before the shock with an error of 80 kilometres as regards the position of the epicentre. The shock magnitude was assessed correctly.

The precursors to a series of shocks in the Tashkent area at the end of 1980 were identified on the basis of geochemical data. The time of the earthquake could not be predicted because the time of the occurrence of anomalies differed on the various components.

In the Garm-Dushanbe area, a series of predictions of earthquakes of moderate strength was made from 1976 onwards as a result of joint work by the Institute of Earthquake-Resistant Construction and Seismology of the Academy of Sciences of the Tadzhik SSR and the Institute of Earth Physics of the Academy of Sciences of the USSR. The earthquakes concerned occurred

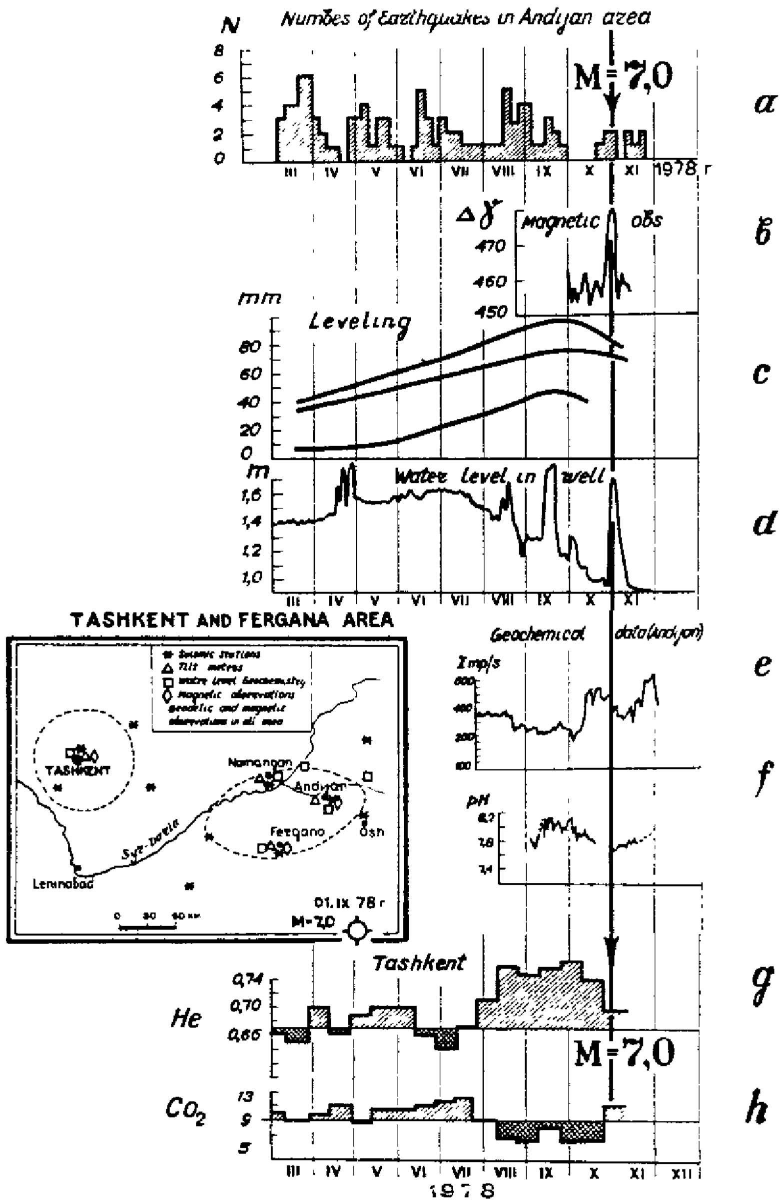

Fig.7. Precursors of the Alaysky earthquake, 1 November 1978, M = 6.8. From top to bottom: seismic activity; magnetic anomalies; levelling; water level in gusher; radon, pH, helium, carbon dioxide.

in 1976, 1979 and 1980. Figure 8 provides an example of the prediction of a small earthquake(magnitude 4.3) at the Garm observation site on 16 April 1979 on the basis of the occurrence of smaller shocks with a magnitude of between 0 and 1 in the area of the forthcoming shock and anomalous tilts of the earth's surface 40 hours before the shock. Several other such examples could be quoted. As far as we are concerned, the most interesting parts of this material are the tiltmeter and deformation observation data reproduced in fig. 9. Prior to the onset of the earthquake proper, there is a change for several dozen hours in the direction of movement, after which the shock usually occurs. Unfortunately, signals of this kind are not received in all cases, but when tiltmeters or deformation gauges do record them, the subsequent alarm never proves false.

We can now say with reasonable certainty that the majority of strong and moderate earthquakes are preceded by anomalous phenomena which can be used to predict the magnitude and time of the earthquake.

This does not mean, of course, that we understand all aspects of the processes occurring in earthquake foci. As already stated, our knowledge of the properties of the earth's crust and upper mantle is inadequate. Their further study will undoubtedly help towards a better understanding of the properties of the earth's interior and the phenomena occurring there and towards the elaboration of a mathematically-founded earthquake prediction theory. However, there is no need to treat the prediction of earthquakes and the establishment of an adequate theory of seismic foci as a single problem.

What we already know is sufficient to make it certain that the problem of prediction can be solved given appropriate technical equipment for the prediction observation system.

At the same time, the data that have been collected have given rise to a number of new questions requiring urgent consideration.

Anomalous signals in any of the fields studied - seismological, geophysical, geodesic or geochemical - are received against a background of continuous noise. As the observation series available are usually limited, we can by no means always identify a signal as meaningful. Such identification is further complicated by the fact that, even at points located close together, the nature of changes in background noise characteristics is often dissimilar.

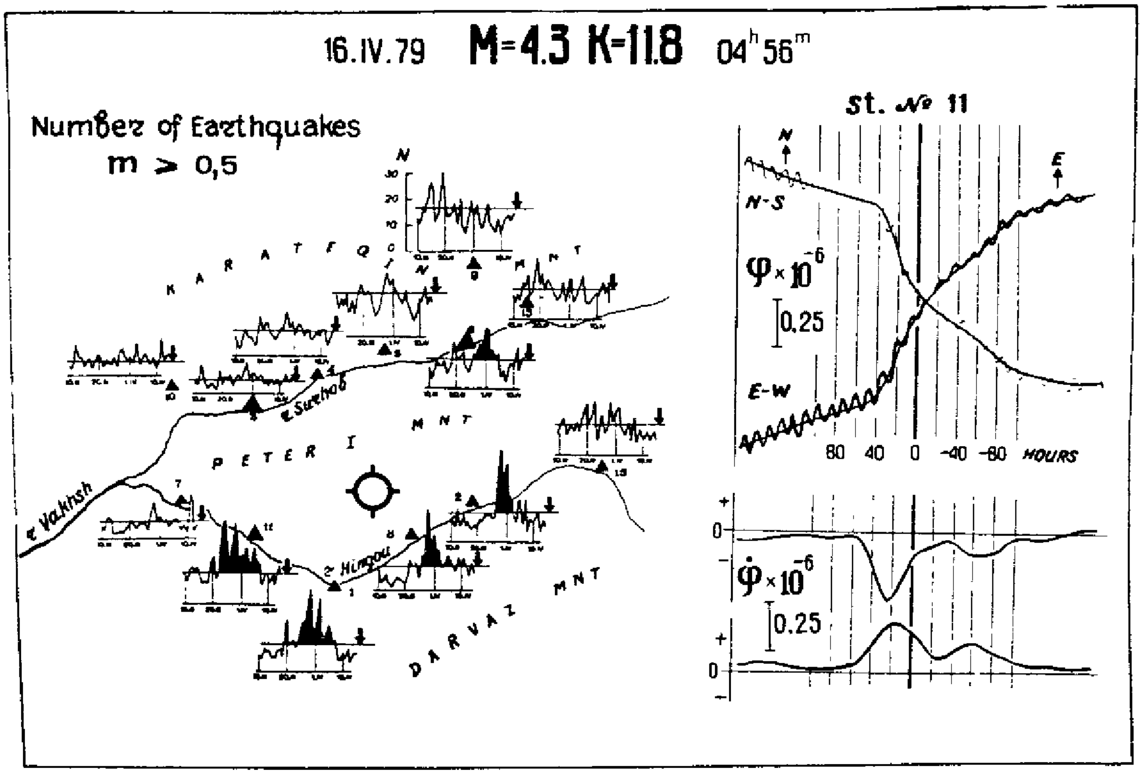

Fig.8. Precursors of the earthquake at Garm, 16 April 1979, M = 4.3. Seismicity and variation in tilts (5).

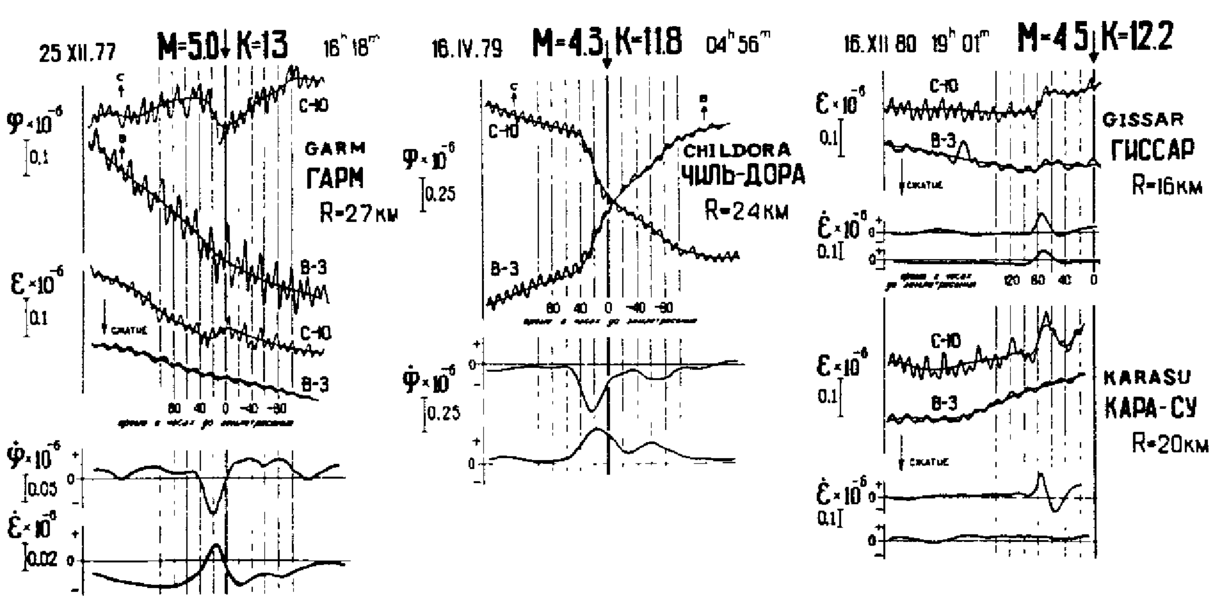

Fig.9. Variation in tilts and deformations before earthquakes in the Garm-Dushanbe areas.

An analysis of published data on earthquake prediction, as well as current observations, suggest that the form of preliminary precursor signals often varies. This is readily verified by comparing, say, various examples of geochemical anomalies, electric resistivity and so forth. Furthermore, experience has shown that anomalous prediction signals are extremely spotty. Even where earthquake foci are located close together, such signals fail to recur at the same stations and may be detected on the basis of different parameters.

The instability and spottiness of anomalous signals make it difficult to apply formal statistical methods of information processing, and especially computer-based methods, in the automation of prediction observations. That is why the elucidation of the nature of instances of anomalous signals is one of the most important problems in developing earthquake prediction methods.

The instability of prediction signals also indicates that different observation points have different "prediction sensitivity". By way of example, it may be mentioned that in a number of cases observations made at points located on regional faults have proved generally unreliable, while points located on smaller secondary dislocations are more significant.

The varying size of crustal blocks, which determines the system of transmission of forces throughout the deformation process, is apparently responsible both for the unevenness of the manifestation of the signals themselves and of their form and for the sensitivity of observation points. Thorough theoretical investigation of these problems is needed in order to establish objective criteria for the selection of observation points for different prediction methods.

In a number of cases, precursors have been observed at unexpectedly great distances from the foci of strong earthquakes. This has been a source of difficulties as it is not always easy to distinguish between local and distant signals. This problem will probably be solved in two ways: first, by developing an observation system for large areas with scattered stations and, secondly, by the more extensive use of long-term prediction, which, as a rule, permits the monitoring of seismic hazards over large areas.

From the technical point of view, prediction should be organized on three levels. First of all, it is necessary to set up stations serving a large area, with observation points spaced at intervals of 100-150 km. Such a system of base stations will ensure that the state of large areas is monitored before strong earthquakes. Second, detailed observations should be obtained for relatively small areas of the order of a few tens of thousands of km^2 in the more important sectors of a seismically active region. The term "important" here applies to major towns, densely populated areas and major industrial towns. Lastly, mobile observation systems should be available for deployment in the most threatened areas. The entire system should be provided with appropriate communications channels so that all data may be collected in a single data processing centre. A great deal remains to be done, of course, to develop suitably reliable and simple equipment for carrying out the actual observations.

The graduated system of processing prediction data in the USSR is reflected in the fact that, at the level of detailed operations, data collection is effected by the research institute in the individual Republics. In the case of large regions, such as Soviet Central Asia, information will be stored at the regional centre, viz., the Institute of Earthquake-Resistant Construction and Seismology of the Academy of Sciences of the Tadzhik SSR. All operations involving mobile equipment are carried out by expeditions based in one or, if necessary, several Republics.

Although some problems remain unsolved, with the improvement of the technical equipment for observation definite progress is being made every year in prediction activities and the number of instances of successful prediction is increasing. In a certain sense, we may say that the problem of predicting the time of earthquakes is now shifting from the field of pure science to that of technology; it should not be forgotten, however, that prediction research is continuously developing and that no adequate model of seismic focus theory is as yet available.

Closer international co-operation in prediction activities, and particularly in more thorough analysis of observation data already collected, could substantially speed up the solving of the outstanding methodological problems. A no less important task would be that of drafting general recommendations specifying the purposes and objectives of prediction, general requirements as regards observation systems, and general guidelines, adaptable to each country's specific conditions, for the submission of prediction reports to administrative bodies.

DISCUSSION

In reply to questions, Prof. Nersesov pointed out that in each republic of the USSR with significant seismic activity, there exists a Commission of scientists located at the Institute of Seismology or Geophysics whose duty is to evaluate earthquake predictions.

He stated that government officials refuse to take into consideration probabilistic predictions. There exist groups that are ready to act in case of emergency resulting from a prediction. He agreed that it is important to bring together officials, scientists and sociologists in order to examine prediction problems.

He mentioned a case where a prediction was made of an event which took place but with 2½ weeks error in time.

He stated that it was not allowed for scientists to issue direct announcements on prediction to the public. However they may give information on what to do in case of earthquakes.

On the subject of precursory phenomena, he confirmed that anomalies could be observed at large distances. But an accurate location of the future earthquake required a network of observatory stations around the suspected area. He said that special observations were currently being made in the eastern part of the Garm region where an earthquake of magnitude 7 is expected at any time. He quoted an example of two 5.2 magnitude earthquakes which occurred with epicentres 7 km apart but where anomalies were observed only for one of them.