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[TRANSLATION OVERLAYS FOR FIGURES* ARE APPENDED.]

EARTHQUAKES IN GARM OBLAST

I. Ye. Gubin

(An Experiment in the Determination of Seismotectonic Regions)

Chapter I

INTRODUCTORY REMARKS

1. Introduction

Earthquakes occur annually in the territory of Garm Oblast in Tadzhik SSR. From the standpoint of the number of seismic shocks recorded within its boundaries from 1912 to 1945, this oblast occupies one of the first places among other regions of the Soviet Union. As many, or possibly somewhat more seismic shocks have occurred only in the nieghboring eastern part of Stalinabad Oblast, which is adjacent to the west. In these two contiguous territories, according to records of seismographic stations from 1912 to 1937, i.e., for a period of 25 years more than 45 percent of the earthquakes recorded in the whole of Central Asia occurred, and about 25 percent of the earthquakes which took place in the territory of the entire Soviet Union (29). For the past 12 years alone, from 1934 to 1947, many hundreds of seismic shocks of medium and weak intensity, and four destructive earthquakes of 9 and 8 points, have been recorded in Garm Oblast.

Strong earthquakes in Garm Oblast are always accompanied by severe hardships. For the 12 years mentioned a large number of population points in various rayons of the oblast were destroyed in earthquakes. During these 12 years the government of the USSR allocated to the oblast several tens of millions of rubles for

*[Note: Hand traced copies of figures 8, 13, 14, 15 are in Appendix I; thermoprint copies of all the figures are in Appendix II. The captions to the figures are in the text.]

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reconstruction work, and repeatedly exempted the population from taxes and deliveries in kind.

In connection with the frequent recurrence of strong earthquakes in Garm Oblast, there is great significance in the search within its boundaries for means of reducing the destructive effects of seismic phenomena. Accordingly, the seismicity of the territory of Garm Oblast has been investigated in this article, and a map of its seismic regions has been drawn up (i.e. places where earthquakes are currently taking place have been located), with a view to the recommendation of appropriate measures for the planning of construction to provide protection against earthquakes.

As is known, earthquakes in Garm Oblast are caused by tectonic, in particular by mountain-forming processes (8, 9). In the course of the author's seismotectonic researches it was ascertained that the epicenters of these earthquakes coincide to a certain extent with the lines of recent Alpine faults in the earth's crust, and that their foci lie along the planes of the faults, at depths from 2 or 3 to 25 kilometers, less frequently deeper. The occurrence of these fault-plane earthquakes is probably caused by breaks in the continuity and shiftings of the mountain masses. The above-noted Alpine tectonic faults, with which the earthquake foci are connected, and along which the shiftings of masses within the boundaries of Garm Oblast take place, show up clearly on the earth's surface. The discovery of these close connections, easily observed in nature, between seismic phenomena and recent faults in the earth's crust has made it possible to divide the territory of this oblast into seismic regions on the basis of the results of study of the various consequences of tectonic movements.

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Data for this study were collected by the author in Garm Oblast during the course of field expeditions made there over a non-continuous period of six years, within the period from 1932 to 1947 inclusive: at first in connection with the mission of the Tadzhik-Pamir expedition of the Academy of Sciences USSR, and subsequently with that of the Tadzhik branch of the Academy of Sciences USSR and of the Geophysical Institute of the Academy of Sciences USSR. This article (Speech at a session of the Learned Council of the Geophysical Institute of the Academy of Sciences of the USSR, May 22, 1948.) was prepared for publication in the seismogeological laboratory of the Geophysical Institute. The author expresses appreciation to the director of the laboratory, Professor G. P. Gorshkov, and likewise to N. V. Veshnyakov and Ye. F. Savarenskiy, for assistance and advice rendered.

2. Selection of a Method for the Determination of Seismic Regions

At present, for the division of various territories into seismic regions, the seismostatistical method is usually applied. This notwithstanding, I have selected another, the seismotectonic method, for dividing into regions the territory of Garm Oblast. Selection of a new method of determining seismic regions requires special explanation.

The seismostatistical method of determining seismic regions is based on the assumption that earthquakes at present occur regularly in the same places -- places which in most cases have already been located through study of the effects of earthquakes. Appropriately, this method is founded on the use only of statistical data on earthquakes. It includes the gathering of information on the distribution of earthquakes of various intensities, analysis of this information, and next the compilation on the basis of the given data of seismostatistical

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maps of seismic regions. On these maps are plotted in one way or another the places of occurrence and areas of diffusion of the strongest earthquakes which have taken place, during the course of some, usually brief, period of time, within the boundaries of the territories being studied. Maps of this nature are considered complete.

The above-mentioned brief periods of time for which seismostatistical data are gathered number for various places from several tens to several hundreds of years, depending upon when within the boundaries of a certain territory the regular recording and study of earthquakes was begun. In compiling seismostatistical charts, it is assumed that in the future earthquakes will repeat themselves in the same places and will from time to time attain the same maximum intensity as earlier, but that in those places where they have not occurred before, they should not be expected. The latter areas are classified on the subject maps in terms of distance from epicenters which have appeared and in terms of the degree of weak tremors which have reached them, either as aseismic regions or regions of low activity. These seismo-statistical maps are accepted by many investigators, and also by administrative organizations, as maps on which essentially all locations of possible future earthquakes have been foreseen.

The seismo-statistical method in question for division of seismic regions, cannot be applied everywhere with uniform success. For its successful application much statistical data is required, which in many seismically active regions is available in extremely inadequate quantity. Statistical data essential for the determination of seismic regions must be collected over such a long interval of time so as to show during the interval the activity of all (or the majority of) earthquake foci existing within the boundaries of the territory being

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studied or situated in neighboring regions and constantly active from time to time, even though they may be recorded only once. If these intervals are short, then many foci and groups of foci will not manifest themselves and therefore will not be discovered.

It is natural that with the subject seismostatistical method of division into regions, places of the development of such unmanifested foci will be erroneously classified as aseismic areas or areas of low activity, although at any moment strong earthquakes may take place within their boundaries. Consequently, under these circumstances, with statistical material scarce, the application of the seismostatistical method of division into seismic regions will not produce the desired result and may even lead to distortion of the truth.

(In literature on the subject there is encountered a large number of maps of seismic regions, called siesmic maps or diagrams of seismic regions, with no indication of the data on which they are based nor of the means by which they have been drawn up. It is necessary to note that an overwhelming quantity of such maps is made up only according to statistical data and by the siesmostatistical method. In connection with what has been revealed, for a true evaluation of various seismic maps and for accommodation in reading them, the method of their compilation and the type of data which forms their basis should be noted. For example: "Map of the siesmic regions of such-and-such an oblast, drawn up by the siesmostatistical method, based on data from 1890 to 1940", etc. For another method of division into regions, see 3.) Therefore, before the seismostatistical method of division into seismic regions can be applied, it must first of all be ascertained whether the corresponding statistical

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data are sufficient for this and whether they will give a true picture of seismicity. It is extremtly complicated to determine the minimum sufficient interval during which all or the majority of foci existing in the seismically active territory being studied should manifest themselves. For different regions this interval will vary and will depend on the degree of activity of tectonic processes and the number of continuously active foci.

Let us attempt to determine for what period statistical data for the mountain oblast's of Central Asia, including Garm Oblast, must be collected so that seismic regions may be located with their help alone.

Within the boundaries of these mountain oblast's there are many tens and even hundreds of different potential seismic faults in the earth's crust, and at the same time there is a corresponding number of associated earthquake foci. In certain of these oblast's strong earthquakes occur on the average of once every 10 to 15 years, in others every 15 to 30 years, now in one, now in another place, now along one, now along another fault. Consequently, the activity of all foci existing within the boundaries of a certain oblast will be able to manifest itself in sufficient degree only in the course of many hundred years, in certain territories only in the course of several thousand years. It is evident that for sufficiently effective determination of seismic regions by the statistical data for such an interval would be needed.

Such data, however, are not available. We have regular siesmic data for these oblast's only for extremely short periods of time, numbering from 50 to 100 years, no more, and for Garm Oblast those

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data are available only for 45 or 50 years. Consequently, the data in question are extremely inadequate for discovery by the seismostatistical method of potential seismicity existing in the territories mentioned. Therefore, the discovery of all seismic foci, or at least the majority of them, within their boundaries, including the boundaries of Garm Oblast, requires the application of other data besides seismostatistical data and the application of another, new method of determining seismic regions, with whose help it would be possible to find potential foci which have not yet manifested themselves as earthquakes during the course of the above-mentioned short intervals. Such an alternative method of determining seismic regions is the seismotectonic method.

3. The Seismotectonic Method of Determining Seismic Regions

This method is based on the assumption that at present in many districts destructive earthquakes in the earth's crust occur mainly at various small depths--up to 25 or 30 kilometers, infrequently up to 50 kilometers and deeper--as the result of sharp relative displacements of masses of rock strata along tectonic faults. These earthquakes occur systematically in definite tectonic zones, at various intervals of time. Proceeding from this as a reference point the method under consideration comprehends, in the author's conception, a study of the mechanics of present-day tectonic movements in the earth's crust, including the finding of various seismic faults, i.e. of faults along which the shifting of rock masses takes place and along which earthquakes occur. Together with these faults are located the constantly active earthquake foci associated with them, and the corresponding epicentral zones. The latter are used subsequently as bases for the compilation of seismic maps.

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Discovery of the mechanics of present-day tectonic movements in the earth's crust and the location of seismic faults are possible by means of study of the effects of these movements on the earth's surface, then by study of seismic phenomena, and likewise by means of study of the nature of the earth's crust as indicated corresponding outcropping of the basic rock-bed. The mechanics of present-day tectonic movements in the depth of the earth's crust can be most precisely ascertained in regions within whose boundaries the effects of those movements manifest themselves in accessible forms, on the earth's surface as well as at depths which are of interest to us. The geological structure of the earth's crust, and at the same time the location of various faults, can be ascertained, depending on local geological conditions, by outcropping of the basic rock-bed on the earth's surface at depths of several kilometers up to 15 or 25 kilometers, and in individual cases up to 100 kilometers or more.

(In geosynclinal areas, in places where there are deep joints which probably penetrate, according to A. V. Peyve's determination (28), the interior of the earth's crust at depths of several hundreds of kilometers, the mechanics of tectonic movements can be ascertained by geological methods within the limits of the whole of the indicated depth. In particular, this can be done in Central Asia in places where the deep Talas-Fergana joint is found.) On the whole, where the effects of present-day tectonic movements are clearly revealed on the earth's surface, the mechanics of these movements can be ascertained by geological methods, with various degrees of detail, at a depth of 10 to 25 kilometers on the average. At greater depths the mechanics of movements can be assumed only in general terms.

If the earth's surface is not broken in a certain region, then it is possible to suppose that tectonic movements there are presently

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at the minimum, that for practical purposes they are absent.

Applying the seismotectonic method of determining seismic regions, one first studies the geological composition of a certain area and ascertains within its boundaries the effects at the earth's surface of the most recent, including quaternary, movements. Investigating

(Fig. 1 Homes of the village of Dzhorako, located in the epicenter of the earthquake of April 20, 1941, which were destroyed and slid downward along a slope.

Photo by I. Ye. Gubin) [Photograph not in Appendix [illegible]]

these effects, one discovers the general plan of these most recent movements and at the same time locates the various recent faults in the earth's crust. Next, with the help of seismostatistical data, if possible instrumental as well as non-instrumental, (Instrumental data, essential for detailed determination of seismic regions, must be possessed to a high degree of precision, as noted below in §6.) one ascertains whether these newest tectonic movements are continuous, what intensity they attain, and whether they are taking place just as before, or in some altered form.

This is done in the following manner. One gathers all recorded seismostatistical data for the area being studied and determines the geological conditions under which various individual earthquakes have taken place. This being done, one ascertains along what main type of faults and under what main geological conditions subterranean shocks are mainly occurring and shiftings of masses are taking place at the present time. Afterwards, summarizing all geological and

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seismic data, one determines the probable general plan of present-day tectonic movements. He ascertains in what principal places, under what principal geological conditions, and also along what principal types of faults rock masses are shifting and earthquakes are taking place at present.

Using this plan, one investigates the geological circumstances relating to all the other, earlier mentioned recent faults which have been located through study of Quaternary and earlier tectonic movements, and finds among the latter potential seismic faults, i.e. faults along which earthquakes have not occurred during the course of the recent brief period when men have been studying earthquakes, but which had been regularly occurring before that period, during the last several thousands of years of the present geological age.

Various seismically active faults (and other seismic structures), which have been located by means of study of the geological causes of individual earthquakes and by means of comparative seismotectonic analysis, are plotted on the map, together with the probable epicentral zones associated with these structures. This map is taken as a basis for the determination of seismic regions. On it are determined in addition what very strong earthquakes have been during the present geological age typical of the epicentral zones which have been located, and what were the radii of their diffusion. This is done in the following manner. With the aid of statistical data one ascertains what very strong earthquakes are characteristic for seismic faults which have already manifested themselves, how often they occur, and what are their zones of diffusion. Next it is assumed that along other, identical faults, under identical geological conditions, there is a possibility of earthquakes of the same character and frequency. In case there is an absence of any seismo-

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statistical data on the region being studied, the given seismic faults are compared with seismic faults in neighboring, and in more remote, places where general geological condtions are approximately the same.

In addition to surface earthquakes, deep-centered earthquakes may occur in the areas being studied. The nature of these earthquakes is not yet clear, and the statistical method must be used to determine the seismic regions into which they may be classed. Incidentally, in many seismic regions deep-centered earthquakes occur very seldom and in the majority of cases do not attain destructive intensity on the earth's surface.

In maps of seismic regions drawn up by the seismotectonic method (On these maps of seismic regions it is possible, for purposes of simplification, not to plot the symbols of certain seismotectonic structures, and on small-scale maps it is even possible not to plot indications of epicentral zones, giving only indications of the tremors of greatest intensity which have occurred.)
are included zones of occurrence and areas of diffusion of the strongest earthquakes typical of these places, which have occurred regularly, not just during the limited period of time when earthquakes have been studied, but even before this period, during the many past millenia of the current phase of the present geological age. Consequently, these maps reflect with extreme completeness the seismicity of a given territory, but they still do not embody the greatest possible completeness, since deep-centered earthquakes are taken into consideration here only within the limits of statistical data. Since these maps of seismic regions are based on conclusions drawn from the study of the now-active mechanics of present-day movements of the earth's crust, they may thus be considered as maps on which basically the places have

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been foreseen within whose boundaries certain strong earthquakes typical of these places may occur in the near future. Applying the given seismotectonic method of determining seismic regions in places where the inhabitants do not remember strong earthquakes, it is possible to ascertain whether such earthquakes occurred regularly at an earlier period in the course of the current phase of the present geological age, i.e. in the course of the past several millenia. Next, it is possible to ascertain whether these earthquakes will repeat themselves during the present time and what is the greatest normal strength which they will attain. It is also possible to determine, as we have seen earlier, the radii of diffusion of these earthquakes.

4. On Certain Conditions of the Application of the Seismotectonic Method

In consequence of the fact that the seismotectonic method of determining seismic regions is based on the use of data acquired in studying the effects of present-day tectonic movements which show up in various forms on the earth's surface, it is natural that this method can be applied only for determining the seismic regions of territories within whose boundaries relative movements of the earth's crust which cause earthquakes manifest themselves either in the relief or as small local cracks in the earth's surface, geological structures, etc. Such territories are the majority of seismic regions of Central Asia, part of the regions of Siberia, the Caucasus, and other places, including the territory of Garm Oblast.

I shall note certain peculiarities of the application of the seismotectonic method of determining seismic regions. Its greatest complexity is in the discovery of relationships between seismic and tectonic phenomena, and in the location of potential faults. The relationships between seismic phenomena and present-day differential

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movements in the earth's crust is ascertained not only through the simple coincidence of earthquake epicenters with the lines of recent tectonic faults, but also by other signs. Specifically, this relationship is disclosed by the coincidence of various types of earthquakes with various corresponding types of geological structures and their peculiar tectonic movements, for example, by the coincidence of surface earthquakes (with foci up to 5 or 6 kilometers in depth) with surface structures which reveal certain local shiftings and complications, or by the coincidence of foci of the deeper earthquakes with steep faults in the area of block movements in the earth's crust. This relationship is also ascertained by coincidence of the pattern of protracted isoseismal lines of various earthquakes with the protracted location of various moving geological structures and even of individual mountain systems, by coincidence of the form and depth of foci with the borders of individual moving folds or blocks of the earth's crust which are bounded by faults, and likewise by the uniform character of certain earthquakes which occur continually in definite tectonic zones, as well as by many other indications.

From the large number of different, recent faults which exist within the boundaries of the territory being studied, seismically active faults are distinguished by various means. First, faults connected with the present-day tectonic movements which are most typical of certain areas of the territory being investigated are distinguished. Some of these correspond in location to epicenters on the earth's surface and are at the depth of earthquake foci in the earth's crust; others are found through traces of dislocations which have occurred along their planes during earthquakes; a third category is found by its coincidence (in mountain regions) with characteristic landslides and by the relief of the earth's surface; a fourth category,

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usually comprising an important part of the seismic faults which are located, is disclosed through comparative seismotectonic and geomorphic analyses, etc. Faults which are hidden within the earth's crust may be found through analysis of certain surface geological structures, for example, of compressional folds of various thicknesses which in the depth of the earth's crust have been torn away from some plane of the substratum and, by virtue of their coincidence with this plane, from the foci of earthquakes.

If possible, various instrumental measurements should be applied to the location of potential seismic faults. In Garm Oblast these have not yet been made, and I shall therefore not discuss them. I shall take this opportunity to mention that probably the most comprehensive method of searching for potentially seismic faults is the application of highly sensitive seismographs in places where such faults are developing, in order to keep abreast of their day-to-day progress; active faults will manifest themselves with weak tremors, and "dead" faults will remain quiet.

5. <u>The History of the Seismotectonic Method of Determining Seismic Regions</u>

In literature on earthquakes it is common to encounter maps of seismic regions, drawn up by the seismostatistical method, on which in certain cases lines of the extent of fold-systems and depressions and in other cases lines of faults, have been meticulously plotted. Such combined maps of seismic regions are sometimes called, erroneously from this author's point of view, seismotectonic. This is erroneous because in compiling them a tectonic analysis of the mechanics of present-day tectonic movements has not been made, and potential foci, i.e. foci not recorded by statistics, have not been detected. Tectonics in this case adds nothing to statistics. In essence, such maps are

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merely seismostatistical, with tectonic diagrams plotted on them, and they have all the defects of statistical maps, if the latter have been made up on the bais of sparse data.

Let us take for example such a map of Central Asia (25). On it have been plotted as small spots the nine-point zones of the strongest earthquakes recorded up to the moment of the map's compilation. Intervening areas between these zones are indicated by symbols of low activity, with point-readings decreasing according to distance from the epicenters, similar to the way this is done on statistical maps. Tectonic considerations have not been made here, and potential foci have not been detected, i.e. nothing has been added to the statistical method. In consequence of this, the map in question could not withstand the test of time even for 12 years. From 1933 to 1946 six eight-and nine-point earthquakes occurred in Central Asia,

(Argankul', 1934; Argankul', 1935; Karategin, 1939; Garm, 1941; Fayzabad, 1943; Naryn, 1946 (9, 13).)

in zones designated on this map as five- and six-point zones, i.e. where they had been excluded and where foci had not been detected by' statistics, but where they existed potentially. These foci could have been detected by the seismotectonic method. The author of this map in discussing in his text the probable reasons for individual earthquakes, noted the possible existence of potential foci, but in compiling the map this admission was not taken into consideration.

Nor have other similar maps of Central Asia and of certain other regions withstood the test of time; this includes also various statistical maps, some of which are called seismic without indication of the fact that they were compiled by the seismostatistical method.

It is also incorrect to class as a seismotectonic method of de-

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termining seismic regions the simple process, often applied in literature on the subject, of the combination or juxtaposition of statistical and tectonic maps which have been produced without analysis of the mechanics of present-day tectonic movements and without adduction of factual data or even of special conclusions as to the geology of all of the territory under investigation. Through such a combination or juxtaposition we ascertain only the possible geological premises of individual earthquakes, but as in the preceding case nothing is added to the seismostatistical method, i.e. other, potential foci are not sought out. Consequently, maps compiled with the assistance of such juxtapositions are, from this author's point of view, as before statistical maps.

Incidentally, one of the most important distinguishing features of such maps of seismic regions, compiled as they are by an essentially statistical method, is the presence on them of eight- and nine-point zones, indicated by small patches, in only those places where tremors of corresponding intensity have been recorded. The intervening areas, where such strong earthquakes have not been recorded, are indicated on these maps by symbols of low activity, although in certain cases, according to tectonic data, may occur in these areas, according to tectonic data.

It is interesting to note that, with every new destructive earthquake, corresponding new eight- and nine-point zones appear in new editions of such maps. On maps compiled by the seismotectonic method the majority of these zones would have been detected beforehand. As has been mentioned already, seismotectonic maps include the epicentral zones of earthquakes which have not been recorded, as well as of recently destructive earthquakes which have been recorded, i.e., they include the epicentral zones of the majority of active foci.

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The individual elements of the method of determining seismic regions which has been considered above, and which is properly seismotectonic, began to be conceived long ago, when various investigators, beginning with I. V. Mushketov, E. Zyuss, and A. P. Orlov (22), pointed to the relationship between tectonic earthquakes and definite faults in the earth's crust, and classified the latter as seismic lines, subsequently as lineaments. These relationships between seismic phenomena and tectonic faults were also studied in succeeding works. In particular, in 1946 G. P. Gorshkov and A. Ya. Levitskaya (4), in a work on the seismicity of the Crimea, demonstrated the relationship between Crimean earthquakes and a fault assumed to exist on the floor of the Black Sea. N. K. Paffengol'ts (27) detected an identical relationship between earthquakes in the southern Caucasus and other faults in the earth's crust, etc. The general problems of the seismotectonic method of determining seismic regions were not touched upon in these works; this method was not developed in the form in which it has been set forth herein, and was not applied to the solution of practical problems in determining the seismic regions of areas. In particular, this literature failed to develop the problem of locating potential foci and the strongest earthquakes characteristic for them. Until the present time the latter were not sought out and were given no special distinction in connection with the determination of the seismic regions of areas.

In determining seismic regions various investigators, and also construction engineers, have been recognizing as continuously active only those foci which had appeared recently, in the course of a brief historical period of time, as earthquakes of substantial intensity. At the same time certain other investigators have understood the inadequacy of the seismostatistical method; however, knowing no other

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way to determine seismic regions in individual cases, they have increased, without sufficient justification, the seismic point-readings of various mountain regions to 8 or 9 points, although this does not correspond to statistics, according to which there have been no strong earthquakes in these regions (36). This being the case, large areas frequently appeared on maps as eight- or nine-point zones, with no consideration of the fact that within their boundaries there might be substantial areas of lesser activity.

As early as 1943 (8, p. 58) the author had applied analysis of the mechanics of modern movements in the earth's crust and had traced out potential foci for determining the seismic regions of a substantial area and ascertaining the seismic conditions of many population points. In this article an attempt has first been made to establish and develop the seismotectonic method of determining seismic regions, including as a fundamental component part the location of potential as well as already-manifested foci. This method has been applied here for the determination of the seismic regions of an extensive territory of Garm Oblast and is recommended instead of the statistical method for further practical application in other regions of Central Asia, the Caucasus, and Siberia. Important achievements in the past ten years in the study of the geological structure of the territory of USSR, during which time detailed geological data have been assembled have made possible the application of this method.

It may be supposed that large-scale application of the seismotectonic method will bring us close to a solution of the problem of forecasting earthquakes. In particular, with the aid of this method it is possible to locate places where strong earthquakes will occur in the future in a given territory. Having studied the various physical phenomena which probably precede strong earthquakes, for

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example,

(Fig. 2. Home in village of Dusti) [Thermoprint in Appendix III]

(Fig. 3. The rayon dispensary in the village of Garm, which was destroyed by the earthquake of April 20, 1941. Part of the northern wall collapsed.

Photo by I. Ye. Gubin) [Thermoprint in Appendix III]

weak preliminary tremblings, inclinations in the earth's surface, subterranean noises, etc., it seems that it will be possible in the future to learn how to predict in these places the time of occurrence of destructive seismic shocks.

6. History of the Investigation of the Seismicity of Garm Oblast and the Data Used

Seismostatistical data on the territory of Garm Oblast, as already noted, has been collected only in the course of no more than 45 or 50 years. Until 1895 there was an absence of any information on earthquakes which had occurred there, and from 1895 to 1912 there were only brief, fragmentary reports of individual subterranean shocks (18,22). Since 1912, with the opening of the seismic station in Tashkent, earthquakes in the territory of the oblast have been regularly recorded with instruments, but at this station, due to the great distance from the objects of its observations, only individual very strong tremors have been noted. The epicenters of these tremors were fixed with an error of the order of 20 - 25 kilometers and more.

Earthquakes of particularly great intensity have of course been recorded at more remote stations. Since 1940 earthquakes in Garm Oblast have also been recorded at the seismic station opened in the

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city of Stalinabad. But at this station, due to its remoteness (200 to 300 kilometers), many weak surface quakes occuring in the territory of the oblast have not been noted. Thanks to the expansion of a network of regional seismic stations in Central Asia, particularly to the commencement of operations of stations in Samarkand and Stalinabad, the precision with which epicenters in Garm Oblast are determined has been raised since 1940 to 15 kilometers (33).

Certain valuable information on earthquakes which occurred in the oblast between 1908 and 1937 has been furnished by local correspondents. These data have been added to the catalog of earthquakes in the territory of the USSR (18).

More detailed data on seismic phenomena in the territory of the oblast for the past 20 years have been acquired by means of field study of the destructive effects of strong subterranean shocks. Specifically, V. I. Popov (31) has studied in the field the destructive effects of the Argankul' earthquake of 1934 and by noninstrumental data has located its epicenter in the region of the villages of Lyayrun and Argankul' (Fig. 4.).

The author of this article has studied, within the boundaries of the oblast, the destructive effects of six other strong earthquakes which occurred during the period from 1932 from 1947, and by means of inquiries among the local population and also of documents of local organizations has ascertained the effects of several other similar earthquakes which occurred during the period from 1895 to 1932. Through these investigations nine earthquake epicenters were located, according to the varying degrees of destruction of buildings in various population points, and maps of their isoseismal

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curves were compiled (Fig. 4). In certain thickly populated regions, for example in Garm where villages are located at distances of from 2 to 4 kilometers apart, the precision with which the above-mentioned epicenters were fixed reached approximately 2 to 3 kilometers. In other places, where villages are more sparsely located, at distances from 5 to 7 or 8 kilometers apart, the precision with which the epicenters were fixed was correspondingly lower.

In studying the geological premises of earthquakes in the territory of Garm Oblast use was made of detailed hand-drawn geological charts, compiled by the author, of the territory of the Peter I range Khingou and Surkhob valleys, the northern slope of the Darvaz range, and certain parts of the southern slope of the Gissar range. Also used were hand-drawn geological charts of individual sections of the southern slope of the Gissar range, compiled by I. K. Nikitin, A. P. Nedzvetskiy, and A. G. Ivashentsev. Special detailed geological investigations were made by the author in regions of earthquake epicenters. The author made the sections of Mesozoic and Tertiary deposits mentioned in this article. Data on the thickness of Neocene deposits on the Peter I range were borrowed from A. R. Burachek (2).

Special instrumental measurements, particularly seismometric measurements, essential for the solution of problems in determining seismic regions, have not yet been made in the territory of Garm Oblast. However, as has been noted already, the epicenters of several strong earthquakes occurring there between 1912 and 1947 were determined instrumentally from remotely located seismic stations, particularly from Tashkent, with an error of 15 kilometers. Within these limits of precision, i.e. 15 kilometers (range of error of up to 30 kilometers), are usually located several different geological structures and often many different faults in the earth's crust in

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the territory of the oblast. In these conditions it is naturally impossible to ascertain with what concrete geological structure or with what fault a given earthquake has been connected. Such a connection might be found if the epicenter of a given earthquake were determined with small error on the order of 1 to 3 kilometers.

(I shall take this opportunity to note that with an increase of up to 1 to 3 kilometers, or even up to 5 kilometers, in the precision of fixing epicenters and seismic foci by regional seismic stations it would be possible to connect these observations with individual geological structures. This would open up an extremely broad perspective for the tracing of faults along which earthquakes occur, and at the same time would greatly simplify the determination of seismic regions.)

This desired precision in fixing epicenters has been attained in certain cases through field study of the destructive effects of strong earthquakes in thickly populated regions of Garm Oblast. Therefore, only epicenters fixed by the noninstrumental method have been used in this article for ascertaining the relationship between seismic and tectonic phenomena. The depths of seismic foci of various earthquakes have likewise been determined by the noninstrumental method, and only hypothetically, by comparing

(Fig. 4. Schematic map of destructive earthquakes occurring in the territory of Garm Oblast in the period 1934-1947.

Compiled by I. Ye. Gubin in 1947

1--Zones of 8-point shocks on the earth's surface; 2--Earthquake data; 3--Lines of isoseismal curves (Roman numerals in dotted lines are point-readings) [Thermofax in Appendix II]

the distances between isoseismal lines. In doing this the peculiarities of the geological structure of the earth's crust in the territory under study and the mechanics of its earthquake-causing movements have been

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taken into consideration.

The geological and seismic data used in this article are, of course, still inadequate for conclusive solution of many problems in the determination of seismic regions, but they make it possible nonetheless to ascertain the main peculiarities of seismicity in the territory of Garm Oblast. At the present time the Garm expedition of the Geophysical Institute of the Academy of Sciences USSR (1) has set up a seismic station near the village of Garm, and is carrying out seismometric, geodetic, gravimetric, and slope-measuring research in the oblast. The results of this work will make it possible in future to increase the precision of many statements made herein.

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Chapter II

THE GEOLOGICAL COMPOSITION OF THE TERRITORY OF GARM OBLAST

In accordance with the plan of application of the seismotectonic method of determining seismic regions, it is essential first of all to investigate the arrangement of the earth's surface and the geological composition of the territory of Garm Oblast in order to ascertain the general conditions of the occurrence of earthquakes within the boundaries of the oblast.

7. Arrangement of the Earth's Surface

Knowledge of the relief of the earth's surface facilitates the acquisition of a true conception of modern movements in the earth's crust. In particular, the mountainous, sharp, and deeply carved relief of the territory of Garm Oblast is evidence of intensive recent upheavals. Within the boundaries of the oblast are located three very high mountain ranges -- the Gissar, the Peter I, and the Darvaz.

The Peter I range (Fig. 4 & 5) occupies the central portion of the oblast. It extends in an approximately west-southwest direction and lies between the rivers Surkhob and Khingou, which meets at its southwestern tip. The length of the range attains 130 kilometers, its greatest width 30 to 35 kilometers, and height 4 to 5 kilometers. The Darvaz range, whose eastern portion bears the name of the Sel'dytau Mountains (Fig. 4), (In literature on the subject the Sel'dytau Mountains are for some reason called at times "the eastern chain of the Peter I range". They are divided from the Peter I range proper by the valley of the river Shaklysu, are parallel to it, and have nothing in common with it geologically.) stretches

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out parallel to the Peter I range, to the southeast of it and divided from it by the gorge of the river Shaklysu and the valley of the middle reaches of the river Khingou. The Gissar range is located in the northern part of the oblast', along the right bank of the river Surkhob, and has an almost east-west orientation. The width of this range's southern slope is as much as 30 kilometers; it is cut by numerous deep longitudinal and transverse valleys.

§8. Tectonic Regions

The geological composition of the territory of Garm Oblast is not homogeneous; in particular, the Darvaz, Peter I, and Gissar mountain ranges are of different composition. The geological structures of the Peter I range are part of the outer arc or zone of the Pamirs, and the structures of the Darvaz range are a component part of the inner zone of the Pamirs (9). The Gissar range is part of another tectonic district, the southern Tien Shans.

Paleozoic deposits play a fundamental part in the composition of the Darvaz range. The Peter I range is formed exclusively of Mesozoic and Tertiary sediments, the Gissar range of Paleozoic and to a lesser extent Mesozoic and Tertiary strata. The plane of the Alpine Karakul' fault serves as the geological border between the structures of the first two ranges. At the surface of the earth its line extends along the central part of the northwestern slope of the Darvaz range (Fig. 5). Along this fault-plane, which falls away ~~to the southeast~~ at an angle of from 25 to 45 degrees, the Paleozoic layers of the Darvaz have been displaced toward the northwest onto the Mesozoic sediments which enter into the composition of the Peter I range.

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The plane of the Vakhsh overthrust-fault serves as the geological boundary between the structures of the Peter I and Gissar ranges. Its line passes along the left bank of the river Surkhob, along the base of the northern slope of the Peter I range (Fig. 5). Within the limits of this slope the plane of the Vakhsh overthrust dips obliquely to the southeast, but in places it undergoes various bendings and even lies horizontal in some areas. Not far from the axial portion of the subject range it assumes a more pronounced descent into the

(Fig. 5. Schematic map of basic Alpine geological structures of the territory of Garm Oblast'.

Compiled by I. Ye. Gubin in 1948

1--Lines of the Bakhsh and Karakul' overthrusts; 2--Lines of faults and overthrusts occurring during formation of the folded structures of the Peter I range; 3--Lines of steep and vertical faults connected with the uneven upheaval of the Gissar range; 4-- Axial portions of the anticlinal folds; 5--Axial portions of synclinal folds; 1--46--Numbers of basic structures)

[Ozonoprint in Appendix II]

depths of the earth's crust (Fig. 6). Along this plane of the Vakhsh overthrust the Upper Jurassic and Cretaceous layers of the northern slope of the Peter I range have been shifted northwest and form the Vakhsh covering.

The section of the earth's crust buried under the above shifted layers of the Vakhsh covering attains a width of 15 to 20 kilometers

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(profiles IV--VII). Paleozoic, Mesozoic, and in some places Tertiary deposits play a part in its composition. The geological structures of this buried section are closely related to the structures of the Gissar range. In places they are divided from the latter, along the valley of the river Surkhob, by a series of steep unconnected folds, which acquired their greatest development during the latest (Quaternary) vertical upheaval of the Gissar range. I have distinguished the section of the earth's crust buried under the Vakhsh covering as the forward (or outer) zone of the southern Tien Shans.

The geological composition of the above-noted mountain ranges is represented schematically on the attached geological profiles (Fig. 6), in particular on

(Fig. 6. Eleven schematic geological profiles of the Peter I range. The profiles are numbered from west to east.

Compiled by I. Ye. Gubin in 1948

1--Various Paleozoic rock strata; 2--Mesozoic and Tertiary sediments of the Gissar range and the forward zone of the southern Tien Shans; 3--Lower Mesozoic sediments (the Sorbulak series of the Peter I range); 4 and 5--Mesozoic and Tertiary deposits of the Peter I range; 6--Line of faults and overthrusts; 7--Epicenters of earthquakes; 8--Seismic foci of earthquakes.)

[Thermoprint in Appendix II]

profiles IV and V. (For determination of the mechanics of present-day movements in the earth's crust the author has made up 11 detailed

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geological profiles of the territory of Garm Oblast, at depths up to 10 kilometers each. Only diagrams of these profiles have been used to illustrate this article.) In the middle part of these profiles is the Peter I range, composed of Mesozoic and Tertiary sedimentary layers which have collected into complex, compressed folds. On the northern slope of the Darvaz range may be seen the line of the Karakul' fault, along whose plane the Paleozoic rock strata have been shifted to the Mesozoic layers of the Peter I range. Under the thick Upper Jurassic and Cretaceous layers of the northern slope of the Peter I range may be seen on the profiles the undulating plane of the buried forward zone of the southern Tien Shans, composed of thin Cretaceous layers typical of this zone. The broad-based, sloping folds which have developed within the limits of the Gissar range have been drawn in (profiles I--III). These folds are divided by faults and broken by uneven vertical upheavals.

The geological composition of the three above-mentioned mountain ranges is considered separately below.

9. The Gissar Range

The geological composition of the Gissar range within the boundaries of Garm Oblast is made up principally, as has been already noted, of Paleozoic deposits, represented by Paleozoic limestones, no more precisely defined, by Upper Silurian shales with seams of limestone, and by granites. The thickness of Paleozoic limestones in the Komsomolabad rayon reaches 1.5 to 2 kilometers, and that of

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Upper Silurian shales 3 to 4 kilometers. The granites penetrate the Upper Silurian shales and come out to the surface of the earth in a large number of places, occupying a substantial area, particularly in the Garm region (Fig. 4). Mesozoic and Tertiary sediments are encountered only in small, dissociated areas between which they have probably been carried by water. Within the limits of the Gissar range proper are encountered mainly Jurassic deposits, represented by dark and black shales and gray sandstones, from tens of meters to 1200 meters in thickness. Just as often Lower Cretaceous sediments are encountered, represented by light-red and gray sandstones and conglomerates from 200 to 300 meters in thickness. These layers occur along the eroded surface of displaced Paleozoic layers.

At the base of the southern slope of the Gissar range, in the Garm region and farther west, a complete section of Mesozoic and Tertiary deposits has developed. On the Paleozoic granites there occur stratigraphically from bottom to top: 1) Lower Cretaceous sediments represented by light-red and gray friable sandstones up to 270 meters in thickness; in the upper third of these sandstones are seams of limestones with marine fauna of the Upper Albian Age; 2) Upper Cretaceous sediments represented by limestones, shales, and gypsums from 290 to 350 meters in thickness; 3) Paleocene layers from the Alay to Turkestan strata inclusive, represented by marine deposits -- limestones and shales up to 330 meters in thickness; 4) A brick-red series (Pg_3+N), represented by gray and light-red sandstones up to 750 meters in thickness; 5) Neocene sediments, represented by a Gissar-foothill layer of light-yellow and light-gray sandstones and conglomerates up to 2000 meters in thickness;

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6) The Sameolyk layer (of Neocene--Quaternary Age) represented by sandstones and conglomerates with a shingle of Paleocene and probably Neocene strata up to 60 or 80 meters in thickness; it occurs on the eroded surface of Paleozoic strata.

The geological structures of the Gissar range are of extremely complex composition. They were created successively by the Varian and later the Alpine revolutions. As a result of the Varian revolution the Paleozoic sediments of the Gissar range were collected in complex, compressed, often broken folds, extending principally in an east-southeast or easterly direction; in places the Upper Silurian shales were puckered. In a large number of areas, mainly along the axial parts of the anticlines, these Paleozoic strata were penetrated by granitoids and in individual areas transformed into migmatites. The granitoids fused with the compressed Varian folds, converting them into unyielding, rigid structures.

As a result of the Alpine revolution, whose effects were greatest at the end of Neocene time, the condensed, uneven folds of the Gissar range together with the Jurassic, Cretaceous, and in places Tertiary sediments on top of them were gathered into broad-based, sloping folds extending in an easterly or east-southwest direction. Many of them were broken by steep and vertical longitudinal, oblique, or even transverse faults (Fig. 5).

Along the planes of these faults, under the added tectonic stresses which have now occurred in the Quaternary, i.e., Modern, Age, individual portions of the sloping Alpine folds have undergone substantial, uneven rising movements with respect to each other. As a result of this in many places the original sloping Alpine

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folded structures were transformed into distinctive irregular horsts and grabens, bordered by faults whose lines in horizontal projection form irregular triangular, quadrilateral, and other figures. These broad broken Alpine folds are shown on the tectonic chart (Fig. 5) and on the attached geological profiles (Fig. 6). The principal folds, from north to southeast, are: the Kazok anticline (Fig. 5, 12*), (A figure with an asterisk corresponds to the number of a geological structure in Fig. 5.) the Kamarou syncline (11*), the Garm anticline (9*), the Gyzhmat syncline (5*), the Samsolyk anticline (3*), and finally the Vakhsh syncline (1*). Cretaceous and in places Tertiary strata enter into the composition of the axial portions of the synclinal folds mentioned. These deposits have everywhere been eroded from the axial portions of the anticlines.

The Vakhsh syncline (1*), the Samsolyk anticline, and the Gyzhmat syncline (3*,5*), located in the region of the lower reaches of the rivers Surkhob and Khingou, extending east-southeast, plunge under the northern slope of the Peter I range, under the Lower Cretaceous layer of the Vakhsh covering, and ultimately reach far enough to form a part of the composition of the forward zone of the southern Tien Shans. The Garm anticline is located north of the settlements of Shul'mak and Garm. Extending eastward, it is clearly visible along the right bank of the river Surkhob almost as far as the region of the settlement of Khait, where all Mesozoic sediments have been washed from it. To the northeast, the Dzhirgatal' anticlinal fold (19*) is located parallel to the Garm anticline. Its axis passes somewhat to the north of the settlement of Khait, in an east-west direction toward the region of the settlement of

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Dzhirgatal' and then toward the village of Darachol (21*). In the region of the latter this anticline also plunges to the east and southwest under the Jurassic and Cretaceous layers of the Vakhsh covering (see profiles X and XI).

The earlier-mentioned rising Quaternary tectonic movements within the limits of the Gissar range which have displaced the sloping folds enumerated above, have been taking place with great unevenness. In many places some parts of the folds have been shifted vertically as much as 2000 to 3000 meters with respect to others. Mount Mandolyul', located to the west of the settlement of Garm (Fig. 5), serves as a typical example of the irregularity of such upheavals. It is in the form of a horst bounded by steep faults whose lines form a triangle in horizontal projection. This horst has been raised more than 1400 meters with respect to places around it. Other clearly visible, unevenly raised blocks, separated by steep faults, can be observed in the basins of the rivers Sholi and Samsolyk, in the axial portion of the Samsolyk anticline (4*,6*,2*), and in other places.

(Fig. 7. The steep southern slope of the Gissar range in the region of the middle reaches of the river Surkhob. It is formed of Paleozoic rock strata. At the foot of the slope can be seen the typical cones of the spur ridges with the villages, surrounded by gardens, which are situated on them.

Drawn by A. N. Popov from the left bank of the river Surkhob)

[Stereoprint in Appendix II]

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The geological structures created by the uneven upheavals which have been discussed are clearly revealed in the towering present-day relief of the Gissar range. In particular, traces of a general large upheaval of the Gissar range by comparison with the forward zone of the southern Tien Shans are revealed along the valley of the river Surkhob in the form of an irregular, composite step which I shall henceforth call the Surkhob structural step. This step is formed by the high, steep (up to 1000 meters) right slope of the valley of the river Surkhob, composed mainly of Paleozoic strata, and the flat bed of the Surkhob valley, composed of displaced Cretaceous and in places Tertiary sediments of the forward zone of the southern Tien Shans. Along the bend of this step, at the foot of the southern slope of the Gissar range, principally along the right bank of the river Surkhob, considerable development has been achieved by steep, vertical disconnected faults (2*,8*,27*, and others), whose lines I have taken as the northern boundary of the forward zone of the southern Tien Shans. In places arc-shaped bends in the earth's crust have occurred here.

The differential, rising tectonic movements of the Gissar range which have been discussed have been taking place quite recently. They have disturbed the strata of the Samsolyk layer of Neocene-Quaternary age. The geological structures created by these movements are revealed in relief and have been little disturbed by erosion. Plants (grasses) peculiar to low expanses of steppe have been preserved on many individual highly elevated areas of the

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territory of the Gissar range. In these conditions, new to them, they have not yet perished, but their functional activity has been disturbed (P. N. Ovchinnikov). At the present time earthquake epicenters coincide with the lines of certain steep and vertical faults along which these movements have taken place. The presence of these eipcenters provides a basis for the supposition that the movements are occurring even now, causing subterranean shocks. These present-day movements have been considered in more detail below (17), following investigation of seismostatistical data. (For knowledge of present-day movements in the earth's crust, a geomorphological description and analysis of the earth's surface must be made concurrently with a geological analysis. This is done herein jointly with the discussion of geological data in 17. The author supposes that in later works on seismotectonics the geomorphological analysis will more suitably be separated into an individual chapter.)

§10. The Forward Zone of the Southern Tien Shans

The rock strata which compose the forward zone of the southern Tien Shans are hidden under the thick Jurassic and Cretaceous layers of the Vakhsh covering, i.e. of the northern slope of the Peter I range, which have advanced over them from the southeast, and have cropped out from under these layers on the earth's surface only along the deep-valley trails which cut through the northern slope of the Peter I range to the forward zone of the southern Tien Shans. An outcropping, substantial in size, of the forward zone is located in a tectonic window in the ridge portion of the Peter I range, to the south of the village

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of Daray-nushor, on the floor of the deep Sefedorak and Shikerga valleys (29*). Here limestones with Upper Cretaceous fauna (profile VIII) protrude to the surface of the earth from under the Upper Jurassic and Lower Cretaceous layers of the Peter I range, which form the sloping arch of the anticline.

In other sections of the northern slope of the Peter I range the layers which compose the forward zone of the southern Tien Shans are represented by Lower and Upper Cretaceous and in some places Tertiary deposits whose strata, bending obliquely, compose the broad-based folds shown on the attached profiles (Fig. 6). The protrusions of these layers on the earth's surface in the above-noted outcroppings are located hypsometrically at various altitudes, evidence of substantial irregularities in the buried surface of the forward layer of the southern Tien Shans. Not far from the axis of the western extreme of the Peter I range (Fig. 6) this surface, as may be judged from outcroppings in the valley of the river Khingou, dips rather sharply to the southeast, forming a distinct uneven step which extends in the depths of the earth's crust along the axial portion of the Peter I range (Profiles I--III). I shall henceforth designate this the Vakhsh structural step. It is possible that in the region of this step, prior to the formation of the Vakhsh overthrust, there was a joining of the layers of Cretaceous and Tertiary sediments of the forward zone of the southern Tien Shans with layer s of uniform age of the frontal portion of the Vakhsh covering, this junction subsequently being disturbed by tectonic shiftings.

Toward the east the width of the Vakhsh structural step

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gradually decreases and, judging by pertinent outcroppings in the Safedorak valley (see above), it becomes almost smooth in the central portion of the Peter I range (Fig. 6, profiles VI and VII). The Mesozoic and Tertiary sediments which enter into the composition of the forward zone of the southern Tien Shane have lithologically the same make-up and the same thicknesses as the sediments of uniform age which have developed at the base of the southern slope of the Gissar range in the Garm rayon (§9). For exampel, near the village of Daran-nazarak (Fig. 5, near anticline 28) sediments characterized by their fauna as Upper Cretaceous, represented by Senoman, Turon, and Senon layers of the comparatively small overall thickness of 250 meters typical for this zone, have cropped out from under the Lower Cretaceous deposits of the Vakhsh covering. It is interesting to note that the displaced Upper Cretaceous sediments of the Vakhsh covering which have developed in this locality attain a thickness of 750 to 800 meters. The Neocene sediments which have developed in the northern foothills of the Vakhsh range and which enter into the composition of the Vakhsh syncline are represented by typical sediments of the Gissar-foothill layer, formed of materials transported from the Gissar range.

(Fig. 8. View down the river Surkhob from the village of Zarargok, located on the left bank of the river 17 kilometers east of the settlement of Garm. At right can be seen the granitoids (indicated by crosses) which enter into the composition of Mount Mandolyll' and the

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southern slope of the Gissar range. Near the river bed Lower Cretaceous sandstones (indicated by dots with the symbol Cr_1) of the forward zone of the southern Tien Shans normally occur. At left can be seen the thick layer of Lower Cretaceous sandstones of the Vakhsh covering, which has advanced over earlier deposits. The line of the Vakhsh overthrust is shown by the heavy line (See profile IV in Fig. 6). The Upper Cretaceous layers of the forward zone are indicated by the symbol Cr_2.

Relief drawn by A. N. Popov. geological contours furnished by I. Ye. Gubin) [illegible]

In considering the geology of the Gissar range it was noted that the latitudinally extended folded Alpine structures of its southern slope, formed of Tertiary, Cretaceous, and Paleozoic strata, plunge successively one after the other to the east and southeast in the region of the river Surkhob's course, going under the Cretaceous layers of the northern slope of the Peter I range, and entering there into the composition of the forward zone of the southern Tien Shans. What has been set forth makes it possible to assume that the Paleozoic strata of this forward zone are represented by the same Upper Silurian shales and limestones, and also granitoids, as on the southern slope of the Gissar range. Those and other strata enter into the composition of the same closely connected latitudinally extended Varian and Alpine structures which were separated

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due only to the rising Quaternary movements of the Gissar range by faults which developed along the Surkhob structural step, along the right bank of the river Surkhob.

The Mesozoic and Tertiary layers of the forward zone of the southern Tien Shans, gathered into slanting folds as has already been mentioned, are overlapped by the Vakhsh covering. The frontal part of this covering, in the valley of the river Surkhob on the river's right bank, in the eastern portion of the Peter I range not far from the mouth of the Say Tokusbulak (Fig. 5, near fold 22) extends to the raised flank of the vertical fault along which an upheaval of the Gissar range has occurred during Quaternary time. This fault cuts short the frontal part of the covering. The overlapping of the folds of the forward zone and the cutting short of the frontal part of the covering permit the assumption the Vakhsh covering was shifted after the formation of the slanting folds in the forward zone, but before the intensive Quaternary upheaval of the Gissar range.

It is quite possible that at the time of the formation of the Vakhsh covering the forward zone of the southern Tien Shans, as well as the southern slope of the Gissar range, was much lower hypsometrically than now, and that the Vakhsh covering slipped down along these to the lowland. During subsequent rising movements of the Gissar range a reverse inclination of the forward zone and the Vakhsh covering was created (Fig. 6, profiles IV-VI).

This process took place quite unevenly. The gissar range

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was heaved up more intensively than the forward zone; adjoining sections of the forward zone were carried upward to a certain extent during this, but the whole territory of the zone dipped and inclined to the southeast.

(In the northern foothills of the Vakhsh range this upheaval of the forward zone of the southern Tien Shans together with the higher ensuing forward part of the Vakhsh covering exceeded, as may be well observed in the appropriate outcropping, by 300 to 500 meters the upheaval of neighboring sections of the covering's development. Concurrently, the surface of the forward zone was inclined there to the southeast at an angle of as much as 40 or 45 degrees.)

It may be assumed that as a result of this dipping and inclination of the territory of the forward zone in its upper portions, composed of complex-folded Cretaceous layers of the Vakhsh covering (profiles III and IV), slippings have taken place along the inclined faults within the Vakhsh covering, and also sliding of the latter along the substratum in places of greatest dipping and inclination. This process is easily imagined if we squeeze with the hand one end of a closed deck of cards, and raise the other end upward, bending the deck. At the free end of the pack the cards will be mutually displaced. Judging by the fact that on certain laminal structures of the Vakhsh covering, located at points of similar bending (profiles III and IV), surface earthquakes often occur at the present time, we can assume that these complex movements are

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continuing even now, causing the subterranean shocks mentioned. It is possible that these movements are complicated by gravitational phenomena, and also by uneven rising movements within the forward zone itself and the Peter I range.

§11. The Peter I Range

Mesozoic and Tertiary sediments typical of the outer zone of the Pamirs enter into the composition of the Peter I range. These include (from bottom to top): 1) a Sorbulak series (Trias-Jura), represented mainly by red-colored sandstones, shales, porphyries, and tufas no less than 2000 meters in thickness; 2) an Upper Jurassic salt-bearing series, represented by gypsums, rock salt, clays, and sandstones up to 170 meters in thickness; 3) Lower Cretaceous sediments, represented by dark-red sandstones and shales (without veins of limestone) from 1200 to 1500 meters thick; 4) Upper Cretaceous deposits, represented by complex-stratifying layers of limestones, shales and gypsums from 750 to 800 meters in thickness; 5) Paleocene strata, represented from the Alay to the Sumsa layer inclusive by marine and lacustrine limestone-deposits, shales, sandstones, and gypsums from 340 to 400 meters in overall thickness; 6) a brick-red series ($Pg_3 + N$), represented by dark-red sandstones and shales up to 1200 meters thick; 7) the Khingou series (Neocene), represented by dark-red sandstones and conglomerates from 1800 to 2000 meters thick; 8) the Tavil'dara (The strata of the Tavil'dara series and all subsequently noted deposits were developed in the Tavil'dara region, along the left bank of the river Khingou.) (Neocene), represented by gray and red sandstones

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and conglomerates 1200 meters thick; 9) the Karanak series (Neocene), represented by light-gray sandstones and conglomerates up to 1200 meters thick; 10) the Polizak series (of Neocene and Quaternary age), represented by gray sandstones and conglomerates; this occurs on displaced earlier sediments and on Paleozoic strata.

(Fig. 9. The northern slope and ridge portion of the Peter I range, in the region of the middle reaches of the river Surkhob near the village of Kuglik. Near the village of Kadzhuraga, in the lower half of the right slope of the transverse valley, Upper Cretaceous limestones and shales of the forward zone of the southern Tien Shans have cropped out. On top of them are Lower Cretaceous sandstones (indicated by dots with the symbol Cr_1) of the Vakhsh covering, which have been shifted from the south. The line of the Vakhsh overthrust is shown by a heavy line. Below and to the left of the Kaudal' peak can be seen the puckered layers of the Upper Cretaceous strata (indicated by the symbol Cr_2) of the Safidou syncline, which enters into the composition of the rear part of the Vakhsh covering. At the foot of the Vakhsh covering the Upper Jurassic gypsums are indicated by the symbol J.

Relief drawn by A. N. Popov, geological contours furnished by I. Ye. Gubin) [thermoprint in Appendix II]

The overall thickness of the above-listed Mesozoic and Tertiary deposits reaches 10,600 meters. In the region of

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the northern slope of the Peter I range the above-noted thick Upper Jurassic, Cretaceous, and marine Paleocene layers have been shifted onto the relatively thin Cretaceous and Tertiary layers of the forward zone of the southern Tien Shans (see 9 and 10).

The geological structures of the Peter I range were created by the Alpine revolution, which was at its peak at the end of Neocene time. The Mesozoic and Tertiary layers composing the subject range were collected in complex, compressed folds (Fig. 5-6) which spread slightly in west-southwest directions (in horizontal projection). These folds enter into the composition of two basic structures--the Vakhsh tectonic covering and the Tavil'dara synclinorium. The former includes the rock strata making up the northern slope and the axial portion of the Peter I range, and the synclinorium includes the strata of the southern slope of this same range and the lower half of the northwestern slope of the Darvaz range.

In the advanced portion of the Vakhsh covering the Cretaceous layers which form it are collected into folds of small amplitude. They are sharply, clearly revealed (profiles V, VI, VII), in places strongly rippled (profiles X, XI) and disturbed (profile IV). Not far from the axial portion of the Peter I range the amplitudes of these folds are substantially larger and they are made more complicated by local faults and overthrusts. One of these overthrusts, the Yafuch, is located in the western portion of the subject range (43*, 44*). It extends in a southwest direction from the region of the village of Zyubet across the region of the village of Ortot

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(profile II) to the river Khingou. Its plane is inclined to the southeast in various places at angles of from 30 to 45 or 50 degrees. Similar discontinuities are likewise found in the central and eastern parts of the Peter I range (Fig. 5). Lower Cretaceous and Upper Jurassic salt-bearing layers enter into the composition of the lower part of the Vakhsh covering. The strata of the Upp er Jurassic salt-bearing layers enter into the composition of the lower part of the Vakhsh covering. The strata of the Upp er Jurassic salt-bearing layer, represented mainly by gypsums with lenticles of rock salt, have served as a lubricant facilitating the forward movement of the Vakhsh covering.

Within the limits of the Tavil'dara synclinorium, along the left bank of the river Shaklysu (Fig. 4), the Mesozoic layers have been collected into the complex, compressed Faalay synclinal fold (25*) extending to the west-southwest (profiles VII, VIII). The Upper Cretaceous layers which enter into the composition of the nucleus of this syncline have been collected into a number of frequently small, broken, complicated folds, probably torn in a number of places from the underlying strata. In the region of the mouth of the river Shaklysu, not far from the village of Lyayrun, the axis of the Faalay syncline, keeping its former extent, dips gradually to the west-southwest. In the course of this dipping the flanks of this syncline separate, and in its nucleus a few clearly revealed subsidiary folds develop (33*, 35*, and others), spreading out in flat projection in southwest and west-southwest directions.

The geological composition of this area, proceeding from the mouth of the river Shaklysu to the village of Mionadu and

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then to the settlement of Tavil'dara, are extremely complex. The subsidiary folds mentioned undergo bends and breaks. In them has developed a non-harmonic undulation of individual especially plastic layers and the wrenching of these latter from their bases. The Sayat anticline (38*), located along the left bank of the river Khingou in the region of the villages of Sauzikharv and Sayat, is also one of the number of folds which have formed here. It has been pushed to the northwest and broken along its flank.

In the region of the settlement of Tavil'dara and to the northwest, Neocene layers, which describe relatively sloping bends, enter into the composition of the southwestern continuations of these subsidiary folds. Layers of a brick-red series which have developed here, but on a lower level, and also of Paleocene and Cretaceous materials form infrequent non-harmonic bends and even a slight undulation which does not correspond to the sloping twists of the higher Neocene layers. This may be observed in various outcroppings. For example, at the base of the high, steep left slope of the valley of the river Khingou, 10 to 12 kilometers northwest of the settlement of Tavil'dara, not far from the villages of Yezgan and Kal'pak near the bed of the river, layers of Neocene sandstone which form two clearly distinguishable small anciclinal folds protrude to the earth's surface. Hypsometrically higher than the latter on this slope other, more recent layers of sandstones and conglomerates of the Khingou series have cropped out, describing a single broad and sloping anti-clinal baend (the Yezgan anticline) which encloses within its nucleus the two preceding folds (40*).

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Complication of the folding deep under the surface and development of particular undulations in various plastic cross-sections enclosed by more rigid layers is typical of many other regions of the Peter I range. For example, in the axial portions of certain synclines formed of Cretaceous and Tertiary strata the marine Paleocene layers have been puckered. One such structure--the Yafuch synclinal fold (42*)-- is well exposed in a transverse section in the region of the village of Yafuch on the left slope of the gorge of the lower reaches of the river Khingou, between Lake Kabudkhauz and the village of Pun'yekba. Here along a vertical cliff more than a kilometer high marine Paleocene layers protrude to the earth's surface. These layers are collected into small irregular, compressed folds up to 150 or 200 meters in amplitude, torn from the underlying Upper Cretaceous layer and non-harmonically rippled with respect to the layers of the over-lapping brick-red series,

(Fig. 10. The northern slope and ridge part of the Peter I range in the Kalaylyabiob region. View from the direction of the settlement of Khait. In the fore-ground, near the village of Polizak, can be seen the Lower Cretaceous sandstones (indicated by dots) of the frontal portion of the Vakhsh covering. Sagunaki peak is formed of vertically arranged, thick layers of Upper Cretaceous limestones which enter into the composition of the rear part of the Vakhsh covering.

Relief drawn by A. N. Popov, geological contours furnished by I. Ye. Gubin) [thermoprint in Appendix II]

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which form a sloping synclinal bend.
(During study of these complex folds in outcroppings, clear stratigraphic angular discrepancies were nowhere found between the various layers entering into their composition. This points to the fact that these were all created basically during one phase of Alpine folding. However, as we shall see below (§13 and 14), the process of creation of the basic geological structures of the territory of the Garm Oblast' took place during several clearly distinguished stages.) Such non-harmonic bendings are described in many places by Upper Cretaceous layers. They may be observed, for example, in the nucleus of the Faalay syncline (25*).

Along the gorge of the river Tokusbulak on the northern slope of the eastern part of the Peter I range, strata of a Lower Cretaceous layer have been collected into characteristic small folds (Fig. 6, profile XI). In the gorge of the river Runou, between the villages of Ortot and Zyubet (Fig. 5, region of figure 44) on the northern slope of the western part of the Peter I range, twisted Upper Jurassic gypsums have cropped out. Near these villages the rippled Upper Jurassic gypsums describe a series of diapir rods.

In all the above-mentioned non-harmonic structures a special role is played by the layers of gypsum which are encountered at various levels of the Mesozoic and Paleocene sediments along which various tectonic displacements have taken place. Of all the strata which enter into the composition of the Peter I range the most wavy are the Upper Jurassic, followed by the Cretaceous and marine Paleocene

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layers. The layers of the brick-red series and of Neocene sediments have undergone considerably less bending in many places. It must be noted that in the nuclei of a number of compressed anticlines of the axial part of the Peter I range, formed of a double, upside-down Lower Cretaceous layer, the underlying rock strata play no part. This may be observed, for example, in outcroppings of the Nuranch anticline (41*), and also of the Lyulikharva anticline (31*). The nucleus of the latter is well exposed along the say, which passes near the villages of Mark and Almalyk (profile VII) in a perpendicular cliff up to 1500 meters high.

These phenomena are evidence of the tearing from their bases of Cretaceous folds which have developed here. This is reflected in the corresponding geological profiles (Fig. 6). The tearing up of these folds was probably closely connected with the formation of the Vakhsh covering, made up of Mesozoic strata. I have determined that the displacement of the latter is more than 12 or 15 kilometers, in analyzing the geological composition of the territory of Garm Oblast.

During Quaternary time the Peter I range has undergone a considerable overall upheaval, but of less extent than that of the neighboring Gissar and Darvaz ranges. As a result of this Mesozoic and Tertiary sediments have been preserved within the limits of the Peter I range on its whole area. These sediments were highly elevated and therefore eroded in the majority of regions of the Gissar and Darvaz ranges.

The unevenness of the raising of the three subject ranges has led to the formation of local bendings and inclinations of the geological structures in the boundary zones between them, and particularly within the limits of the southern and northern slopes of the Peter I

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range. These bendings and inclinations are determined by the different heights of occurrence of deposits of uniform age and also by inclinations of the denuded surface, on which occur sediments of the Polizak series of Neocene material.

These local bendings and inclinations have been accompanied in the Peter I range by various compressions of surface regions of the earth's crust, by faults in the continuity of the rock strata and by characteristic movements, which have led to complication of the folded structures which have developed here in the boundard zones. The probable mechanics of these movements in the forward part of the Vakhsh covering has already been discussed in the preceding paragraph. These movements within the limits of the Tavil'dara synclinorium are considered below.

§12. The Northwestern Slope of the Darvaz Range

The northwestern slope of the Darvaz range and the same slope of the Sel'dytau Mountains are formed in the upper half by thick Middle and Upper Paleozoic strata, and in the lower half by Mesozoic and Tertiary layers. The latter have the same lithological composition and approximately the same thicknesses as sediments of uniform age of the majority of regions of the Peter I range proper, but they are slightly thicker than corresponding layers entering into the composition of the forward part of the Vakhsh covering.

At the end of Neocene time, but before the deposit of sediments of the Polizak layer of Neocene-Quaternary age, the above-mentioned Paleozoic, Mesozoic, and Tertiary deposits were displaced jointly into a broad, complex synclinal fold (profiles IV--XI), which I mentioned earlier (in §11) under the name of Tavil'dara synclinorium.

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The southeastern flank of this synclinorium is arranged vertically and broken by the Karakul' fault, whose plane inclines to the southeast at an angle of from 25 to 45 degrees. At the end of Neocene time the Middle and Upper Paleozoic layers of the Darvaz range and the Sel'dytau Mountains were shifted to the northwest along the plane of this fault.

After this shifting the region of development of the line of the Karakul' fault was exposed to erosion and became a peneplain. In the basin of the river Zida-dara (Fig. 4, 5) sediments of the Polizak stratum of Neocene-Quaternary age occur on this surface, which has been smoothed by erosion, and these sediments overlap here the line of the Karakul' overthrust. Following the deposit of sediments of the Polizak series the regions of development of the line of the Karakul' overthrust underwent, in Quaternary Time, a considerable but uneven vertical

(Fig. 11. The northern slope of the Peter I range near the villages of Kadzhuraga and Kuglik. Visible is the slopingly twisted surface of the Vakhsh overthrust (indicated by a heavy broken line), along which Lower Cretaceous sandstones of the Vakhsh covering (indicated by dots) were shifted from the south onto Upper Cretaceous limestones and shales of the forward zone of the southern Tien Shans.

Relief drawn by A. N. Popov, geological contours furnished by I. Ye. Gubin) [Thermoprint in Appendix III]

elevation. During this process some sections became more elevated

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than others; between them occurred inclinations and, probably, sloping bends in the earth's crust. For example, the region of the Sel'dytau Mountains is elevated more than 2000 meters with respect to the region of the basin of the river Zida-dara, and between them a bend, probably sloping, has developed in the earth's crust, embracing the region of the villages of Argankul' and Mionadu.

A considerable relative elevation has also been experienced by a section of the middle reaches of the river Khingou in the regions of the villages of Sayat (Fig. 5, place where fold 39 has developed), Sauzi-Kharvi, and the settlement of Tavil'dara. The elevation of this section created the conditions of the 8-to 10-degree inclination toward the southeast in the basin of the river Zida-dara, of the plane of denudation which underlies the Polizak conglomerates.

In the regions of the villages of Iyayrun, Mionadu, and Sayat, and in other places located near them, these various above-mentioned inclinations and bendings in the earth's crust, embracing the places of development of the Zaalay syncline and its subsidiary folds, have apparently been accompanied by deformations of the latter, particularly by faults in the continuity of the rock strata which make up these folds, along their base. Judging by the fact that in the regions of the above-mentioned villages surface earthquakes often occur at the present time, we may assume that these movements continue right up to the present, causing subterranean shocks.

Traces of the forward movement of the Vakhsh covering are not perceptible currently, and it probably has already ceased or has extremely small proportions. Therefore we do not connect with it presently occurring shifts along the various faults, inside the Tavil'dara

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synclinorium as well as in the forward part of the Vakhsh covering.

§ 13. History of the Formation of the Geological Structures

Beginning with Jurassic time, a zone of almost exclusive depression, extending in a southwest direction, became separated in the central portion of the territory of Garm Oblast, in regions now occupied by the southern slope of the Peter I range. This depression was a component part of the forward Pamir concavity (9). In it accumulated the thick (up to 10,600 meters) Mesozoic and Tertiary strata of the Peter I range and the northwestern slope of the Darvaz range, i.e. of the outer zone of the Pamirs. To the southeast of this concavity were located the inner Pamir zone, and to the northwest the southern Tien Shans, including their forward zone. The southeastern extreme of the forward zone of the southern Tien Shans, dipping to the southeast, entered into the composition of the northwestern slope of the above-noted forward concavity.

Many coarsely fragmented Mesozoic and Tertiary sediments of the forward Pamir concavity consist of products of the destruction and wearing down of the Paleozoic rock strata of the inner zone of the Pamirs. This is evidence of the fact that certain regions of this zone, including regions of the Darvaz range proper, have undergone repeated upheavals and destruction during the whole time of formation of these sediments.

The lithological make-up of Mesozoic and Tertiary deposits which have developed in many regions of the southern slope of the Gissar range and in the forward zone of the southern Tien Shans is evidence of the fact that these districts also have undergone repeated upheavals

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and depressions. The Lower Cretaceous submersion may be noted, when in the Upper Albian period the sea covered a part of the southern slope of the Gissar range. In the Neocene system the axial portion of the Gissar range underwent an upheaval, and regions adjacent to the present valley of the river Surkhob underwent a relative depression. Here occurred one particular concavity in which were deposited the thick Neocene sediments of the Gissar-foothill layer, consisting of products of the destruction of various Paleozoic strata of the Gissar range.

At the end of Neocene time broad-based sloping folds occurred on the territory of Garm Oblast as a result of very strong tectonic stresses. In the regions of the modern Gissar range and forward zone of the southern Tien Shans these folds possessed relatively small proportions and extended principally in an east-west direction. In the outer zone of the Pamirs (in the forward concavity) and in regions of the Darvaz range these folds were probably broader, had greater amplitude, and were oriented in a southwestern direction. In particular there were conceived at this time the first contours of the Tavil'dara synclinorium of the Peter I range, which appeared as a broad synclinal fold with a steeply arranged and broken southeastern flank. Subsequently the upper portions of these structures were exposed to erosion. Certain of them in the Darvaz were overlapped by sediments of the Polizak series, and in the Gissar range by sediments of the Samsolyk series of Neocene-Quaternary age.

At the time of subsequent tectonic movements in the surface zone of the earth's crust a shifting to the northwest of rock strata of the forward Pamir concavity and the Darvaz took place. During this

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the Vakhsh covering was formed and the complex folds of the Vakhsh covering and the Tavil'dara synclinorium were conceived. It is possible that at the same time the Alpine folds in the regions of the Gissar and Darvas ranges became slightly more complex.

In the following Quaternary Period predominant importance was acquired by rising movements which attained their greatest proportions in the regions of the Gissar and Darvaz ranges. In the Gissar range these movements were accompanied by shiftings along various steep faults.

(Fig. 12. In the foreground is part of the northern slope of the Peter I range near the village of Askalon, not far from Garm. In the distance are the river Surkhob and the southern slope of the Gissar range, composed of granitoids (indicated by crosses). Here on the right bank of the river Surkhob Lower Cretaceous sandstones of the forward zone of the southern Tien Shans, have cropped out. At the bottom of the drawing, near the village of Askalon, Upper Cretaceous limestones of this same zone have cropped out. Near the village of Sary-Shokhon they are overlapped by shifted Lower Cretaceous sandstones of the Vakhsh covering. The overthrust is shown by a heavy broken line (see profile IV)

Relief drawn by A. N. Popov, geological contours furnished by I. Ye. Gubin) [Thermoprint in Appendix III]

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The forward zone, overlapped by the thick, heavy Vakhsh covering, has not undergone such a large uneven upheaval. In consequence of this it has been separated from the regions of the Gissar range by faults which have developed along the valley of the river Surkhob.

The above-mentioned vertical movements in the earth's crust have continued right up to present in Garm Oblast, accompanied by complications of various geological structures, as indicated above.

The roots of the Vakhsh covering are hidden deeply in the earth's crust, and consequently it is not imagined possible to ascertain with a sufficient degree of probability the mechanics of its conception. It may be assumed hypothetically that the Vakhsh overthrust occurred in the depths of the earth's crust, in regions which now coincide with the axial portion of the forward Pamir concavity, as a fault in the Paleozoic strata (Fig. 6), possibly as late as Varian time. The upper portion of its plane probably fell quite slopingly to the southeast. In Alpine time the higher-occurring Mesozoic layers were not broken by this tectonic fracture.

At the beginning of the process of formation of the Alpine Vakhsh covering only the rear portion of the suspended flank of the overthrust, consisting of the Paleozoic, Mesozoic, and Tertiary strata of the Tavil'dara synclinorium, moved obliquely toward the northwest. The Upper Jurassic, Cretaceous, and Tertiary layers of the forward part of the Vakhsh covering at that time occurred on the southeastern slope of the forward zone of the southern Tien Shans, i. e. south of the Vakhsh structural step (§10), occupying a section no less than 12 to 15 kilometers in thickness. Under the influence

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of the above-mentioned movement of masses and the corresponding pressure, mainly on the part of the Cretaceous and Tertiary strata of the rear portion of the suspended flank of the Vakhsh overthrust, these layers were compressed and gathered into folds. Subsequently they were dislocated from their base and in the region of the Vakhsh step were moved onto the forward zone of the southern Tien Shans.

The movement of the rear portion of the suspended flank of the overthrust occurred upward, obliquely to the northwest along the plane of the substratum from which had been dislocated the Cretaceous and Tertiary strata of the forward part of the covering. It is possible that, as the thick Paleozoic, Mesozoic, and Tertiary sediments of the rear portion of the suspended flank were shifted onto it, this substratum, composing the recumbent flank of the overthrust, yielded and became depressed. At the time of shifting of the Bakhsh covering, the Cretaceous and Tertiary layers of its rear portion, which now enter into the composition of the Tavil'dara synclinorium, underwent a considerable reverse pressure on the part of the layers of uniform age of the forward part of the covering, and in consequence also slid off the substratum, but now in the opposite direction, and were likewise collected into folds.

The Upper Jurassic, Cretaceous, and Paleocene strata which developed in the axial portion of the Peter I range were exposed to a particular compression, since they transmitted pressure forward to the northwest and, experiencing the resistance of the forward part of the Vakhsh covering, transmitted this resistance to the structures in the rear. In consequence of this increased compression in this zone (in the axial portion of the Peter I range), particularly complicated compressed folds of large amplitude were formed. They are represented

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schematically on the corresponding profiles (Fig. 6).

The formation of the Vakhsh covering is closely connected with the displacement to the north of the whole northern portion of the Pamir tectonic district (9). It is possible to find the geological premises of this phenomenon only through special consideration of the geology of the whole Pamir range. Nevertheless, we shall note here that one of the possible reasons may be the considerable rising movements of the territory of the Pamirs proper, which on the northern outskirts of this range has probably assumed the form of lateral movement, i.e. to the north, along inclined faults, including the Vakhsh and Karakul' overthrusts.

§14. The Geological Profiles

In usual practice geological profiles are made up for maximum depths on the order of one or two kilometers. In such form they help to envision the geological composition of the territory being studied, but are quite inadequate for knowledge of the mechanics of movements of the earth's crust and for the ascertainment of the geological premises of earthquakes, particularly at large depths. Taking this into consideration, for determining the mechanics of modern movements of the earth's crust the author has made up for the territory of Garm Oblast, as already mentioned, eleven detailed geological profiles at depths up to 8 or 9 kilometers. Within the limits of this depth the majority of strong subterranean shocks occur here.

The profile-diagrams mentioned are in Fig. 6. The upper portions of these profiles are made by the usual method -- on the basis of outcroppings of the crustal rock strata which have developed at the earth's

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surface. In consequence of the great heights, deeply broken relief, and very excellent exposure, it has been possible successfully to survey along the lines of the profiles at depths up to 1500 or 2000 meters, and in some places up to 3000 meters. Here the layers which make up the given sections have been measured and studied, and the elements of their composition have also been estimated. Below the zero line corresponding to sea-level the profiles have been made up hypothetically, with consideration of the local peculiarities of various surface tectonic structures and the probable mechanics of their deep-down formation, including the mechanics of the formation of the Vakhsh overthrust. Consequently, the deep sections of the earth's crust have been represented on these profiles not by means of a mere mechanical projection into the depths of the angle of layers which have cropped out at the earth's surface, but by means of a representation of deep-down structures which have been created here as the result of apparent general conformities to rule of the development of the earth's crust in this region.

In all of our profiles, the central portion is occupied by the Peter I range. In representing it it was taken into consideration that its component Upper Jurassic, Cretaceous, and Tertiary layers have everywhere approximately one and the same composition and thickness. The Sorbulak series (Trias-Jura) has developed only in regions adjoining the Darvaz range. According to the hypothesis of the formation of the Vakhsh, its forward part, composed of Upper Jurassic and Cretaceous layers of the northern slope of the Peter I range, was torn from the substratum, from the buried southeastern slope of the forward zone of the southern Tien Shans, and in the region of the Vakhsh structural step (§10) displaced to the northwest.

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On all geological profiles the plane of this fracture, probably formed of Paleozoic rock strata, has been represented southeast of the Vakhsh structural step in the depths of the earth's surface. It dips to the southeast. The Paleozoic strata of the rear part of the suspended flank of the Vakhsh overthrust fault (profiles I--VII) have been pushed onto it from the southeast. The depth of occurrence of this plane of fracture has been determined here as 3 to 4 kilometers from the earth's surface on the basis of the thickness and form of occurrence of the shifted Upper Jurassic, Cretaceous, and Tertiary layers of the Peter I range, and also on the basis of the level of occurrence of the Paleozoic substratum of the forward zone of the southern Tien Shans. The latter was determined on the basis of the thickness of Cretaceous and Tertiary sediments of this zone which have cropped out in the beds of the deep valleys of the rivers Khingou, Darainazarak, Darainushor, and others.

In representing the folds of the Vakhsh covering and adjoining sections of the Tavil'dara synclinorium, formed of Upper Jurassic, Cretaceous, and Tertiary layers (profiles I--VII), it was taken into consideration that during formation of these structures the latter were torn from the base along the Upper Jurassic gypsums, displaced from their base to the northwest and partially to the southeast, and gathered into non-harmonic folds which become more complicated with depth. Here in places two or three folds in the Paleocene and even Cretaceous layers in the depths of the earth's crust correspond to one fold in the Neocene layers.

Within the limits of the Tavil'dara synclinorium in the Tavil'dara region the horizon of tearing of Cretaceous layers along the Upper

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Jurassic gypsums from the substratum probably from the Sorbulak layer, can be particularly distinguished. The depth of this plane of fracturing has been determined here as 4 to 5 kilometers from the earth's surface in various places, according to the thickness and form of occurrence of the higher-lying layers. In the western part of the Peter I range (profiles I--IV) the small folds of the Tavil'dara synclinorium are formed exclusively of Cretaceous and Tertiary layers; the strata of the Sorbulak layer have no part in the nuclei of these small folds, and have not cropped out on the earth's surface. This has provided a basis for assumption that the Sorbulak layer, entering into the composition of the rear portion of the suspended flank of the Vakhsh overthrust, came here as a whole with the underlying Paleozoic strata and possibly was not displaced from its base in the process of formation of the overthrust. During formation of the Vakhsh covering the Cretaceous layers occurring on top of the Sorbulak layer, under the influence of the reverse pressure of the forward part of the Vakhsh covering, were torn from the Sorbulak layer and gathered into folds.

In the eastern portion of the Peter I range the Sorbulak layer plays a major part in the composition of a number of compressed folds of the Tavil'dara synclinorium; these folds have been brought out to the earth's surface. This was probably caused by the fact that the Vakhsh overthrust came into contact here with the area of development of the Sorbulak layer; the latter entered into the composition of the forward part of the covering, was displaced from its base, and gathered into folds, as has been shown on profiles VIII and IX. In these places the Cretaceous layers as well as the Sorbulak layer play an identical part in the composition of the Zaalay syncline.

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To the southwest, in the region of the village of Lyayrun (Fig. 4) only Lower and Upper Cretaceous layers enter into the composition of the Zaalay syncline proper at the surface of the earth. The Lower Cretaceous layer of the northwestern flank of the syncline has in addition been collected into a compressed anticline. This has provided a basis for assumption that the Cretaceous layers in these places were torn from the underlying substratum, i.e. from the Sorbulak layer. The depth of occurrence of this plane of fracture has been determined as 4 kilometers from the earth's surface in the region of the village of Lyayrun on the basis of the thickness and form of occurrence of the higher-lying layers. The corrugated and disturbed Upper Cretaceous layers of the nucleus of the Zaalay syncline, dipping toward the southwest, in the regions of the villages of Lyayrun and Mionadu plunge into the bosom of the earth's crust under the relatively sloping bends of the Neocene layer.

The geological structures of the Darvaz range, which occurred during Alpine time, are considerably more simple, and in consequence they have been plotted on the profiles by means of the simple extrapolation downward of structures which have cropped out on the earth's surface. The complex-folded Cretaceous layers of the forward portion of the Vakhsh covering, entering into the composition of the northern slope of the Peter I range, may be well observed on the edges of valleys which cut into this slope. They have been plotted on the profiles on the basis of sketches from nature.

The geological structures of the forward zone of the southern Tien Shans, in the regions of the southern extreme of the Peter I

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range, are represented on the profiles as continuations of the folds of the southern slope of the Gissar range; these folds plunge to the southeast under the slope, in the valley of the lower reaches of the rivers Surkhob and Khingou (Fig. 5). They are composed there of Paleozoic, Cretaceous, and Tertiary layers. The above-noted folds crop out again on the earth's surface in the central portion of the northern slope of the Peter I range near the floor of the valley of the river Darainushor and in the tectonic window in the Safedorak valley (Fig. 5, area around 29). Here these folds are composed only of Cretaceous layers, forming relatively oblique warp.

In the intervening section (profiles III-VII) the forward zone is represented by means of extrapolation in the form of structures of gradual transition from the folds which have developed in the valley of the lower reaches of the river Surkhob to the folds which have cropped out in the valley of the river Darainushor. This extrapolation has been facilitated by individual outcroppings of the forward zone in the valley of the river Surkhob (profiles III, IV, VII), and also by study of various layers of the Vakhsh covering, on the basis of whose thickness the depth of occurrence of the buried surface of the forward zone has been determined. In the eastern portion of the Peter I range the forward zone is hidden under the Vakhsh covering, from under which it crops out again on the earth's surface only in the western extreme of the Zaalay range, where deeply depressed, obliquely warped Tertiary layers enter into its composition. In the intervening section, i.e. the eastern extreme of the Peter I range, the forward zone is represented again by means of extrapolation, which has been facilitated by two outcroppings of the forward zone --

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near the village of Darachol not far from the river Surkhob and somewhat west of the mouth of the say Tokusbulak (Fig. 5, near numbers 21 and 22).

The upper portions of the geological structures of the Gissar range are excellently exposed on the earth's surface, and in many places may be surveyed, thanks to the infrequently broken relief, at depths up to 1 or 1.5 kilometers.

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CHAPTER III

SEISMOSTATISTICS

§15. General Survey of Earthquakes

Among the large number of seismic shocks of varied intensity which have been recorded instrumentally from 1912 to 1948 in the territory of Garm Oblast', weak earth-tremors, unperceived by man, have been dominant; shocks of intensity from 3 to 4 or 5 points have occurred less frequently; and strong earthquakes have taken place quite rarely by comparison. For the time from 1895 to 1947 there occurred in all five destructive earthquakes there, of 8 to 9 points in intensity, and about twenty earthquakes of intensity up to 6 or 7 points. By comparison with other parts of the Soviet Union the number of strong earthquakes occurring here is of course very great.

The earthquakes noted above have occurred irregularly. In some years more than 100 earthquakes have been observed, and in others fewer have taken place; at times there have even been periods of seeming calm when underground shocks have not been perceived by human beings in the course of many months. For example, in 1930 earthquakes were relatively few, and in 1934 and 1935 two eight- or nine-point earthquakes and many tens of tremors of intensity from 3 to 5 or 6 points took place. In 1940 very few earthquakes occurred, and in 1941 there were a nine-point earthquake, a few tremors of from 6 to 7 points in intensity, and more than 120 seismic shocks of intensity from 2 to 3 or 5 points.

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Earthquakes have not occurred everywhere in the oblast . In some places they have taken place almost annually, in others seldom, and in still others, according to data from interrogation of the local population, strong earthquakes have not occurred for the past 50 to 60 years. (Interrogation data was collected by the author in the course of six years--with interruptions--for many population points, with the stories of inhabitants of some villages being compared with the stories of inhabitants of other villages, and they have almost always concurred. The place of occurrence of a given earthquake has been determined by the strength of its manifestations. As a rule, the local inhabitants have not remembered earthquakes occurring more than 50 to 60 years ago.) For example, earthquakes perceptible to human beings have often occurred within the limits of the narrow Middle-Khingou epicentral zone, which extends in a southwestern direction and includes the valley of the lower reaches of the river Shaklyau and then the valley of the middle reaches of the river Khingou, proceeding from the mouth of the foregoing river downward along its course to the regions of the settlement of Tavil'dara (Fig. 4). Here are located the Zaalay syncline and its subsidiary folds.

Strong earthquakes have occurred just as frequently on the northern slope of the Peter I range, particularly on its western half, in the region of the villages of Ortot and Zyubot of the Garm Region, situated within the limits of the eight-point zone of the earthquake of 1939 (Fig. 4) on the Vakhsh tectonic covering, in places where the Yafuch fault is found (44*). Within

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the limits of the Gissar range destructive underground shocks have occurred in various sections of its southern slope, in places where steep faults in the earth's crust are found. Strong earthquakes have not occurred in the valley of the lower reaches of the river Khingou, below the settlement of Tavil'dara, and in the adjoining central parts of the southern slope of the Peter I range, nor in the head-water region of the river Khingou, in the basin of the upper reaches of the river Zida-dara, and in certain other places.

For the determination of the connections between the various above-indicated earthquakes and certain tectonic structures, including faults, the effects of very strong underground shocks whose epicenters and seismic foci have been adequately detected are briefly considered below. A more detailed enumeration of all underground shocks and a detailed description of their destructive effects has been furnished in the "Catalog of Earthquakes of Garm Oblast" (13); the sources of data used have also been indicated there.

Seismostatistic data for the regions of the Upper-Khingou epicentral zone were collected from 1932 to 1948. During this time there occurred here more than 45 easily perceptible underground shocks, two of them having an intensity of from 8 to 9 points, three from 6 to 7 points, and the rest from 4 to 5 points. The strongest of these earthquakes are noted below.

The Arganikul' earthquake of 1934 (13,52) occurred on September 1 at 1:45 a.m. local time (Henceforth local time is

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used throughout; it differs from Moscow time by three hours.) and attained an intensity of 8 to 9 points. Its epicenter extended in a southwestern direction, along the lower reaches of the river Shaklysu and part of the middle reaches of the river Khingou (Fig. 4) on a section up to 15 or 18 kilometers in length. The isoseismal lines surrounding this epicenter are ellipsoidal in form, extending also in a southwestern direction. The distance between the various isoseismal lines, perpendicular to the path of the epicenter, was as follows: between the 8- and 7-point isoseismals was about 1.5 to 2.5 kilometers, between the 7- and 6-point isoseismals about 6 to 7 kilometers.

The Argankul' earthquake of 1935 (13, §2) occurred on October 8 at 7:55 p.m. not far from the epicenter of the preceding earthquake in the valley of the middle reaches of the river Khingou (Fig. 4). It attained an intensity of 8 to 9 points. The epicenter of the earthquake extended from the village of Argankul' in a southwestern direction and had a length of about 12 kilometers. The distances between various isoseismals here were approximately the same as for the preceding earthquake. The Argankul' earthquake of 1937 (13, §2) occurred in September and attained an intensity of 6 to 7 points. Its epicenter was located on the site of the epicenter of the preceding quake.

The Sayat earthquake of 1943 (13, §2) occurred in November and attained maximum intensity (6.5 to 7 points) in the villages of Syat and Sauzikharv. In the settlement of Tavil'dara its intensity reached 6.5 points. The 6-point isoseismal (Fig. 4)

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of this earthquake has an ellipsoidal form, extending in a southwestern direction. The epicenter of the earthquake was located inside this isoseismal in the valley of the river Khingou.

As may have been noted, the epicenters of the above-listed strong earthquakes shifted successively to the southwest from the regions of the lower reaches of the river Shaklysu to the village of Sayat. The positions of the epicenters of other weaker underground shocks which have occurred in the Middle-Khingou zone have not been determined precisely. However, since these weak shocks were almost always accompanied in the valley of the middle reaches of the river Khingou by subterranean rumbling which is normally audible only near the epicenters, we may consider that they also were located in the regions of the Middle-Khingou zone, possibly in the regions of the epicenters of the strong earthquakes considered above.

Within the limits of the northern slope of the Peter I range, according to the narratives of local inhabitants, weak but perceptible underground shocks with loud subterranean rumbling occur almost every year in one place or another. Strong earthquakes have occurred here three times from 1895 to 1948.

The Karatega earthquake of 1895 (13, §4) occurred on November 1 and attained an intensity of 8 points. Its epicenter was located in the Garm region along the upper portion of the northern slope of the Peter I range, and probably extended from

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the villages of Gazorchashma and Zyubet to the village of Ortot, in a west-southwest direction. (The villages of Gazorchashma, Zyubet, and Ortot are located (Fig. 4) within the limits of the eight-point zone of the May 30, 1939 earthquake.) Along the direction from the epicenter to the river Surkhob, i.e. to the northwest, the intensity of the quake diminished rapidly. The distances between the 8- and 7-point isoseismals did not exceed 2.5 to 3 kilometers here.

The Karatega earthquake of 1939 (13, § 4) occurred on May 30 at 4:09 p.m., local time, and reached an intensity of 7.5 to 8 points. Its epicenter almost coincided in extent with the epicenter of the preceding earthquake, had a length of up to 15 kilometers, and included the regions of the villages of Gazorchashma, Zyubet, Ortot and Damou (Fig. 4). The distances between the 8- and 7-point isoseismals perpendicular to the path of the epicenter did not exceed 2.5 to 3 kilometers and between 7- and 6-point isoseismals did not exceed 4 to 5 kilometers.

The Safedou earthquake of 1941 (13, § 4) occurred in the month of May and reached an intensity of 6 to 7 points. Its epicenter was probably located in the regions of the villages of Safedou and Ganishou in the central portion of the northern slope of the Peter I range in the Kalaylyabiob region (Fig. 4) and extended in a west-southwest direction.

Within the limits of the southern slope of the Gissar Range, according to the narratives of local inhabitants, in their memory

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(that is, within the course of the past fifty to sixty years) up to 1941, destructive earthquakes had not occurred, and weak underground shocks had taken place only infrequently. This picture changed abruptly on April 20, 1941, when the 9-point Garm earthquake occurred there. Since that time many strong earthquakes have occurred on the southern slope of the range in question. In 1941 there were more than 120 of them; in 1942 more than 40; in succeeding years their number decreased. Certain of them reached an intensity of 6 to 7 points.

The Garm earthquake of 1941 (13, §5) occurred on April 20th and attained an intensity of 8 to 9 points. Its epicenter was located in the valleys of the Rivers Kamarou and Yasman and extended in a southeastern direction, reaching lengths of 35 to 40 kilometers (Fig. 4).

The distances between the highest intensity isoseismals of this earthquake, proceeding perpendicular to the path of the epicenter zone, were as follows: between the 8- and 7-point isoseismals, an average of from 15 to 18 kilometers, and between the 7- and 6-point isoseismals, about 40 or 50 kilometers. The Garm earthquake of 1941 was recorded by all seismic stations of the Soviet Union. The Senior Fellow of the Geophysical Institute of the Academy of Sciences USSR, Ye. F. Savarenskiy, figured the depth of its focus at 25 kilometers with an error of 10 kilometers, according to the instrumental data of the Central Asiatic stations (33). (There were several opinions as to the depth of the focus of the earthquake of April 20, 1941. The author ..

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adheres in general to the views of E. F. Savarenskiy, and therefore the assumptions of other investigators are not included here; they may be found in the appropriate articles (20, 21).)

Certain peculiarities of this earthquake's manifestation at the earth's surface are additional evidence of the similar relatively small depth of its focus. For example, with high intensity at the epicenter, the distances between the highest intensity isoseismal, curves near it were comparatively small. In regions adjacent to the epicenter various bendings of different layers which have developed on the earth's surface have had a considerable deviating effect on the direction of seismic waves, and in addition waves transverse to the layers have been noticeably more attenuated than waves passing along the direction of such layers. The epicenter of the earthquake coincided with the lines of vertical faults (Fig. 6) whose surfaces pentrate the earth's crust scarcely more than 15 to 20 kilometers here. It is probable that the focus of the earthquake was also connected with these faults. If this earthquake had occurred at greater depth, let us say up to 60 to 70 kilometers or more, then the distance between its isoseismals would have been from two to three times greater (33, p. 186) and the surface geological structures would not have had a substantial influence on the distribution of its seismic waves in the earth's crust.

I shall clarify the last thought. Seismic waves proceeding from a deep focus pass out to the earth's surface at steep angles over a large area and intersect variously warped folded layers

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which have developed in the upper zone of the earth's crust (if a given region possesses them) at relatively short distances. This being the case, folded layers have almost no effect on the direction of movement of seismic waves. Seismic waves proceeding from a shallow focus intersect such structures at oblique angles and at great distances are exposed to the deviating effects of various warped planes; this is reflected in the bending of the corresponding isoseismals. As already noted, the latter phenomena have been clearly observed in connection with this earthquake.

Certain peculiarities of the destruction of buildings in the pleistoseismal zone also testify to the relatively small depth of its focus. For example, only in the epicenter did the destroyed buildings bear traces of vertical or steeply inclined seismic waves; off to the side of the epicenter at a distance of 8 to 10 kilometers and more, they bore clear traces of the arrival of sharply oriented seismic waves coming from the direction of the epicenter and at a small angle. The small magnitude of this angle has given the author (8) the basis for the assumption that the depth of the focus of this earthquake reached 14 kilometers. In consequence of these considerations expressed above, including the calculations of Ye. F. Savarenskiy, it is possible to assume that the focus of the earthquake of April 20, 1941, occurred in the surface zone of the earth's crust, probably at 14 or 15 up to 25 kilometers.

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The Nazaraylek earthquake of 1941 (13, 5) occurred on May 6th not far from the village of Nazaraylek, near the ridge part of the Gissar range (Fig. 4), where it attained an intensity of 7 points. Its 7-point isoseismal describes an ellipse extending in an east-west direction.

The Pitaukul' earthquake of 1941 (13, 5) occurred on May 19th in the Dzhirgatal' region and reached 7 to 7.5 points in the village of Pitaukul'. The 7-point isoseismal of this earthquake has the shape of an ellipse extending in a north-northeast direction (Fig. 4).

T e Khait earthquake of 1942 occurred on March 22 at 2:09 a.m. in the Khait region, where it attained a maximum intensity of 7. This earthquake was distributed over a large area, the same as that of the earthquake of April 20, 1941.

§16. Earthquake Foci and Geological Structures

The various destructive earthquakes considered above had linear epicenters extended in various directions, (In certain articles on instrumental seismology the epicenters and foci of tectonic earthquakes are conventionally accepted as points. However, as is known, under natural conditions, the foci of such earthquakes have various lengths, in certain cases up to tens of kilometers. Determination of the lengths of epicenters and foci is important for knowledge of the conditions under which various earthquakes occur.) and correspondingly extended isoseismals. This serves to indicate that the foci of these earthquakes had

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a linear shape in horizontal projection and were evidently displaced along the planes of faults in the earth's crust, which in various places have various directions and angles of declination. Projections of these planes on the earth's surface by means of vertically rising seismic waves have also been revealed in the form of extended, variously oriented linear epicenters. As noted above, the depth of occurrence of the focus of the earthquake of April 20, 1941 was determined as from 14 or 15 to 25 kilometers. Let us attempt to ascertain by the comparative method the depths of occurrence of the foci of various earthquakes.

It is well known that earthquakes with large areas of diffusion and large distances between isoseismals have deeper foci than earthquakes with the same intensity at the epicenter but smaller areas of diffusion and smaller distances between isoseismals.

The area of the 8-point shock of the earthquake of April 20, 1941 reached 600 to 650 square-kilometers, and the distance between the 8- and 7-point isoseismals, measuring perpendicularly to the path of the epicenter, reached an average of 15 to 18 kilometers. The destructive Argankul' earthquakes of 1934 and 1935, and also the destructive Karatega earthquake of 1939 on the northern slope of the Peter I range, had approximate the same intensity of seismic shock in the epicentral zones as the earthquake of April 20, 1941, but the areas of eight-point intensity and the distances between 8- and 7-point isoseismals of

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these earthquakes were considerably smaller. Specifically, the area of the eight-point seismic shock of the earthquake of 1934 reached 100 to 110 square-kilometers, that of the earthquake of 1935 about 50 to 70 square-kilometers, and that of the earthquake of 1939 up to 100 square-kilometers. The distances between 8- and 7-point isoseismals, measuring perpendicularly to the path of the epicenter, reached 1.5 to 2.5 kilometers for the 1934 and 1935 earthquakes and as much as 2.5 to 3 kilometers for the 1939 earthquake.

If we now take into account that these distances between 8- and 7-point isoseismals were in general 5 to 7 times smaller for the earthquakes of 1934, 1935 and 1939 than for the earthquake of April 20, 1941, we may assume that the depths of the foci of the first earthquake were also substantially smaller. The depth of the focus of the 1941 earthquake has been determined as from 14 or 15 to 25 kilometers; consequently, the foci of the 1934, 1935, and 1939 earthquakes were located much closer to the earth's surface. At the locations of the epicenters of these earthquakes faults of various types (Fig. 13, 14) are located at depths up to 4 kilometers in the earth's crust, in the complex-bent Mesozoic layers. Along the surfaces of these faults displacements of the rock strata, caused by uneven upheavals, may occur at the present time, and at the same time surface earthquakes may occur.

In deeper zones of the earth's crust, within the limits of these sections, faults of a geologically similar character do not

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occur. Taking into consideration everything that has been said above, we may assume that the earthquakes of 1934, 1935, and 1939 occurred in the surface zone of the earth's crust, at depths of 3 to 4 kilometers.

Certain other peculiarities in the appearance of the subject surface earthquakes are also indirect evidence of the fact that their foci were located along various faults which have developed there at depths up to 3 or 4 kilometers or within surface folds composed of Cretaceous strata, or at points of contact between these folds and the underlying substratum. Specifically, the epicenters and isoseismals of the Middle-Khingou-zone earthquakes of 1934, 1935, and 1937 extended in a southwestern direction, corresponding to the range of surface geological structures which have developed there--the Zaalay syncline and its subsidiary folds (Fig. 4, 5), composed of Cretaceous strata. The depths of these folds within the earth's crust in these places probably does not exceed 3 to 4 kilometers (Fig. 13 and 15). Deeper structures composed of more ancient raock strata occur.

The coincidence between the extent of the subject epicenters and the extent of the surface structures serves as an additional indication that the subject earthquakes have occurred either within these structures or at their point of contact with the underlying substratum, and that the shapes of their foci are somehow dependent on the shapes of these folds. If these earthquakes occurred deeper, then their isoseismals on the earth's surface would have other contours and orientations, corresponding

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to deep geological structures and conforming to other shapes and other mechanics of foci. If this were the case the surface structures would not be able to exercise a substantial deviating effect on the directions of seismic waves proceeding from such a deep focus, since the latter would intersect these surface structures at too great an angle. In this case the epicenters and isoseismals would not coincide with surface structures.

The epicentral zones of destructive earthquakes of the northern slope of the Peter I range, particularly those of the 1935, 1937, and 1939 earthquakes, have been oriented in a west-southwest direction, corresponding to the extent of the tectonic structures of the Vakhsh covering (Figs. 4 and 5). The depth of these structures within the earth's crust at places where the subject earthquakes have occurred is evidently no greater than 2 or 3 kilometers (Fig. 14). Deeper, the structures of the forward zone of the southern Tien Shans occur; these have other shapes and somewhat different orientations. The coincidence of the epicenters of the subject earthquakes with the surface structures of the Vakhsh covering, as in the preceding case, are evidence that these earthquakes have occurred either within the covering or the region of contact with the inclined surface of the forward zone.

The destructive Middle-Khingou earthquakes of 1934, 1935, and 1937 had relatively short epicenters--from 10 to 15 or 18 kilometers. These lengths correspond in general to the lengths of individual parts of the subsidiary folds of the Zaalay

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syncline or the laminations which have developed there; those in occurring deflect or somewhat alter the paths of the epicenters by relatively short distances. The coincidence of the lengths of the above-mentioned epicenters with the lengths of various individual parts of the surface folds serves as additional proof of the dependence of the shapes of the foci of the subject

(Fig. 13. Assumed diagram of the mechanics of occurrence of the 1934 Argankul' earthquake.

Compiled by I. Ye. Gubin in 1948

1 and 2--Mesozoic rock strata, which enter into the composition of the axial portion of the Kulay syncline; 3--Lower Cretaceous layer (Korbulak series); 4--Paleozoic deposits; 5--Lines of faults and overthrusts; 6--Directions of motion of seismic waves of various intensity at the earth's surface, proceeding from the focus of the earthquake; 7 and 8--9---point-readings.) [hand drawn copy in Appendix I, and [illegible] in II.]

(Fig. 14. Assumed diagram of the mechanics of occurrence of the 1939 Karatega earthquake.

Compiled by I. Ye. Gubin in 1948.

1 and 2--Mesozoic and Tertiary rock strata of the Vakhsh tectonic covering; 3--Mexozoic and Tertiary rock strata of the

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forward zone of the southern Tier Shans; 4--Paleozoic rock strata of the forward zone of the southern Tier Shans and the Gissar range; 5--Lines of the Vakhsh and Yafuch (indicated by asterisk) overthrusts; 6--Directions of motion of seismic waves of various intensity at the earth's surface, proceeding from the focus of the earthquake; 7 and 8-9--point readings.) [Hand drawn copy in Appendix I, and [illegible] in II]

earthquakes on the shapes of these surface folds and, at the same time, is evidence of the genetic connection between the subject earthquakes and the movements of corresponding parts of these folds.

The epicenters of the destructive earthquakes of 1895 and 1939 attained lengths of 12 to 15 kilometers; the epicenter of the Safedou earthquake of 1941 was relatively short. These epicenter lengths correspond in general to the lengths of individual variously formed parts of the folds and luminations of the Vakhsh tectonic covering, which occur here to deflect or alter the epicenter path or configuration, likewise at comparatively short distances. Consequently, the coincidence between the lengths of the above-mentioned epicenters and the lengths of those individual surface structures, just as in the preceding case, is evidence that those earthquakes have occurred within the limits of the structures noted, either within the Vakhsh tectonic covering or in the region of contact of the latter with the surface of the forward zone of the southern Tier Shans.

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Various strong earthquakes of the Middle-Khingou zone have manifested themselves almost uniformly on the earth's surface. This is evidence of the approximately uniform depths of their foci, evidently connected with one and the same tectonic zone occurring at an approximately uniform level. Along the middle reaches of the river Khingou such a zone can only be the zone of fracture of folds, composed of Cretaceous sediments, from the substratum, together with faults which have developed inside these fractured folds. The depth of this zone, according to geological data, presumably reaches 3 to 4 kilometers in the regions of the villages of Lyayrun and Argankul', i.e. in the region of the eight-point zone of the 1934 earthquakes; in the region of the settlement of Tavil'dara it is slightly deeper (Fig. 15). The presence of some generally uniform level of foci within the limits of the Middle-Khingou zone again corroborates the assumption that these foci occur either within the surface structures or in the region of contact of the latter with the substratum, which has in general an approximately uniform level.

On the northern slope of the Peter I range the earthquakes of 1895 and 1939 likewise manifested themselves almost uniformly on the earth's surface. This is evidence of the existence there also of some integral zone in which earthquakes often occur. This zone includes places of contact between the strata of the Vakhsh covering and the buried surface of the forward zone of the southern Tien Shans, together with faults which have developed inside this covering.

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The Safedon earthquake of 1941 had an insignificant area of diffusion. This points to a small depth of occurrence for its focus, which probably was located here inside the Vakhsh cover-ing, along the plane of the inclined Safedon fault (30*).

On the basis of the data considered above it may be assumed that in the Middle-Khingou zone and on the southern slope of the Peter I range, in the places mentioned earlier, along faults which have developed inside the complex-folded Upper Jurassic and Cretaceous surface layers and along the region of contact between the Vakhsh covering and the substratum, shiftings of masses of rock strata are continuing at the present time, and that they are causing corresponding surface earthquakes.

Having assumed that earthquakes in the Middle-Khingou epicentral zone and on the northern slope of the Peter I range are caused by shiftings of surface folds composed of Upper Jurassic and Cretaceous layers, we can easily explain certain of their peculiarities. For example, the relatively great frequency of earthquakes in the Middle-Khingou zone and on the northern slope of the Peter I range is explained by the fact that, for the displacements of small covering folds---which cause earth-quakes---small stresses are required; due to general uneven vertical movements of the earth's crust these stresses have accumulated rapidly and been rather easily relieved.

The short lengths of individual covering folds and the relative softness of the young Upper Jurassic and Cretaceous strata forming them, together with unevennesses of the more

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rigid substratum, have been causing faulting of these covering folds under circumstances of general stress-increase in them; this faulting has occurred not along the whole extent of the northern slope of the Peter I range or the Middle-Khingou zone, but in restricted places which have been most greatly weakened at a given moment. This has also caused the small length of the foci (epicenter) of the given earthquakes, and also their frequent repetition in the same places or in adjacent sections.

The successive displacement of epicenters in a southwest direction which has occurred during recent years in the Middle-Khingou zone has probably been connected with successive movements of individual torn and broken folds, closely connected with each other and composed of Cretaceous and Upper Jurassic layers. It may be assumed that movements of these folds in 1934 near the village of Lyayrun caused in the vicinity the first

(Fig. 15. Assumed diagram of the mechanics of occurrence of the 1943 Sayat earthquake.

Compiled by I. Ye. Gubin in 1948.

1-2--Mesozoic and Tertiary rock strata; 3--Lower Mesozoic layer (Sorbulak series); 4--Paleozoic rock strata; 5--Fault line; 6--Direction of movement of seismic waves of various intensity at the earth's surface, proceeding from the earthquake focus; 6 and 6-7--Point-readings.) [hand drawn copy in Appendix I, and thermoprint in II.]

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Argankul' earthquake and simultaneously altered to a certain extent the location of these folds and disturbed the equilibrium of other parts of them near the village of Mionadu. In consequence of this new displacements took place there in a year, causing the second Argankul' earthquake in 1935, with its epicenter near the village of Mionadu. In this earthquake the location of the Sayat anticline was changed and a corresponding stress grew in magnitude within the limits of the latter, which provoked new tectonic displacements there, causing weak earthquakes including the Sayat earthquake of 1943.

The epicenters of the strongest earthquakes within the limits of the Gissar range have coincided in various measure with the lines of profound, steep tectonic faults along whose surfaces individual sections of the territory of the subject range recently underwent considerable differential vertical displacements. These epicenters of the strongest earthquakes were oriented in horizontal section at various angles with respect to each other, independently of the general position of the Gissar range and at times even its Varian and Alpine geological structures, but in conformity to the position of the lines of the young, steep faults which have developed there, which have various orientations (Figs. 4 and 5) and which are connected with a modern differential upheaval. Specifically, the epicenter of the Garm earthquake of April 20, 1941 had an east and southeast path, the epicenter of the Pitaukul' earthquake of May 19, 1941 was extended in a north-northeast direction, and the epicenter of the

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Nazaraylok earthquake of May 6, 1941 was oriented in an east-west direction, in conformity to the positions of the lines of steep and vertical faults which have developed there.

Inside the epicentral zone of the earthquake of April 20, 1941 extend a few so-called Dashtikhirsun faults, whose planes have almost vertical angles and which divide the sloping Alpine folds at great depths (16*, 17*). Along the planes of these faults compact masses of granitoids are in contact with layers of metamorphic shales. A certain difference in the masses of these strata has to some extent made possible, probably, the unevenness of their upheaval and the displacements along the faults mentioned, which have caused the subject earthquake. The foci of the Nazaraylok earthquake of May 6, 1941 and the Pitaukul' earthquake of May 19, 1941 probably occurred along the steep planes of faults whose lines pass through their epicentral zones. They also separate strata of different masses.

The various strong earthquakes of the Gissar range have had epicenters of different lengths. For example, the epicenter of the Garm earthquake of April 20, 1941 reached a length of 40 kilometers, just as that of the Karatag earthquake of 1907 (9), which occurred in the Gissar range of the Stalinabad Oblast. Belonging to other earthquakes, particularly the many-focused Fayzabad earthquake of 1943 (9) which occured in the Stalinabad Oblast, the lengths of certain epicenters on the southern slope of the Gissar range did not exceed 10 to 15 kilometers; - probably the Nazaraylok and Pitaukul' earthquakes of May 6 and 19, 1941

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had similar or shorter epicenters.

These epicenters of various lengths have in many cases corresponded to similar lengths of various individual blocks of the earth's crust, bounded by the planes of steep tectonic faults; this was particularly noticeable for the Fayzabad earthquake of 1943. However, in other cases the epicenters were shorter than these blocks. This, and also the coincidence between the lengths of the above-mentioned epicenters and the lengths of various blocks of the earth's crust which have recently undergone vertical upheavals, serves as additional proof of the dependence of the shapes of the foci of these earthquakes on individual local geological structures which have a relatively deep occurrence.

The strongest earthquakes of the Gissar range, enumerated above, have had certain small differences in the sizes of their areas of diffusion, and small differences in the distances between their corresponding isoseismals. This points to the fact that the foci of these earthquakes were located at some varied, but close-together, depths and, judging by the manifestations of the corresponding earthquakes, scarcely deeper than 20 to 25 kilometers. Many other earthquakes of the Gissar range, including those which were weak, local, and had small areas of diffusion, have probably occurred at lesser depths approaching the earth's surface. Their foci were evidently located in the higher zones of steep faults.

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All of the data given above permits the assumption that in the Gissar range displacements of individual sections of the earth's crust, in vertical directions, are continuing along the faults with which the subject earthquakes were connected, and that these displacements are causing earthquakes there. It is necessary to emphasize that the epicenters of those or other earthquakes were not located around some single main block of the earth's crust there, along the lines of the faults surrounding it, but only on one side of it, along the line of some single fault, and not along its whole length, but in many cases only along part of it. As an exception it has been observed, for example, that in the many-focused Fayzabad earthquake of 1943 the epicenters were located along the two faults which outline a certain block from two parallel sides or, in other cases, oriented at angles to each other.

The location of epicenters mainly only on some one side of a certain block or only in part of that side is evidence of the extremely uneven displacements of the latter. Displacements in these cases occur consecutively, first on one, then on the other side of the rising block, or even only along some part of one of its sides. It is probable that in this process the strains of the upheaval accumulate unevenly on the whole area of a certain block, and as a result upheavals of the block or its individual parts occur, accompanied by tensions, bendings, and inclinations of the earth's crust in the boundary regions. Subsequently, when these stresses become greater than the tensile strength of

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the rock strata, corresponding faults and movements along these faults occur in the weakest places, causing earthquakes. From this it may be concluded that right at the time of the earthquake, under the given conditions, the movements of the masses of rock strata occur principally along faults and near them, being attervated at the side where the rise has already taken place earlier.

Having assumed that the Gissar range earthquakes are caused directly by uneven vertical movements of the earth's crust, we can easily explain certain peculiarities in the manifestations of these earthquakes. For example, destructive earthquakes in the Gissar range occur relatively seldom and attain considerable intensity at their foci. This is explained by the fact that large stresses are required for the displacement of individual large rigid sections of the territory of this range; these stresses accumulate over extremely long intervals and are released as the movements which cause the occurrence of strong earthquakes. Such earthquakes are ordinarily accompanied by a large number of underground shocks which often take place along faults which have developed off to the side of the main foci. Displacements along these faults are evidently facilitated and accelerated by the general trembling of this region during a basic underground shock.

The above-mentioned uneven vertical displacements of rock masses, which cause earthquakes within the boundaries of the Gissar range, attain various amplitudes in individual cases,

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probably from an extremely small magnitude, measured in fractions of centimeters, to several meters. Ordinarily, small movements take place, in places imperceptible to the eye at the earth's surface, but which in the depths of the earth's crust are accompanied by displacements of masses along fault-planes over vast areas, up to several tens of square-kilometers in size, and are accompanied by disturbances in the continuity of the rock strata. Incidentally, displacements of small amplitude, occurring inside the earth's crust, may not even show up on the earth's surface, since they are compensated by friction and small bendings in the upper zones of the earth's crust.

The small-amplitude displacements considered above cause customary weak, medium, and strong earthquakes. Movements of large amplitude, visible to the eye at the earth's surface, occur--rather infrequently--in various countries during earthquakes. During such movements earthquakes of greater than 9-point intensity ordinarily occur. In the Gissar range there are numerous traces of considerable displacements which have occurred recently along various steep faults, evidence of extremely strong past earthquakes. The epicenters of earthquakes investigated by us have coincided with the lines of these faults, but probably, as the result of relatively weak intensity, they have not been accompanied by visible movements of the earth's crust. It is quite possible that four categories of earthquakes take place along these faults; ordinary weak (up to 3 or 4 points in intensity), medium (up to 5 or 6 points), and strong earthquakes,

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and unusual catastrophic earthquakes (more than 9 points in intensity). The ordinary earthquakes occur often, but the catastrophic ones extremely seldom. During the past 50 years catastrophic earthquakes have not occurred within the boundaries of the Gissar range.

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CHAPTER IV

MODERN TECTONIC MOVEMENTS AND THE DETERMINATION OF THE SEISMIC REGIONS OF GARM OBLAST

§ 17. Modern Tectonic Movements

In considering the geological composition of the Gissar range § (9), it was noted that within its boundaries the latest stage in the history of the development of the earth's crust has been uneven upheavals, accompanied by displacements along the planes of numerous steep faults. Seismic phenomena occurring along the planes of numerous steep faults. Seismic phenomena occurring along the planes of certain of these faults corroborate the assumption that displacements are taking place along them even at the present time. In consequence of the large number of various traces in the relief which are evidence of recently occurred upheavals, and of the absence of traces of depression, it is possible to assume these displacements have as before a positive sign. Consequently, the uneven upheaval of the Gissar range is continuing, and, as before, is accompanied by displacements along the planes of steep faults. Within the boundaries of the Gissar range there are many different tectonic faults connected with its uneven upheaval, but known earthquakes have been traces to only certain of them. It is evident that this upheaval, accompanied by movements along fault-planes, is not taking place simultaneously in all sections of the Gissar range, but in those where sufficient stress has accumulated in consequence of various geological circumstances. In the future displacements and earthquakes connected with them will take place, naturally, not only along the faults along which known earthquakes

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have occurred, but also along other tectonic disturbances, likewise connected with the vertical displacements.

At present the author knows the following faults with steep and vertical planes, along which considerable displacements of the rock masses are probably occurring, with various interruptions: The Degigulemon, Sarybichun, Samsolyk, Sholi, and Turkon faults, separating variously raised individual blocks of the earth's crust. In Quaternary time the amplitudes of the vertical displacements of these blocks relative to each other have reached from hundreds of meters to 2 or 3 kilometers in various places. These movements have disturbed Neocene sediments and the Samsolyk layer of Neocene-Quaternary age.

In the lower reaches of the river Surkhob there are vertical faults: the Yakhak and Surkhob-Khingou (2*). The latter, on the promontory between the rivers Surkhob and Khingou, separates the Paleozoic limestones of the Gissar range from the Neocene sediments of the Vakhsh syncline. Its line is overlapped in several places there by undisturbed modern sediments. This is evidence that displacements along this fault have not occurred during the course of a considerable recent period of time.

In the basin of the river Sorbog there are two faults with displacements of large amplitude along them—the Kamarou (10*) and the Gorif (13*). The plane of the first of them falls to the northwest at an angle of up to 60 degrees; the plane of the second is almost vertical. A number of other similar faults can be observed in the basic of the upper reaches of the river Kamarou (14*, 15*).

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A few vertical faults are situated near the settlement of Garm. Two of them, the Bidak and the Shul' (7*), border a unique, highly-elevated horst on the northeast and northwest—Mount Mandolyul'. The third fault, probably bordering this horst on the south, is hidden under the terrace of the river Surkhob.

To the north of the settlement of Garm is the line of the Naudi fault (8*), along whose almost perpendicular plane the Gissar range has undergone a considerable vertical elevation. Thus, the settlement of Garm is in an area bordered on the north by the Gissar range and on the west by Mount Mandolyul', which in recent time have undergone considerable rising movements.

In the valleys of the rivers Sos and Yasman is the group of vertical Dashtikhirsun faults (16*, 17*). In the Dzhirgatal' region the Pitaukul' fault (20*) must be noted. There are probably some connected steep or vertical faults in the valley of the river Surkhob, in the section from the settlement of Kalaylyabiob to the region of the settlement of Dzhirgatal'. Their existence there is only assumed (27*) on the basis of the relation between the right and left banks of the river Surkhob. The first of them is composed of elevated Paleozoic shales and granitoids, and the second of Lower Cretaceous layers occurring almost horizontally near the river-bed. The lines of these two hypothetical faults are hidden under the present-day sediments of the river Surkhob.

In addition to the faults enumerated, there are evidently other recent tectonic disturbances within the boundaries of the Gissar range, which are not noted on the attached map (Fig.5). They may be found through additional detailed geological mapping.

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Movements of the masses of rock strata along the faults enumerated above will be accompanied by earthquakes of varied intensity. According to seismostatistical data gathered for the whole territory of the Gissar range, from the region of the city of Termez to Garm Oblast, during the past 50 years the majority of earthquakes occurring there have been weak and only several of them have reached an intensity of 8 to 9 points. In conformity to this we may expect, in future also, the occurrence of generally similar earthquakes along the faults enumerated; of these, the normal strongest earthquakes will be 8- to 9-point, with circles of diffusion of the 8-point tremors 5 to 7 kilometers from the epicenter, as of the Garm earthquake of April 20, 1941, typical for the Gissar range.

Incidentally, the possibility of occurrence of considerable simultaneous vertical displacements of the masses of rock strata, with considerable amplitudes (up to 1 or 2 meters), within the boundaries of the Gissar range is not excluded, as already noted (§16), consequently, the possibility of the occurence of earthquakes of greater than 9-point intensity, taking place during such movements, is not excluded. Such catastrophic earthquakes have not yet been recorded within the boundaries of the Gissar range, and they probably occur only as exceptions, in the near proximity of fault-lines.

Apart from movements along faults, the elevation of the Gissar range was accompanied in Neocene and Quaternary time by various inclinations and arch-shaped bendings of certain sections

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of the earth's crust. It is possible that these movements are continuing even up to the present, mainly in places where bending has occurred before and, specifically, along the base of the southern slope of the Gissar range, in the valley of the river Surkhob. These bendings may be accompanied by faults in the continuity of the rock strata and the occurrence of earthquakes of medium and weak intensity.

In enumerating the various faults within the boundaries of the Gissar range it was mentioned that the line of the Surkhob-Khingou fault is overlapped by modern sediments. This should not be regarded as an indication of the complete cessation of movements. It is known that displacements of individual sections of the earth's crust occur along faults at great intervals, and within these intervals, under suitable circumstances, modern sediments of considerable thickness may accumulate on fault-lines. In certain cases such overlapped tectonic disturbances should be regarded, from the seismic standpoint, as particularly dangerous, since in the regions of their development stresses accumulate over long periods, reach great intensity, and can cause great displacements and very strong earthquakes.

The Quaternary upheaval of the Gissar range considered above has produced a considerable reaction on the territory adjoining the range on the south. Specifically, as already noted (§10), it has caused a certain additional raising of adjacent sections of the forward zone of the southern Tien Shans and, at the same time, probably caused bending of the forward zone and inclination of it toward the southeast, together with the Vakhsh covering,

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which has developed there. These bendings and inclinations of the territory of the forward zone have evidently been accompanied by certain bendings, compressions, and displacements along faults in the complex-folded Upper Jurassic and Cretaceous layers of the Vakhsh covering, and also a slipping of the covering along the stratum, in places of its maximum bendings under the northern slope of the Peter I range, particularly in the region of the buried Vakhsh structural step (§10).

The occurrence of earthquakes on the northern slope of the Peter I range in 1895 and 1939 in the regions of the villages of Zyubot and Damou, with foci located either along the plane of the Yafuch fault or along the base of the Vakhsh covering, in the place where it occurs on the Vakhsh structural step (Fig. 14), serves as an indication that these movements are continuing even at present. The Safidou earthquake of 1941 is corroboration of such movements in the Kalaylyabiob region.

In other parts of the northern slope of the Peter I range earthquakes have not been recorded during the past decade, but, as may be judged from the results of structural analysis, displacements of individual elements of the Vakhsh covering are possible in certain sections of this slope, and consequently earthquakes are also possible. Specifically, such displacements probably occur in regions of the lower reaches of the river Khingou, in the zone of contact between the Vakhsh covering and the inclined surface of the Vahksh structural step—in places where the roots of the Yafuch overthrust developed—in whose region the general geological conditions are analogous to similar conditions of the

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region of the villages of Zyubet and Damcu, where the epicenter of the 1939 earthquake was located. In these places, consequently, the occurrence of earthquakes is possible—of earthquakes of the same type as the one near the villages noted. The strongest normal earthquakes there will correspondingly attain an intensity of 7 to 8 points at their epicenters, will have small areas of 8-point shocks extended along surface geological structures, and will have distances between the 7- and 8-point isoseismals of from 2.5 to 5 kilometers, and between the 6- and 7-point isoseismals of up to 8 or 10 kilometers. "

In the central portion of the Peter I range, in the region of the villages of Almalyk and Darainushor, the Vakhsh structural step has small width (profiles VIII, IX) and movements along it of the Vakhsh covering are improbable there. In the eastern portion of the Peter I range displacements of various individual parts of the Vakhsh covering, caused by bending and inclination to the southeast of the forward zone of the southern Tien Shans, are more possible along the buried,inclined extreme southern surface of this zone in places lying under the axial portion of the Peter I range, and along faults which have developed there inside the above-lying Vakhsh covering. Places where such movements are possible extend in the depths of the earth's crust approximately from the valley of the river Safidsu (Fig. 4) to the head-waters of the river Shaklysu, and then to Lake Burunkul' along the northern extreme of the Shaklysu anticline (24*). These displacements may be easily imagined if we consider geological profiles VI—XI, having assumed an elevation of the Gissar range

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and a bending of the forward zone. Strong earthquakes have not occurred here during the past decade, but they are possible with displacements of individual portions of the Vakhsh covering, being of the same type as the earthquakes on the northern slope of the Peter I range in 1895 and 1939, where the geological conditions are in general identical.

The occurrence of many-focused earthquakes within the boundaries of the Middle-Khingou epicentral zone serves as an indication that displacements of masses along faults in the surface zone of the earth's crust are also occurring there at the present time. They are possibly caused, as already noted, by various bendings and compressions of the earth's crust in this zone, these being connected with the relatively great upheaval of the Darvas range and, possibly, of the inner portions of the Peter I range, by comparison with regions of the Middle-Khingou epicentral zone.

Uneven rising movements of these ranges cause, in the zone of contact, movements along various faults (§16), not only in places where known earthquakes occurred in 1932, but probably also in other, adjacent sections where there are sufficient premises for this. Specifically, such movements are probably occurring along faults whose lines extend from the head-waters of the river Zida-dara to the region of the village of Mionadu (35*, 34*). The planes of these faults fall steeply to the southeast and intersect folds which are closely connected with moving subsidiary folds of the Trans-Ala syncline. Displacements of all or parts of these folds evidently cause earthquakes of the same

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character as those in the valley of the river Khingou near the villages of Lyayrun, Argankul', and Mionadu (1934, 1935, 1937), i.e. in the epicenters the strongest normal earthquakes probably reach an intensity of 8 points and have 8-point shocks of small area, extending along the surface geological structures.

In the basin of the river Zida-dara (Fig. 4) movements along faults hardly occur, since within the boundaries of this region there has been wide development of unbroken layers of the Polizak stratum of conglomerates of Neocene-Quaternary age, of more than 150 meters in thickness, overlapping the lines of tectonic disturbances which have developed there, including the line of the Karakul' fault (37*). In the Sel'dytau Mountains, which recently underwent a considerable vertical upheaval, strong earthquakes have not occurred during the past decade, but movements along the plane of the Karakul' fault are fully possible there, and consequently earthquakes are also possible. The line of this fault in these places passes among snow-capped peaks up to 6 kilometers in height, and its plane cleaves the mountains into two parts, of which the southeastern occupies the higher position. Movements along this plane recall somewhat movements along tectonic disturbances which have developed in the boundaries of the Gissar range. It is possible that infrequent earthquakes of varied intensity also occur there, at various depths, including quakes of the type of the Garm earthquake of April 20, 1941, with epicenters occurring on the suspended flank of the Karakul' fault.

Apart from the above-mentioned displacements of large masses of rock strata along various fault-lines, within the limits of

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the territory of the Peter I range there probably occur phenomena of secondary partial complications of the surface folds in the surface zone of the earth's crust, caused by these displacements and the pressure of the higher-lying rock strata. Specifically, intra-layer displacements of the plastic rock strata and pulling of these from their base take place, diapir rods develop, on the northern slope of the Peter I range composed of Upper Jurassic gypsums (16), individual layers of the rock strata break apart, etc. All of these processes can cause the occurrence of local surface underground tremors of small intensity. Premises for the occurrence of such underground tremors are to be found in almost all regions of the Peter I range, but their greatest number is probably concentrated in sections of greatest movement; for example, in the Middle-Khingou zone and others.

In the deep portions of the earth's crust of the territory of the Peter I range, under its southern slope, movements of great masses of rock strata are possible along the plane of the Vakhsh fault in places where this plane, in conformity to our hypothesis on the occurrence of the Vakhsh overthrust, cutting the Paleozoic strata, assumes a relatively steep angle of descent (profiles I-XI). These movements of the rear part of the suspended flank of the Vakhsh covering may be caused either by tangential movements or by eneven upheavals of the Darvaz range and the forward zone of the southern Tien Shans. In consequence of the fact that for such movements displacement of very great sections of the earth's crust are required, many times greater than individual blocks of the Gissar range, we may assume that

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the stresses essential for this accumulate there much longer than in various epicentral zones of the Gissar range, probably during many centuries or even millenia. Correspondingly to this, the strong earthquakes caused there by these movements occur so infrequently that it is possible not to take them into account in determining seismic districts.

§18. The Determination of Seismic Regions

Having considered in the foregoing section the mechanics of modern tectonic movements, and having distinguished faults along which earthquakes occur, we have thus essentially carried out the determination of seismic regions of the territory of Garm Oblast. It remains to make only several generalizations.

Within the limits of the Gissar range the faults along which earthquakes occur are located on the whole width of the area of its southern slope, the greatest distances between individual faults not exceeding 12 to 14 kilometers (Fig. 5, 16). (The lines of these faults within the boundaries of the Gissar range have been plotted on Fig. 16; the corresponding probable epicentral zones have been indicated with dots, provisionally along both sides of these steep faults because on the basis of outcroppings on the earth's surface it is impossible to determine various inclinations or bendings of the planes of vertical or steep faults in the depths of the earth's crust, and at the same time it is impossible to determine on which side of a certain fault epicenters will be located. Along each of them during vertical displacements earthquakes of varied intensity may occur,

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including very strong quakes up to 8 or 9 points with surrounding areas of 8-point shocks up to 5 or 7 kilometers, normal for these places (§17). Consequently, during further tectonic movements eight-point shocks will be experienced in turn by all regions of the Gissar range, depending on the place of occurrence of the next strong earthquake. Therefore in determining seismic regions we have classed the entire southern slope of the Gissar range within the boundaries of Garm Oblast as an eight-point zone. Sections directly adjacent to the lines of active faults are classified as nine-point zones.

During upheaval of the Gissar range in Quaternary time displacements of maximum amplitude have occurred along faults which have developed along

(Fig. 16. Schematic map of seismic regions in the territory of Garm Oblast of the Tadzhik SSR, compiled on the basis of the seismotectonic method

After I. Ye. Gubin, 1948

1--Possible epicentral zones, including those of destructive earthquakes from 8 to 9 points in intensity; 2--Possible 8-point zone; 3--Possible 7-point zone; 4--Possible 6-point zone; 5--Lines of Alpine faults and overthrusts occurring during formation of the folded structures of the Peter I range; 6--Lines of steep Alpine faults connected with the uneven rise of the Gissar range; 1--25--numbers of tectonic destructions mentioned in the text)

[Photoreprint in Appendix II]

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the base of its southern slope; during the past 50 years strong earthquakes have occurred most frequently in these same regions. In the remaining sections of the range they have been less frequent. It may be assumed that in future more intensive movements will take place along the border-zone of the southern slope of the Gissar range and that underground tremors will occur more often.

This provides the foundation for classifying this zone as particularly seismic in the limits of the Gissar range. In this zone, proceeding from the Baysun region of southwest Uzbekistan to the Dzhirgatal' region of Garm Oblast on a section up to 360 kilometers in length, four 8- to 9-point earthquakes and many underground tremors of medium and weak intensity occurred from 1907 to 1948. The 8- to 9-point earthquakes occurred in various widely-separated places and did not reoccur at their former locations. Thus, for the given period of time (41 years) within the boundaries of this zone only one earthquake apiece occurred along certain faults. Consequently, it may be assumed that minimum average interval for the occurrence of earthquakes along a given fault is 41 years or more there.

In Garm Oblast, within the boundaries of the Gissar range, a destructive earthquake occurred only once—in 1941—during the period mentioned, in the valleys of the rivers Kamarou and Yasman. Consequently, in these valleys also, eight- and nine-point earthquakes occur just as seldom, at minimum intervals of 40 to 50 years on the average. In other places in the Gissar range, within the boundaries of Garm Oblast, destructive earthquakes have not occurred during the past 40 to 50 years along a

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as narrow strips, extending in a southwest direction. The seismic activity of the first of these zones, i.e. the epicentral zone of the northern slope of the Peter I range, is non-uniform in its various parts. Earthquakes occur most frequently in the regions of the villages of Ortot, Zyubot, and Casorchashma, where during the period from 1895 to 1939, i.e. for 44 years, two destructive earthquakes and several underground tremors of medium intensity occured. In the region of the mouth of the river Khingou destructive earthquakes have not occurred during the period indicated above.

In regions of the epicentral zone of the eastern extreme of the Peter I range there are no populated points. In consequence of this no information on earthquakes has been forthcoming from there. For this region there are likewise no instrumental data. In consequence of this it is awkward to determine the seismic activity of these places. Nevertheless, if we take into account that displacements of the Vakhsh tectonic covering within the limits of the eastern part of the Peter I range are caused, as in the epicentral zone of the northern slope of the Peter I range, by uneven rising movements of the Gissar range and the forward zone of the southern Tien Shans, we may then make a preliminary conclusion that destructive earthquakes occur there with the same frequency as on the northern slope of the Peter I range, i.e. with minimum intervals of 45 to 50 years.

Within the boundaries of the southern slope of the Peter I range are clearly distinguished the Middle-Khingou epicentral zone and a possible Mionadu--Zida-Dara zone, closely connected

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single one of the faults located and mentioned above, in whose regions stresses of various degrees have naturally accumulated. It is probable that also in these places destructive earthquakes along individual tectonic faults occur at nimimum intervals of 40 to 50 years, but judging from all that has been said and is evident, even at considerably greater intervals--now in one place, now in another.

In the preceding section we distinguished within the boundaries of the northern slope of the Peter I range a tectonically active epicentral zone, corresponding to places of contact between the Vakhsh covering and the buried surface of the Vakhsh structural step, and beginning within the limits of our map in the region of the mouth of the river Khingou and ending in the region of the tectonic window of Darainushor (29*). For this epicentral zone of the northern slope of the Peter I range the strongest normal earthquakes are of 8 to 9 points, with small areas of diffusion. We distinguished a similar epicentral zone in the eastern portion of the Peter I range, proceeding from Lake Burunkul' to the river Safidsu (Fig. 16). Its western end, declining gradually to the south, is remote from regions of the Gissar range, near which the greatest inclinations of the forward zone of the southern Tien Shans occur.

In the central portion of the Peter I range, in regions of the river Safidsu, this zone is quite far from the Gissar range, and the inclinations noted probably no longer occur. In consequence of this I assume that this epicentral zone ends there. Both zones are represented on the map of seismic regions (Fig. 16)

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with it. Earthquakes of varied intensity, including very strong 8- and 9-point earthquakes, normal for these zones, with small-area 8-point shocks extending along the geological structures which have developed there, are typical of these zones.

In the regions of the villages of Mionadu--Lyayrun (Fig. 4), the distances between 8- and 7-point isoseismals during destructive earthquakes have not exceeded 3 to 4 kilometers.

On the section between the village of Sayat and the settlement of Tavil'dara surface geological structures composed of Cretaceous sediments occur somewhat more deeply than in the region of the villages of Mionadu--Lyayrun; they are more simple than the latter and have experienced fewer displacements along faults. It is possible that also at present fewer displacements are occurring there, and that at the same time weaker earthquakes than in the eastern portion of this zone are occurring. This is corroborated also by seismostatistical data, admittedly quite few in number. In accordance with the foregoing, on the attached map (Fig. 16) the southwestern part of the Middle-Khingou epicentral zone is directly surrounded by 7-point regions, just as its northeastern portion is surrounded by 8-point regions in the immediate vicinity.

In the northeastern part of the Middle-Khingou zone, in the regions of the villages of Argankul' and Mionadu, two 8-point earthquakes and many seismic shocks of medium and weak intensity occurred between 1932 and 1947 (i.e. over 15 years). This indicates the considerable seismic activity of this zone in the small interval mentioned, but still does not give bases for

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for estimating its average seismic activity for a greater period of time (50 or 100 years). It is quite possible that there, as in the valley of the river Yasman in the Gissar range, i.e. in the region of the epicenter of the April 20, 1941 earthquake, long periods of seismic calm are replaced by short periods (5 or 10 years) of increased seismic activity, after which there comes another long period of calm.

The possible epicentral zone of the Karakul' fault is located to the southeast of the line of the latter in the Sel'dytau Mountains and the adjacent portion of the Darvaz range. We have not yet detected destructive earthquakes there, but they are probable (§17), with foci at various depths and epicentral zones of various areas, extending along the suspended flank of the fault. In consequence of the deep penetration of the plane of the Karakul' fault and the great dimension of the section of the earth's crust which has undergone rising movements there, it may be assumed that tectonic displacements along this fault and their associated earthquakes occur very seldom in this zone, evidently more seldom than earthquakes caused by displacements of small blocks in the Gissar range, for which relatively small stresses are required.

In certain other regions of Garm Oblast, and particularly in the boundaries of the central portion of the southern slope of the Peter I range, in the basins of the rivers Surkhsu, Yezgan, Dashtikavak, and others, Tertiary sediments unbroken by faults have developed. Consequently, there is an absence there, in the surface zone of the earth's crust, of geological premises for

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the occurrence of destructive earthquakes, but these sections will still undergo 7- and 6-point shocks proceeding from the foci of earthquakes which occur in neighboring places on the northern slope of the Peter I range and in the Middle-Khingou epicentral zone. The absence of faults in the surface zone of the earth's crust within the limits of the places noted above does not exclude the possible of occurrence of earthquakes in deeper zones of these territories. Specifically, it is probable that displacements of the plastic rock strata are occuring there, at relatively shallow depths, in folds composed of Cretaceous and Paleocene sediments (see the geological profiles). They may cause weak earthquakes on the earth's surface.

In analyzing the mechanics of modern tectonic movements we did not consider deep zones of the earth's crust (deeper than 25 to 50 kilometers) within the boundaries of Garm Oblast, due to the absence of the essential detailed data on their geological composition. According to seismotectonic information available to us, strong earthquakes have not occurred during the past 50 years in these deep zones. These deep zones of the earth's crust are, over a large section of the territory of Garm Oblast north of the plane of the Vakhsh overthrust (Fig. 6), closely connected tectonically with the southern Tien Shans, with the territory of the Zeravshan-Gissar mountain system (9, 11). Deep-focused earthquakes are not typical of the latter. Therefore they are probably also not typical for the subject northern part of Garm Oblast.

Deep sections of this same oblast, located south of the plane of the Vakhsh overthrust, are closely connected tectonically

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with the territory of the inner zone of the Pamirs (§8), which also includes northern Afghanistan. Within its limits we know of (32) infrequent strong deep-focused earthquakes; consequently, they are also possible in the southern portion of Garm Oblast, principally south of the line of the Karakul' overthrust, i.e. within the limits of the Pamirs' inner zone proper. The foci of these earthquakes evidently occur in a deep tectonic zone of the earth's crust, closely connected with the Afghan zone.

The deep-focused Afghan earthquakes cause weak earth-tremors in Garm Oblast which reach 6 points in exceptional cases. It is probable that deep-focused earthquakes of the southern portion of Garm Oblast, closely connected with them territorially as well as genetically, will cause tremors of similar intensity. In general, they will barely change the general picture of seismicity of the oblast, which is conditioned by movements of the surface sections of the earth's crust and represented on our map of seismic regions (Fig. 16).

All earthquakes occuring in the territory of Garm Oblast are divided into several types, according to the conditions of their occurrence and also their manifestations on the earth's surface. It is possible to distinguish probable deep-focused earthquakes of the Afghan type, earthquakes of the Middle-Khingou type, earthquakes of the northern slope of the Peter I range closely related to them, which I shall call henceforth Pri-Vakhsh earthquakes and Gissar earthquakes of the April 20, 1941 type. The first of these as already noted, probably occur south of the line of the Karakul' overthrust. Their origin is not clear to us. They are connected

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territorially with deep sections of the Alpine orogenesis of Central Asia (11). On the earth's surface these earthquakes are of normally small intensity and extend over enormous areas of uneven shape, not connected with the shapes of surface geological structures. Their foci occur at depths up to 100 or 150 kilometers or more.

Middle-Khingou earthquakes occur in complex surface folds and are caused by displacements of these folds along the planes of faults which have developed between them, and in lesser degree along faults which have developed between these folds and their bases. These earthquakes are of large intensity at the epicenters and small-area destructive shocks, extending at the earth's surface along the geological structures mentioned above. Their foci occur at depths up to 4 or 5 kilometers.

Pri-Vakhsh earthquakes occur in the base of individual shifting parts of the tectonic covering or inside its individual component folds, which ex-

(Fig. 17. A Bridge of Local Construction)

perience uneven local displacements. These earthquakes are almost the same in their manifestations on the earth's surface as the Middle-Khingou type. Their foci occur at depths up to 2 or 4 kilometers. Earthquakes of the Gissar type occur along the planes of steep and vertical faults with rock masses moving along them, undergoing rising or descending movements. They are of large

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intensity at the epicenters and relatively vast-area destructive shocks, extending along the lines of various steep tectonic faults. The depth of occurrence of their foci reaches 15 to 25 kilometers, infrequently more. The various types of earthquakes noted above have been occurring in Garm Oblast between 1895 and 1948 only under suitable geological conditions, which we took into consideration in carrying out the determination of seismic regions.

For determination of the extent of relative displacements of individual sections of the earth's crust in modern tectonic movements, particularly in earthquakes, large-scale special geodetical measurements, embracing the southern slope of the Gissar range, the Peter I range, and other regions have been carried out in Garm Oblast with the author's participation. In many countries of extremely small tectonic activity, for example, in France, Hungary, and Finland, fluctuations of the earth's surface in certain places reach 3 or 4 millimeters a year (17, 26). In Garm Oblast, within whose boundaries movements of the earth's crust are considerably more intensive, we may expect at present considerably greater displacements which it will probably be possible to measure in the course of subsequent geodetical work in the near future.

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19. Conclusion

In the process of our investigations it has been determined that earthquakes in Garm Oblast do not occur everywhere, but in various epicentral zones within whose boundaries the greatest destructions occur. The seismic activity of the various epicentral zones is non-uniform: in some zones strong earthquakes occur often, in others seldom, and in still others quite infrequently. Certain sections of the Middle-Khingou epicentral zone, particularly the region of the villages of Argankul' and Mionadu, must be classified provisionally as places of high, destructive seismic activity, i.e. places in which, according to S. V. Medvedev's definition (23), strong earthquakes occur at intervals of 10 to 25 years and less.

The epicentral zone of the northern slope of the Peter I range, in the region of the villages of Zyubet and Ortot, where strong earthquakes evidently occur on an average of every 45 or 50 years, is classified as a place of medium activity. The remaining epicentral zones, including the epicentral zones of the Gissar range, have mainly a low destructive seismic activity, i.e. within their boundaries strong earthquakes occur at intervals of more than 40 to 60 years.

In the various epicentral zones which we have located, as a rule, earthquakes of a definite type occur, possessing various typical proportions and areas of maximum destruction. Determination of the seismic principles enumerated above makes easier and less expensive the campaign against the destructive effects of strong seismic shocks, by providing not for construction measures in all places, which is very difficult and expensive, but firstly only within the boundaries of epicentral zones discovered which

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possess high and medium destructive seismic activity, and secondly in all points of greatest population which are located in regions of 8- and 7-point earthquakes, even if these points are located in regions of low seismic activity. This is essential because in many of these points earthquakes may occur at any, unknown moment, including the years of the near future.

During strong earthquakes in Tadzhikistan, especially in Garm Oblast, the basic centers of destruction are the villages, in which human beings and domestic animals often perish under collapsing structures. Village buildings are erected without observance of the most essential antiseismic rules of construction, they are very unstable, and many of them are destroyed even in 7-point seismic shocks. The majority of these buildings are of pise-de-terre construction, with unstable walls and heavy earthen roofs, whose thickness in some cases reaches 0.5 to 0.7 meters. Before these living structures are sheds whose thick earthen walls rest on one side on the front walls of the buildings, and on the other side on poles, sometimes not dug into the earth but merely set on it. In strong seismic shocks these unstable roofs are the first in such buildings to crumble (8).

I shall take this opportunity to mention that until the present time standards of antiseismic kolkhoz construction were not studied and were not worked out (35). It is obviously necessary to develop these standards, taking into account local construction possibilities and the customs of local inhabitants. These standards should then be introduced in the various epicentral zones which we have noted, if not as obligatory at least in the form of recommendations. Specifically, these standards should first of all be introduced, as already mentioned, in places of high and medium seismic activity,

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particularly in the rural soviets sel'sovets of Yakhakpast (Garm Rayon), Argankul' and Mionadu (Sangvor Rayon), and the sel'sovet of Sayat (Tavil'dara Rayon), and also in the valley of the river Surkhob. In building up population points, they should be located far from earth-covered mountain slopes in order that in earthquakes they should not be in the path of landslides (13, 5).

Development of inexpensive and simple methods of village anti-seismic construction and the introduction of these methods of construction in the places which we have mentioned will make possible reduction in the destructive effects of the strong earthquakes which often take place in the territory of Garm Oblast. In view of the ease with which modern tectonic movements and seismic phenomena may be observed in the territory of Garm Oblast it is possible to solve successfully within its boundaries many general problems of seismology, particularly the problem of the mechanics of the occurrence of earthquakes. (Editor's Note: After this article went to press and had been set in type, a nine-point earthquake with radius of 8-point shock 6 to 7 kilometers from the epicenter occurred in 1949 along the valley of the river Surkhob, based between the settlements of Khait, Kalaylyabiob, and Dzhirgatal', i.e. in the above-noted (p. 47 and Fig. 16) epicentral zone, located by the author with the seismotectonic method.)

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APPENDIX I [hand drawn copies of figures 8, 13, 14, 15.]*

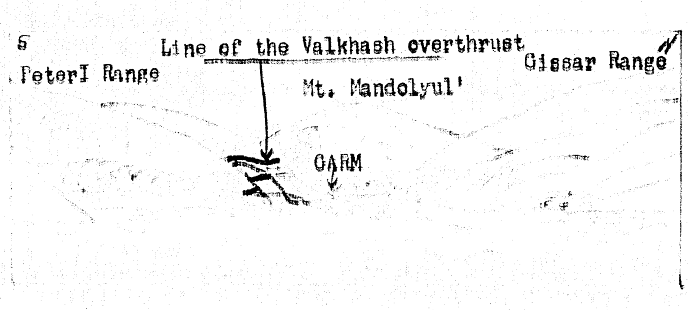

Figure 8.

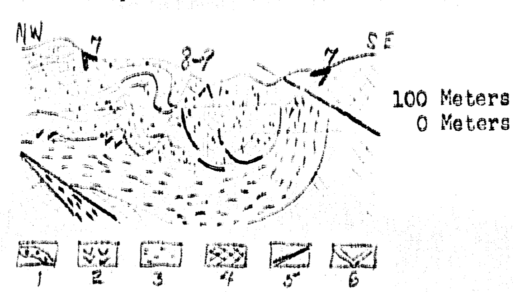

Figure 13.

*[Note: See Appendix II for thermoprint copies of all the figures.]

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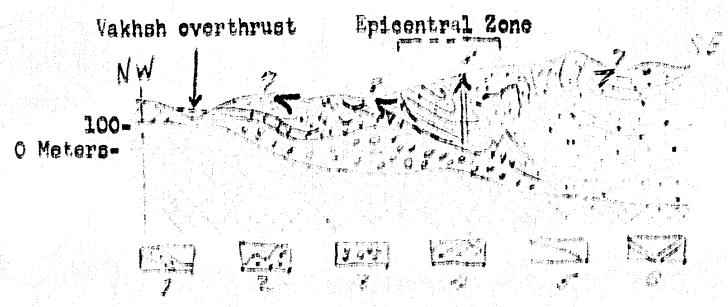

Figure 14.

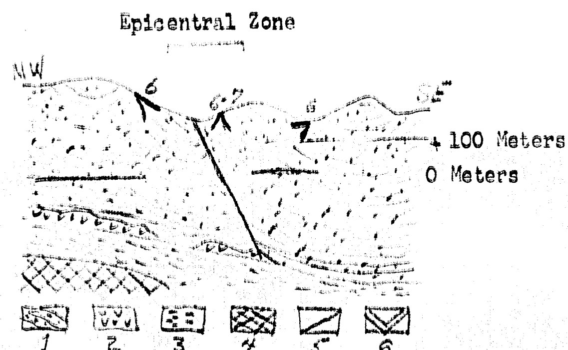

Figure 15

[END OF APPENDIX I]

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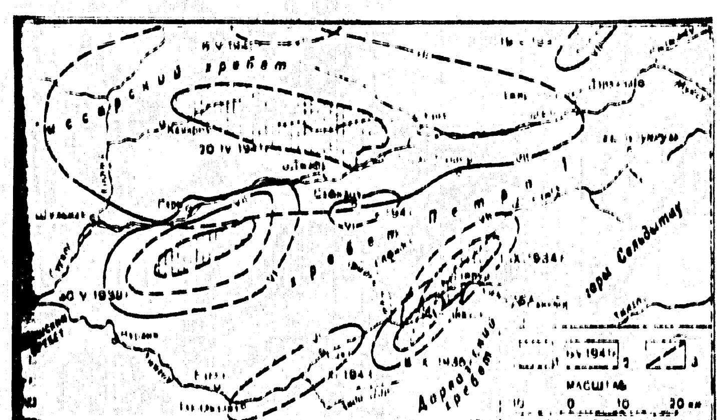

Фиг. 4. Схематическая карта разрушительных землетрясений, возникших на территории Гармской области [illegible] 1947 г.

Составил И. Е. Губин в 1947 г.

[illegible]

-A-

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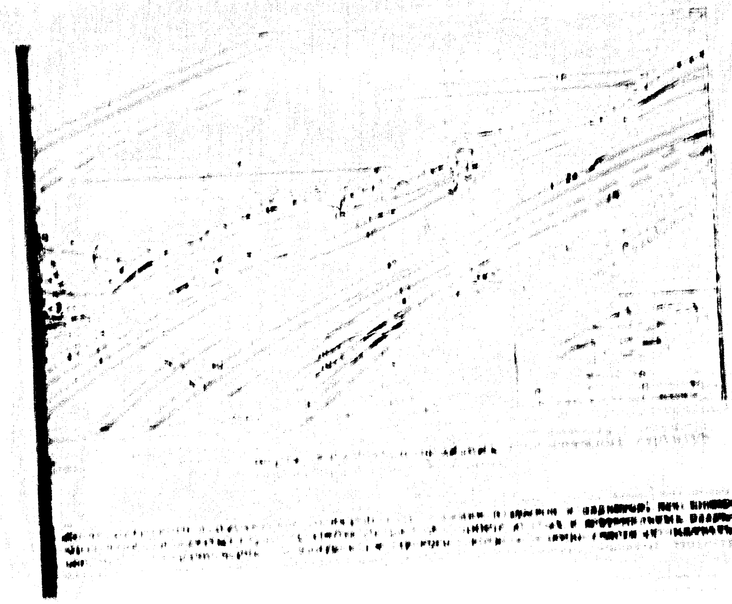

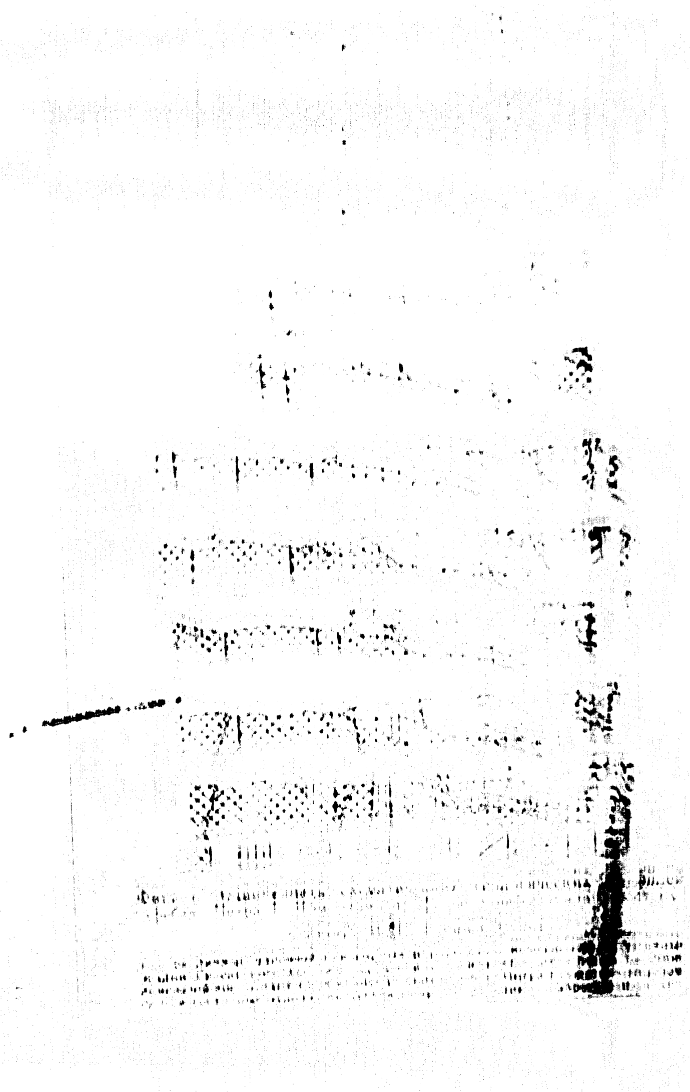

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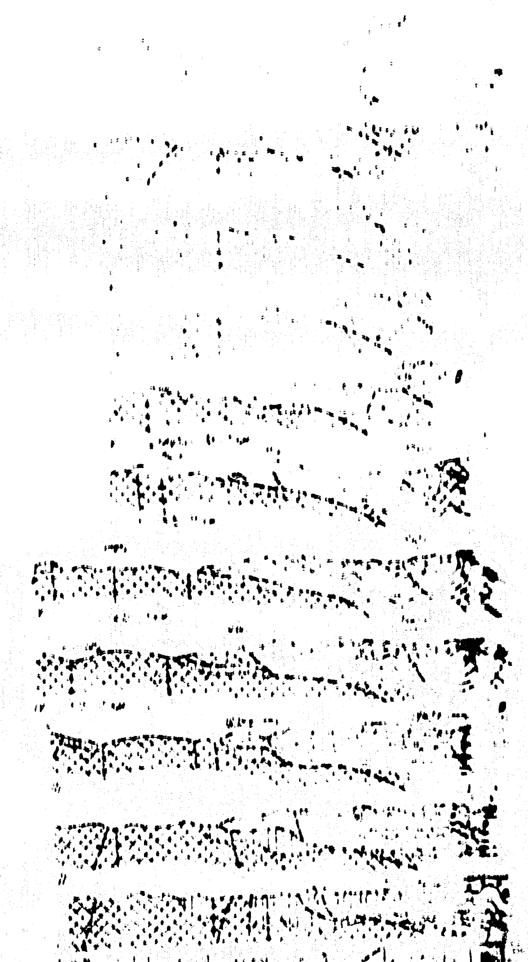
Фиг. [illegible] ...матическая [illegible] альпийских геологических структур территории [illegible] области

Составил [illegible] в 195[illegible] г.

[illegible]



Фиг. 6. [illegible] хребта Петра I [illegible]

Составил Н.П. [illegible]

[illegible]

-B-

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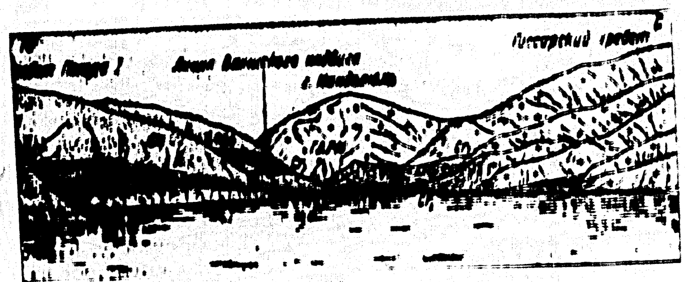
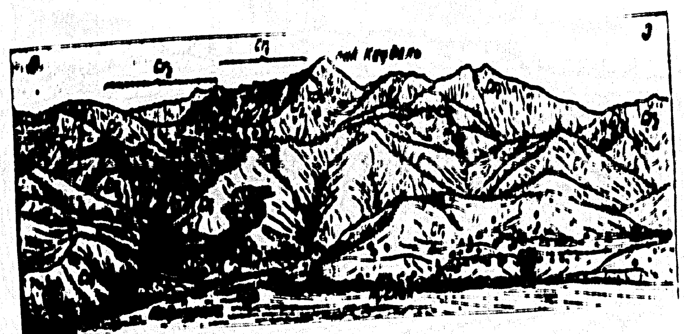




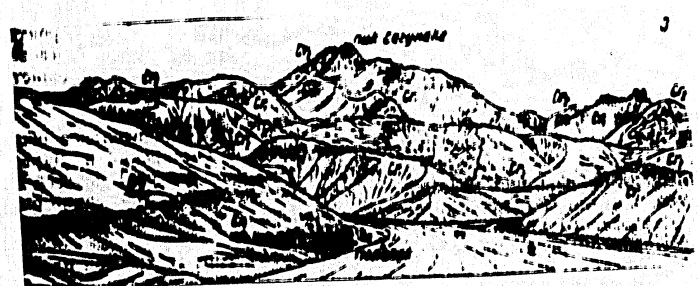
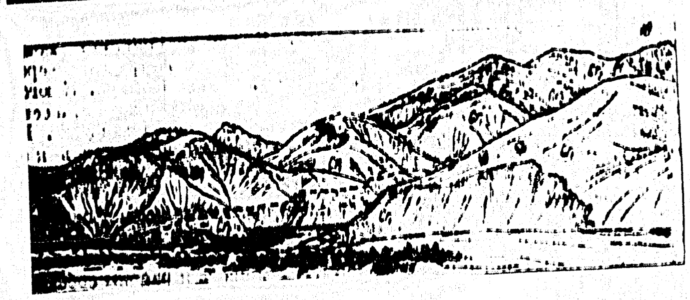


Fig. 11.



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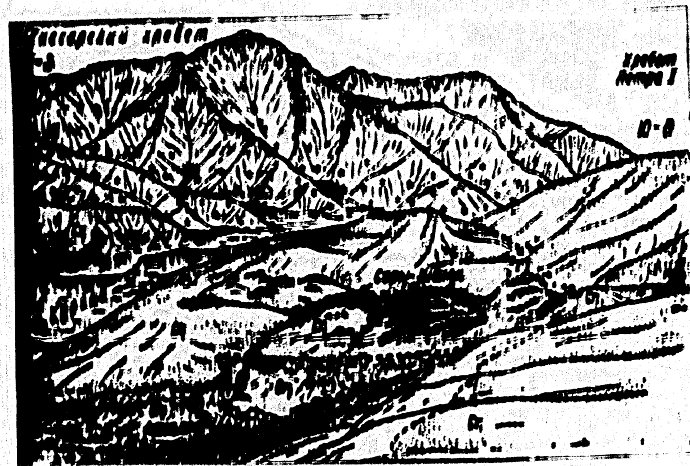

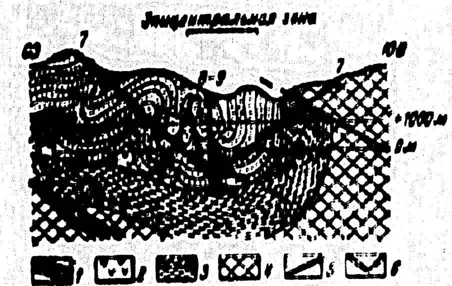

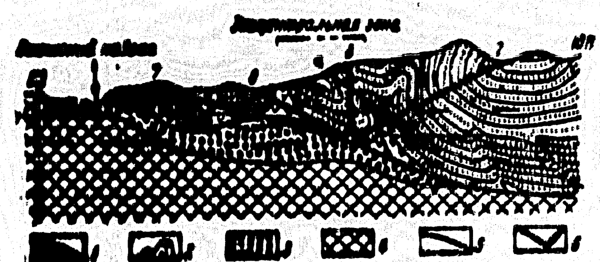

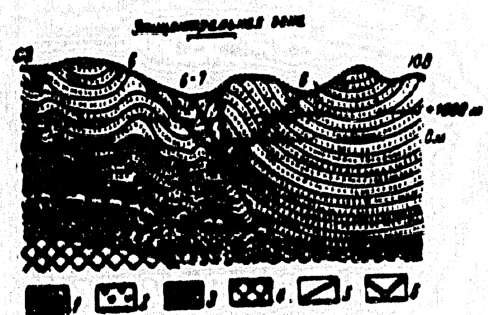

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[END OF APPENDIX II]

— E —

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