GEOLOGICAL-GEOMORPHOLOGICAL STUDY OF MODERN TECTONIC MOVEMENTS

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ABSTRACT

In studying, and especially in interpreting, modern movements of the Earth's crust, one should take into account its tectonic variability, its layering and the deformations exposed at the Earth's surface, which reflect the evolution of deep processes. No less important is the solution of the opposite problem, i.e., the study of deep tectonic processes, using data on modern movements of the surface. In both cases, analysis of the distribution of types of movement and regions along (active) faults is essential. Active faults in Asia between 20° and 60°N are taken as examples.

Time and again, various authors have correlated instrumental data on modern movements of the Earth's crust, or rather the Earth's surface, with recent Quaternary and Holocene tectonic structures exposed at the surface, and have made it evident that this information is not sufficient for a complete understanding of the essence, general direction, nature and cause of such movements. The literature cites many examples of when instrumented data can be well correlated with young tectonic structures, but there are also quite a few examples where such correlations are impossible, and movements may be complicated and negatively associated with structures.

The relationships of the individual and general features of tectonic movements, as well as their ranking and subordination, are evidently of a crucial importance in the study of modern tectonic movements, their origin, mechanism and space-time peculiarities. This problem is to be clarified further. We can assume that individual movements (recorded instrumentally and limited in space and time) could either reflect certain complex processes (e.g., growth of a tectonic form) directly, or reflect it through a general tendency, having in fact a more complicated evolution and spectrum; alternatively, they may possess a peculiar significance and not be related to other tectonic structures exposed at the surface. Particularly important for

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the solution of the problem are geological-geomorphological methods which, combined with seismological and other geophysical methods, permit us to determine long-term features and the development of tectonic structure throughout the Earth's crust and the upper mantle more precisely. On the whole, the geological-geomorphological investigations of modern tectogenesis consists in identifying and analysing deformations and many other related peculiarities of the Earth's surface (land forms and Holocene deposits). Air and satellite images are indeed of great help in this.

Requiring no space limitations, geological-geomorphological methods are found to be really advantageous. Unlike instrumentally investigated lines and areas, and unlike ancient tectonic structures preserved in fragments, young deformations can be investigated throughout their entire length and are represented in their real spatial relations. If considered on the geological time scale, all Holocene tectonics formations are coeval; however radiocarbon datings, as well as archeological and historical data, enable us to investigate the Holocene tectonics both on the geological and in the real time scale and to demonstrate the complicated and often uneven course of the processes of evolution.

The idea of the application of geological-geomorphological methods to the investigation of modern movements of the Earth's crust is not new. But we consider it necessary to emphasize its significance once again and in this connection to dwell on certain recent results of studies of crustal disturbances in tectonically active regions and on some new aspects of this problem. We shall discuss three interrelated aspects of the geological-geomorphological study of modern tectonic movements:

1. Holocene tectonic deformations and disturbances of the Earth's crust in vast areas of the Alpine-Asian orogenic belt;
2. Deep-seated components of modern tectonic processes, recorded at the surface;
3. Geological-geomorphological criteria for the assessment of seismically dangerous tectonic movements.

There is sufficient evidence to show that modern deformations of the Earth's crust are, in fact, recorded everywhere. However, it is only within mobile belts and within present-day orogenic regions that high velocities and high gradients of the vertical and horizontal components of tectonic movements lead to the appearance and active development of faults. We have used the latter as a very important and easy way to study characteristic features of modern movements of the Earth's crust for the purpose of evaluating spatial features and the nature of modern tectogenesis in the vast European continent.

A map of active faults in the USSR and adjacent areas was prepared at a scale of 1:8,000,000 (authors: A.I. Kozhurin, N.V. Lukina, V.I. Makarov and V.G. Trifonov of the Geological Institute of the USSR Academy of Sciences; K.G. Levi and S.I. Sherman of the Institute of the Earth's Crust of the Siberian branch of the USSR Academy of Sciences; and S.S. Shults of VSEGEI). The map shows major faults that enable the authors and other researchers to

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follow traces of Holocene movements. In addition to ground observations, air-borne and satellite photos were used to map such faults, which are grouped according to morphological types. In addition, the map shows modern and Holocene volcanoes, indicates the Earth's crustal thickness, and epicentres of strong earthquakes since 1900, arranged according to magnitude and focal depth. Using this map and data by C. Allen, M. Berberjan, N. Wellman, Ding Guyoyu, N. Pavoni and K. Khuzit, V.G. Trifonov later on made a map of active faults in Asia between 20° and 60°N (figure 1).

Both the above-mentioned maps confirmed previous conclusions and hypotheses about the predominance of horizontal displacements over vertical ones, about the rapprochement between the Arabian and Hindustan peninsulas and the more northern areas of Eurasia and, as a consequence, the separation of mountanous massifs of Anatolia, the Islamic Republic of Iran, Afghanistan, the Tadzhik Depression, Tibet and west China from areas of maximal collision and merging.1/ Besides the Earth's crust, active deformations involve not only boundaries of lithospheric plates and blocks, but also embrace mobile belts, hundreds of kilometres wide. In the Pamir-Himalayas region, for example, the area of intense Holocene disturbances is commensurable with the rather poorly deformed part of the Hindustan subcontinent. In central and eastern Asia, the belt of recent deformations grows wider. The kinematics of numerous diversely directed faults which conforms (and this is quite natural) to late Quaternary and Holocene folded deformations and warping of the Earth's crust, could be more correctly regarded as evidence of the deformation of extensive lithospheric masses, and not as a result of the interaction between a limited number of rigid plates and microplates.

Nowadays, most active faults in Asia stretch along boundaries between ranges and intermontane and piedmont depressions and vertical displacements, of overthrust, upthrow and normal fault-types must be recorded along such marginal faults. In addition to these, strike-slip faults are found along the majority of faults, which commonly surpass vertical displacements of coeval formations, often being many times as large. Average velocities of Holocene strike-slips are measured in millimetres and often exceed 1 cm per year.

Areas with a predominant distribution of longitudinal left and right displacements can be distinguished. So right strike-slip faults dominate in the area extending from North Tyan-Shan up to Mongolian Altai and on the eastern margin of the Asian continent Kamchatka to East China; a left strike-slip fault recorded in the south China belt changes its strike from east-north-east near the Altyntag fault to north-west near the Ksyanshuj and Ksyaochan faults. The trend of strike-slip faults of similar type changes considerably in other belts as well.

Dislocations along longitudinal active margins, expressed mostly in strike-slip faults, are typical for island arcs and active margins of the Pacific, but not without exceptions.2/ Strike-slip faults are found only in areas with a granite metamorphic layer; in structures with oceanic transitional crust, they give way to distrubances of a different kind. Moreover, the location of hypocentres and the focal mechanisms of earthquakes show that the right-lateral median line of Japan goes no deeper than 15-20 km;

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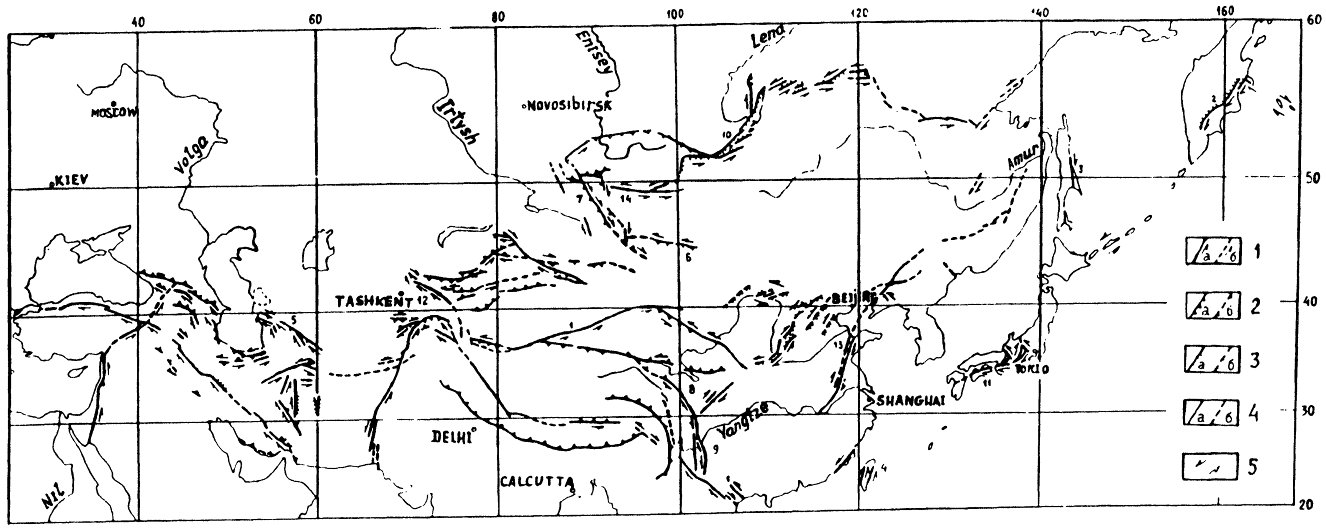

Faults in Asia between 20° and 60° N, active in the Holocene. Prepared by V. G. Trifonov on the basis of published data by C. Allen, M. Berberjan, N. Wellman, Ding Guoyu, A. Kozhurin, G. Levi, N. Lukina, V. Makarov, A. Nikonov, N. Pavoni, K. Khusit, S. Sherman, S. Shults and personal observations. Active faults are shown on the map by figures: 1) Altyntag, 2) East Sakhalin, 3) Eastern face of the Central Kamchatka depression, 4) Main Himalayan boundary, 5) Shansi graben, 6) Darvaz-Alay, 7) Dzhungar, 8) Kobdin, 9) Ksyanshuy, 10) Ksyaochan, 11) Primorsky of Baikal, 12) North Tyan Shan, 13) Median line of Japan, 14) Talas-Fergana, 15) Khangay.

Figure 1

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lower, at a depth of about 30 km, a structure of a different direction and of another kinematic type was found in the same region. Strike-slip faults obviously dominate in the upper part of the continental crust. Here they play a much more significant role than was previously considered to be the case.

As compared with the areas with strike-slip faults, those areas with dominating fold-overthrust Holocene disturbances (like the outer zone of the Pamirs and Himalayas) or active strike-slips -- separating faults (like the Baikal depression or Shansi graben), are rather small, indicating a limited structure-forming power of rapprochement and separation of uppermost crustal sheets. These sheets, being disrupted by numerous faults, may not convey structure-forming powers to large distances, and strike-slip faults do not seem to be a result of such interactions; rather they reflect movements of deeper lithospheric masses. The latter suggests that deformation properties, tectonic styles and movement velocities are different at different lithospheric levels, i.e., here we are dealing with tectonic layering and this should necessarily be kept in mind if one is dealing with modern movements of the Earth's crust and particularly with structural interpretations of instrumental observation data and the preparation of corresponding forecasts.

It is generally known that in many cases an instrumentally established picture of movements of the Earth's crust corresponds better to the structure of geophysical fields which characterize deep-seated layers of the lithosphere than to the near-surface geological structure. A similar tendency has long been familiar to geomorphologists, who also investigate space-time relationships and other aspects of the development of crustal landforms.

Some time ago, in analysing the nature of lineaments recorded in satellite pictures of the Earth's surface, but without marked structural, lithological or other geological features being observed, we came to the conclusion that many such lineaments reflect active (including seismoactive) elements of the structure of the deep layers of the Earth's crust and upper mantle.5/ Subsequent investigations carried out by us and by other authors gave sufficient evidence in favour of this conclusion and allowed us to define various geological, structural-tectonic, geomorphological, landscape and other features of the Earth's surface which, if taken together, make up such lineaments and other similar formations, which we generally regard as concealed deep structures.4/ 5/

On the whole, it is obvious that here we have rather widely spread manifestations on the Earth's surface of deformations and other processes which take place in deep layers of the lithsphere and whose type, nature, morphology and trend are not repeated in near-surface formations. This phenomenon requires particular attention. On the Earth's surface, such deformations are characterized by considerable width and small gradients of change of various characteristics. This refers particularly to young Holocene forms which are of special interest to us at present. The fact is that during so short a period of time as the Holocene, the deposits have not accumulated considerable changes in composition, thickness, position or other features. That is why these changes are often missed during land observations and are not kept in mind during interpretations which are usually done on the basis of the near-surface structure. Particular attention should be paid to active forms of such kinds which do not conform to the near-surface structure.

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A comparative analysis of the activity and ways of expression of active structures in different lithospheric layers that we made, using geophysical and seismic data for many areas of the Alpine-Asian mobile belt, has made evident the structural-dynamic and kinematic variety of the lithosphere.6/ There is every reason to suggest that the morphology, kinematics, direction and velocity of modern deformations are different at various lithospheric levels. This leads to the appearance of compensatory decollements and other transformations along some more or less extended subhorizontal zones, i.e., to tectonic layering of the lithosphere (figure 2). This latter can easily be augmented by spacial distributions of seismic phenomena in a section of the lithosphere and by corresponding changes of their characteristics or the characteristics of the environment in which an earthquake begins.6/

Modern deformations of the Earth's surface reflect the processes going on deep in the lithosphere. Thus, in studying modern movements of the Earth's crust it is necessary to take into account and to investigate these processes in order to interpret the data obtained from instrumental observations correctly. In this respect, the most effective methods of analysis of deep-seated tectonics are: correlation of structural-geomorphological and geophysical data, space-time analysis of earthquake focal distributions and of their mechanisms and peculiarities, study of heat and geochemical anomalies, and analysis of air-borne satellite data.

The aspects of the geological-geomorphological study of modern movements of the Earth's crust mentioned are extremely important for working out criteria for identifying places of strongest earthquakes. This work includes the following geological and geomorphological investigations:

1. Study of neotectonic structures as a whole and the tendencies of their evolution and reconstructions, with a view to identiying areas of the highest Late-Quaternary and modern activity;
2. Mapping of areas of possible Late-Quaternary activity of systems of active tectonic disturbances and deformations of the Earth's surface that appeared and were rejuvenated in the Holocene;
3. Within active systems and zones, the definition of areas of possible strong earthquakes by discovering traces of past earthquakes and places of possible concentrations of tectonic strain in vast mountain masses.

The last point needs some explanation. Tectonic movements in active zones may find their expression either in strong impulses, or in creep and relatively weak impulses. High tectonic activity is an indispensable condition for strong earthquakes, but alone it is not sufficient. There should exist, in addition, conditions for quite long concentrations of strain in an extensive volume of rocks. Such a possibility may be defined in two ways.

The first one is based on the study of paleo-seismodislocations -- traces of disturbances of the Earth's surface, occurring due to previous strong earthquakes, prehistoric and Holocene ones included.

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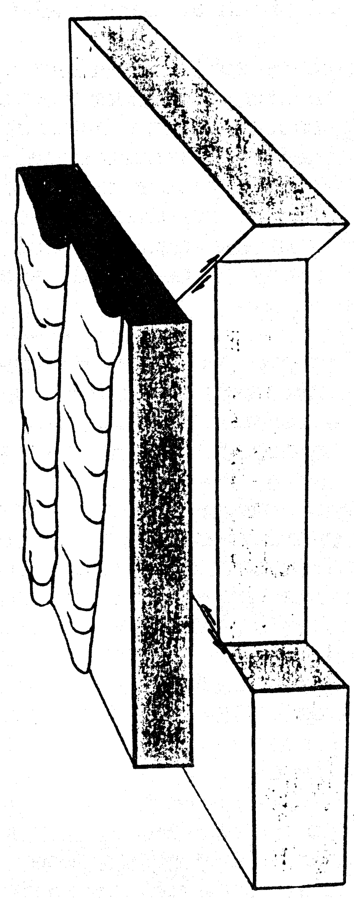

Scheme of variably deformed area

Figure 2

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This method enables us to determine the average recurrence period of strong earthquakes in any section of the active zone; the latter cannot be done with instrumental observations because they are short-term. Besides, it is also possible to predict the force of possible seismic impacts, due to the fact that different types and complexes of seismodislocations take place under different tremor intensities. The works by V.P. Solonenko and other seismotectonists of the Irkutsk school who have been involved in investigations of various areas of South Siberia, as well as the works by V.K. Kuchay and A.A. Nikonov, who mainly used data from Central Asia have considerably advanced the study of paleo-seismodislocations of seismo-gravitational type. To identify traces of seismic impulses in strike-slip faults along most active faults is found to be very difficult. One of the authors of this article has elaborated a method of such analysis of active faults.1/ 7/ 8/ It is based on material from Mongolia, central Asia and the best of the United States. Numerous measurements of strike-slips of non-coeval landforms and deposits were made and the ages of sediments accumulated in the process of such movements were determined for this purpose (figures 3, 4).

However, this method has space limitations due to insufficient conservability or due to the absence of seismodislocations. For this reason, we have to use indirect methods to discover zones and areas of high concentrations of tectonic strain in vast volumes of the Earth's crust. Among these methods are: the definition of the morphological and kinematic characteristics of Holocene disturbances and the clarification of the conditions of origin and most possible mechanisms of the foci of strong earthquakes. No less important is the study of the geological structure of active zones (their structure, substance, composition, degree and nature of dislocation, and other properties which determine the strength of rock masses). And finally, a very important element of such an analysis is the study of the deep-seated tectonics of active zones and identifying areas of possible tectonic strain concentration. Discovering active structures concealed at a certain depth is of particular importance; their morphology, orientation and other parameters are different from the structures of the near-surface layer, in such a way, the nature of the 1976 and 1984 Gazliy catastrophic earthquakes in central Kyzyl Kum was investigated (figures 5, 6).9/ 10/

Thus, the application of geological-geomorphological methods for the study of modern tectonic movements of the Earth's crust is necessary to obtain a more complete picture of their activity and of their relation with tectonic structures, and for a more correct practical application. In view of this, the careful study of Holocene tectonics as a whole is necessary as well as Holocene deformations and the régime of their develoment. It would seem useful to start the preparation of a map showing the active faults of the World which could present a complete picture of modern movements of the Earth's crust.

In studying, and particularly in interpreting, modern movements of the Earth's crust, one should keep in mind tectonic layering of lithosphere, and the specific forms by which the deformations reflecting the evolution of deep-seated processes are represented on the Earth's surface. No less

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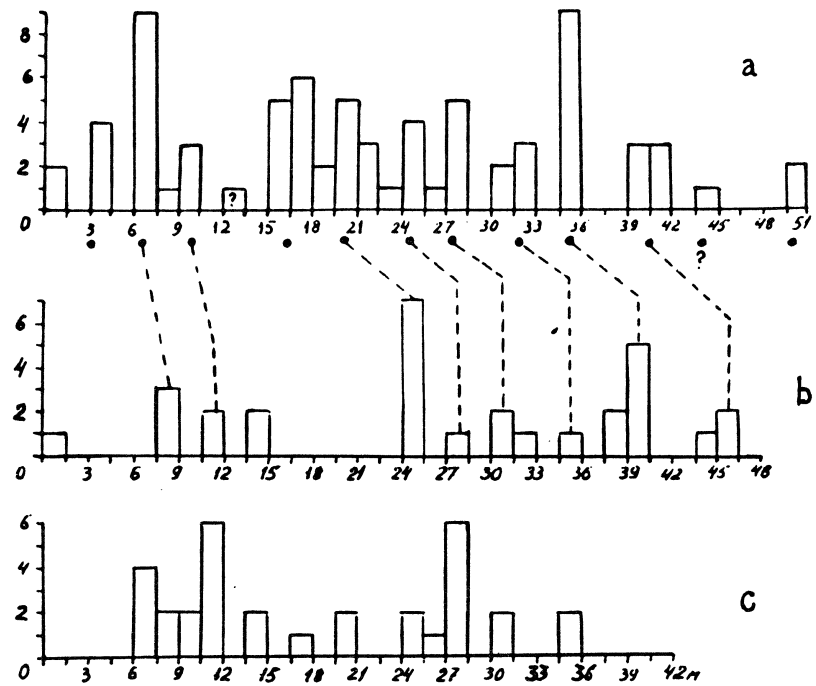

Histogram of the distribution of amplitudes of Holocene right strike-slip faults, of water flows and other minor landforms along the Talas-Fergana fault (Tyan Shan): a) from Kokkia pass to upper reaches of the Pychan river (thick points — possible traces of strong earthquakes); b) from the upper reaches of the Pychan river to Kylkow valley; c) in the Kuroves and Keklikbel river basins.

Figure 3

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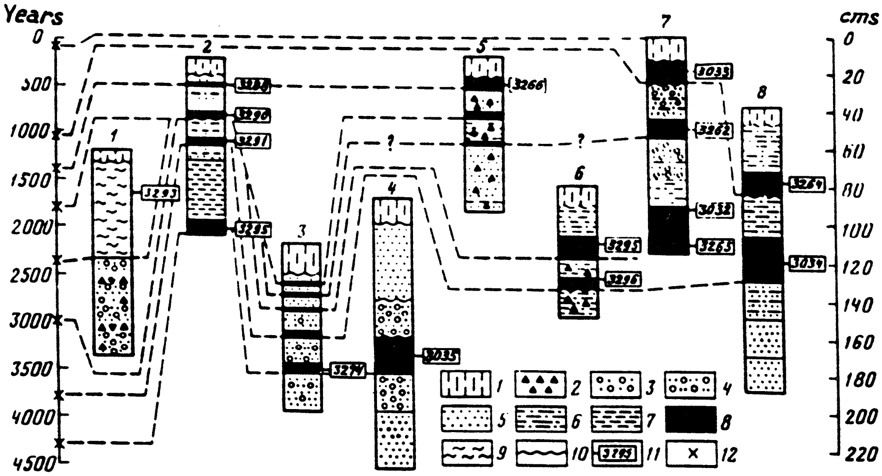

Comparison of sections of Holocene deposits of small impounding lakes and enclosed depressions of the Khangay fault zone (North Mongolia): 1) soil layer; 2) pebbles; 3) gravels; 4) course-grained sand; 5) middle and fine-grained sand; 6) sandy loam; 7) loam and clay; 8) loam and clay, rarer – sandy loam, enriched in organic matter; 9) peat bog; 10) erosion surface; 11) radiocarbon datings of the age of deposits, by L. D. Sulerzhitsky in the Geological Institute of the USSR Academy of Sciences in 1982. (3032 = 2690 ± 110 years; 3033 = 1090 ± 50 years; 3034 = 3720 ± 160 years; 3035 = 4280 ± 250 years) and 1983 (3262 = 1300 ± 80 years; 3264 = 920 ± 60 years; 3265 = 2900 ± 90 years; 3266 = 1300 ± 250 years; 3274 = 4210 ± 80 years; 3288 = 1400 ± 100 years; 3290 = 1780 ± 200 years; 3291 = 3870 ± 180 years; 3293 = 2360 ± 100 years; 3295 = 4340 ± 20 years; 3298 = 3280 ± 180 years; 3297 = 2950 ± 150 years); 12) proposed sites of catastrophic earthquakes in the time scale.

Figure 4

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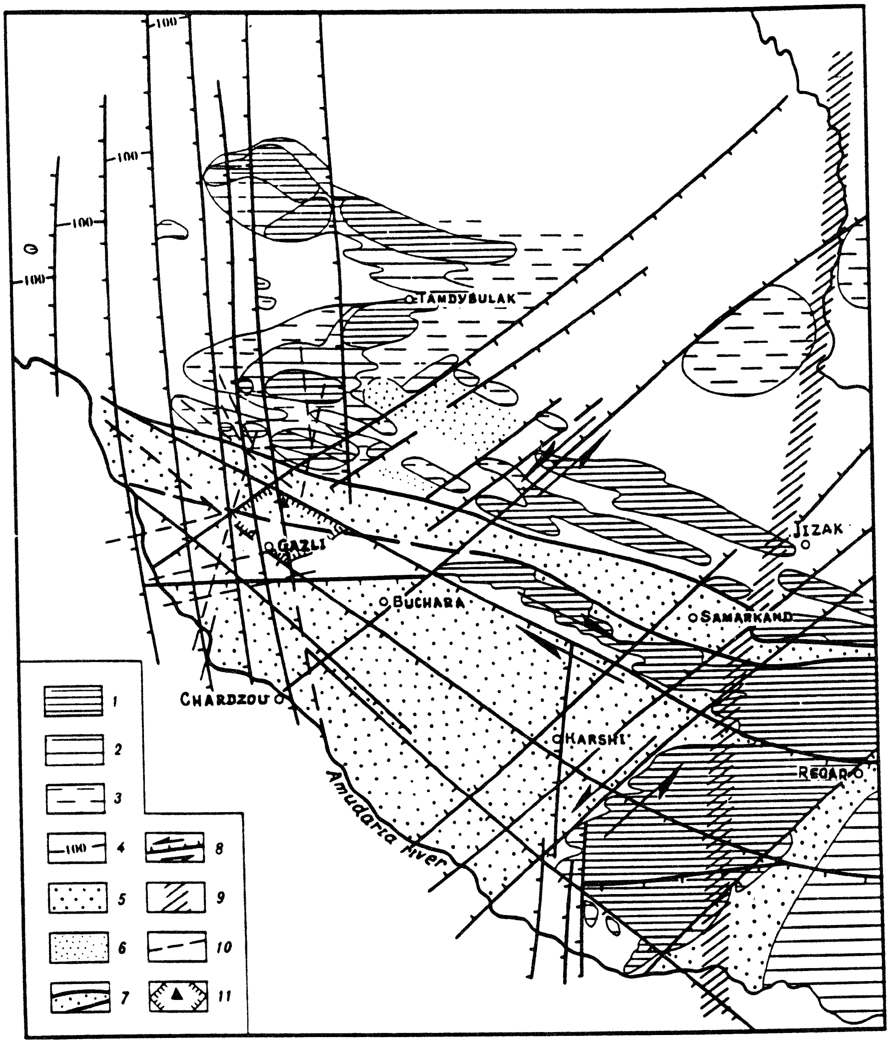

Scheme of present-day arrangement of deep-seated structures in Central Kyzyl-Kum (according to Makarov *et. al.*, 1984): 1–3) anticline uplifts (basement folds), their zones and systems (Central Kyzyl Kum uplifts are distinguished according to the degree of relative upwarming of the fold basement); 4) position of 100 m contour line of the Earth's surface in the area between Amu Darya and Syr Darya; 5) zones of most active downwarping and of accumulation of Neogene-Quaternary deposits; 6) deepest depressions within Kuldzhuktau-Nuratau system of uplifts; 7) general contouring of the Zeravshan synclinal zone; 8) zones of flexure faults of concealed type (striations are directed to the lowered limbs, pointers indicate the direction of possible dislocations along these zones); 9) Turkestan-Akchay lineament (zone of concealed deep disturbances of the Earth's crust); 10) faults proposed on the basis of the results of analysis of satellite pictures; 11) contour of seismoactive block and seismostation Karakyr.

Figure 5

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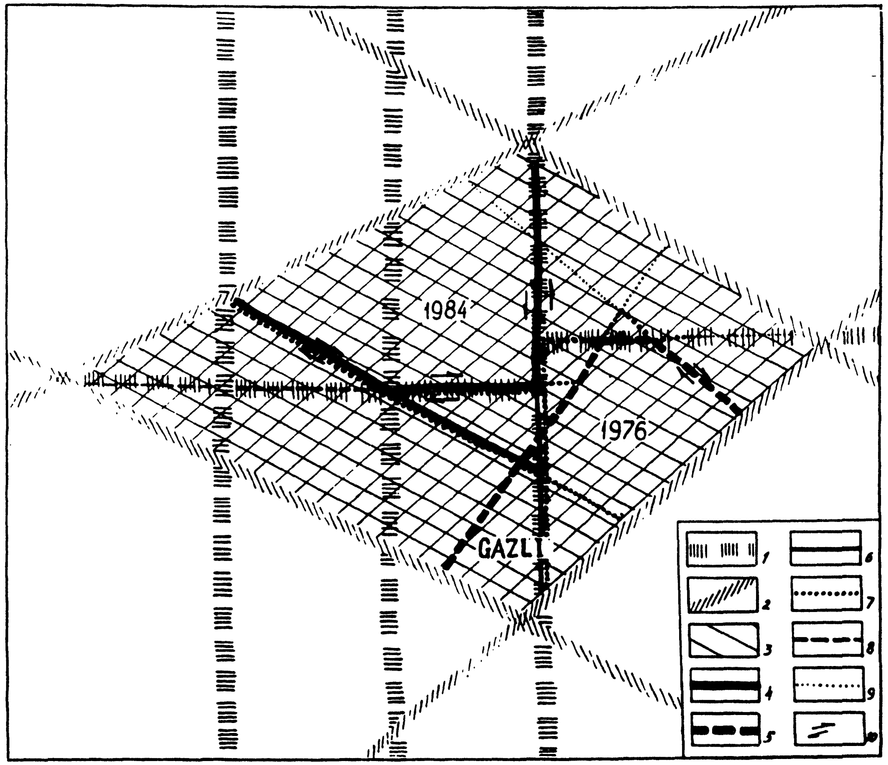

Scheme of active lineaments and of principal seismic dislocations of the region of the 1976 and 1984 Gazliy earthquakes. 1–2) major lineaments of orthogonal (1) and diagonal (2) orientations; 3) Earth's crust block marked by major seismic dislocations of 1974–1984; 4–5) mean lines of possible seismic dislocations of 1984 (4) and 1976 (5); 6–7) additional lines of possible seismic dislocations of 1984 (6) and 1976 (7); 8–9) directions of possible occurrence of weak dislocations of 1984 (8) and 1976 (9); 10) proposed directons of possible strike-slip faults according to geological evidence.

Figure 6

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important is the application of data on modern movements of the Earth's crust for studies of its deep-seated structure. This aspect of the investigations evidently needs to be further elaborated. For a better understanding of modern geodynamics and the processes taking place in deep lithospheric horizons, extensive work is needed on measuring modern deformations of the lithosphere along elongated transregional profiles.

NOTES

1/ Trifonov, V.G., Late Quaternary Tectonics, Nauka, Moscow, 1983.

2/ Kozhurin, A.I. and Trifonov, V.G.,. "Young Strike-Slip Faults of the Pacific Margin", Geotectonics, vol. 16, No. 2, (1983) pp. 93-104.

3/ Makarov, V.I., Trifonov, V.G. and Shchukin, Yu. K., "Images of Fold Belts Deep Structure on Satellite Pictures", Geotectonics, 3, (1974), pp. 114-132.

4/ Space Information for Geology, (Nauka, Moscow, 1983).

5/ Makarov, V.I., "Active Deep-Seated Deformations and Lithosphere Seismicity of Neotectonic Active Belts". Major Seismotectonic Problems. (Nauka, Moscow, 1986), pp. 36-39.

6/ Makarov, V.I., Trifonov, V.G. Shchukin, Yu. K., Kuchay, V.K. and Kulagin, V.K. Tectonic Layering of the Lithosphere of Neotectonic Active Belts. (Nauka, Moscow, 1982).

7/ Trifonov. V.G., "Active faults and Seismicity", In Present-day Tectonic Activity of the Territory of the USSR, (Nauka, Moscow, 1984), pp. 24-34.

8/ Trifonov, V.G., "Peculiarities of the Development of Active Faults", Geotectonics, 2, (1985), pp. 16-26.

9/ Makarov, V.I. and Shchukin, Yu. K., "Assessment of the Activity of Concealed Faults", Geotectonics, vol. 13, No. 1, (1980), pp. 65-73.

10/ Makarov, V.I., Lukina, N.V. and Shchukin, Yu. K., "Investigation of Residual Deformations of the Earth's Surface in an Epicentral Zone. Geologo-Tectonic Characteristics of the Central Kyzylkum: Gazliy Earthquakes", Geologo-Geophysical Nature of Foci., (Nauka, Moscow, 1984), pp. 106-130.

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