

THE EVOLUTIONARY GEOLOGY OF THE FORMATION OF THE FERGANA DEPRESSION AS A RESULT OF THE MOVEMENT OF THE MIDDLE AND SOUTHERN TIEN-SHAN (UZBEKISTAN)

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ABSTRACT

This article deals with the history of the geological development and paleotectonic reconstructions of the Fergana Depression, which occurred as a result of the middle and southern Tien-Shan movement. Using the geological and geophysical profiles of the Fergana depression, a geodynamic model of the crust structure of the Middle and Southern Tien-Shan and the Fergana depression was built according to the catalog of earthquakes that recorded in between 1978-2023.

Keywords: *Earthquake, Fergana basin, Magnitude, Fault, GPS, Tien-Shan*

INTRODUCTION

The formation of the Middle and Southern Tien-Shan region or active blocks is limited by the active intra-continental Alpine-Himalayan compression region of the Fergana intermountain depression, and the Fergana depression is described as an ancient intercontinental-orogenic basin. In its geological development in the Meso-Cenozoic era, the Fergana depression passed two tectonic stages: platform and orogenic. The study of the geological structure and history of geological development of the seismically active Fergana basin is directly based on geological profiles, block diagrams, and paleotectonic reconstructions of the Fergana basin.

The Middle Tien-Shan Hertzian volcanic-plutonic belt developed on the Baikal Caledonian accretionary complex. The volcanic-plutonic belt is divided into 3 layers. The lower layer (S_2 - D_{1-2}) is composed of I-granitoids and the Lower Devonian terrigenous-volcanogenic (andesites, dacites, liparites, alkaline basalts) formations. The middle layer (C_1 - C_3) consists mainly of I-granites (montsonite-granite, montsodiorite-granodiorite, granite-adamellite, gabbro-syenite complexes), rhyolite, dacite, trachybasalt, trachyandesite lava and tuff. The upper level complexes include trachybasalt-trachyriolite series of volcanics and gabbro-syenite and granite-granosienite complexes (Mirkamalov R.Kh, 2018).

The border of the Southern Tien-Shan fold belt (Turkistan Paleo-Ommanian suture) with the Middle Tien-Shan is traced by the upper baric metamorphic shales of the Majerum, Kumbulok, Uzhuduk suites and Konsoy series of allochthonous structures, mostly buried under the Permian molasses, in the north of this belt. Belt formations are exposed in Molguzar, Nurota and Turkestan ridges, Kyzylkum highlands and Sultan-Uvais. Along their southern border, the Katarmai suture serves.

The main feature of this belt is that three blocks with different three-layer structure were formed by the late Hertzian thrusting processes: the Caledonian base, the olistostrome Herzian carbonate shell in the upper part of the section, and the Herzian tectonic covering of the ophiolite and island arc products, the blocks are separated by the Aktau-Molguzar and Galvanian thrusts.

The main nadvig separating the last two blocks is observed in tectonic windows in the form of melange layers. Kokpatas antiform in the region carbonate formation (D - C_2) emerges from the base of silicon-carbonate bluepatas suite (R_3) superimposed on the surface of the earth (Mirkamalov R.Kh, 2018). (Fig. 1).

The thickness of the sedimentary layer reaches 10 km in some places. It is represented by strong horizons that reach the maximum thickness in the central part of the Fergana basin (Mordvintsev D.O, 2020). Pre-Mesozoic thicknesses have a clear layer-block structure, while the thickness of individual layers is very

small - about 1.5-2 km. The thickness of the blocks in the lower part of the section is 4-5 km, and in some models it is more than that. On average, the density of the sediment layer represented by Cenozoic and

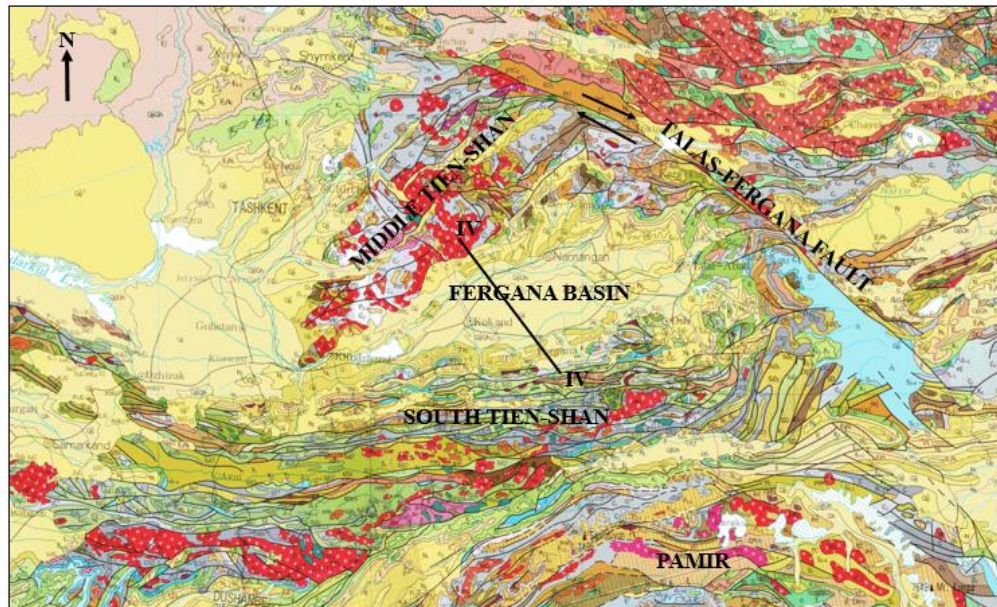


Figure 1. Map of geological structure of Middle and South Tien-Shan region (Uzbekistan).

Mesozoic rocks varies from 2.22 g/cm³ in the upper part of the section to 2.65 g/cm³ in the lower part (Mordvintsev D.O, 2020). The density of the Cenozoic sections is 2.35-2.49 g/cm³, while the Mesozoic layers have a density of 2.55-2.65 g/cm³. The density of Paleozoic rocks is 2.67-2.72 g/cm³ and remains within these limits in almost all models. The lower, strongest part consists of large blocks with a density of 2.79 to 3 g/cm³ (Mordvintsev D.O, 2020). On average, the density of upper crust rocks is 2.85-2.9 g/cm³. In addition, all sections contain decompressed blocks with a density of 2.5-2.56 g/cm³ in one way or another, which we characterize as probably acidic intrusives (Fig. 2) (Mordvintsev D.O, 2020).

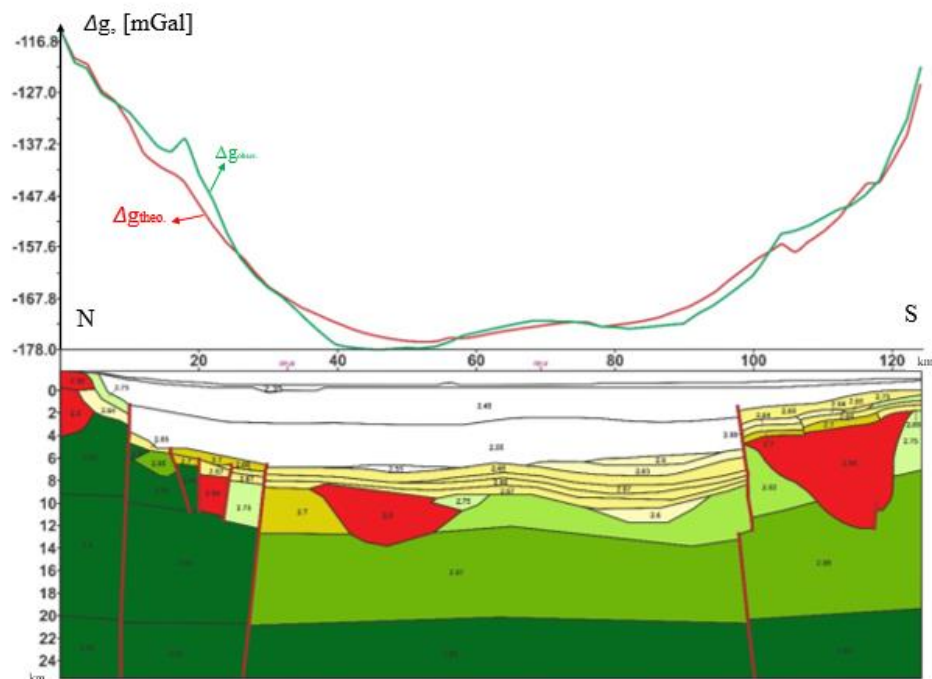


Figure 2. The geological-geophysical cross-section of the upper part of the crust of the Fargona botik was taken according to the IV-IV profile (Mordvintsev D.O. 2018).

According to the obtained data, the internal structure of the density models of the geological sections of Fergana basins can be divided into three parts, including: the decompressed sedimentary layer, the pre-Mesozoic horizon and the lower layer consisting of dense blocks. Later, as a result of seismological survey conducted in order to identify hydrocarbon deposits in the Fergana depression, the common deep point (CDP) method confirmed that the Mesocenezoic cover has a complex allochthonous structural formation. On the central side of the Fergana depression, Mingbulok hydrocarbon field exposed the upper part of 6000 m of Cretaceous deposits after passing Paleogene deposits. In the Gumkhana structure in the eastern part of the central board, a 5000 m deep borehole reached Paleogene deposits.

Until now, there is no information about drill wells that have exposed Jurassic deposits in the central part of the depression. On the southern and northern sides, it is represented by an uneven geological situation. That is, Paleozoic deposits are exposed in the Kurama and Turkestan mountain ranges at +2000 m absolute altitudes. A large-scale geophysical survey was carried out comparing the southern side of the depression with the northern side using the Seymosurvey method.

Allochthonous Paleogene Bukhara layer on the northern and southern sides of the Paleogene Bukhara floor obtained through the CDP (common deep point method) seismic survey conducted by the South Korean "KNOC operating company" in 2009-2012 in the southeastern part of the Kurama Mountains and in 2011-2014 in the southern parts, have recorded limestones (Fig. 3).

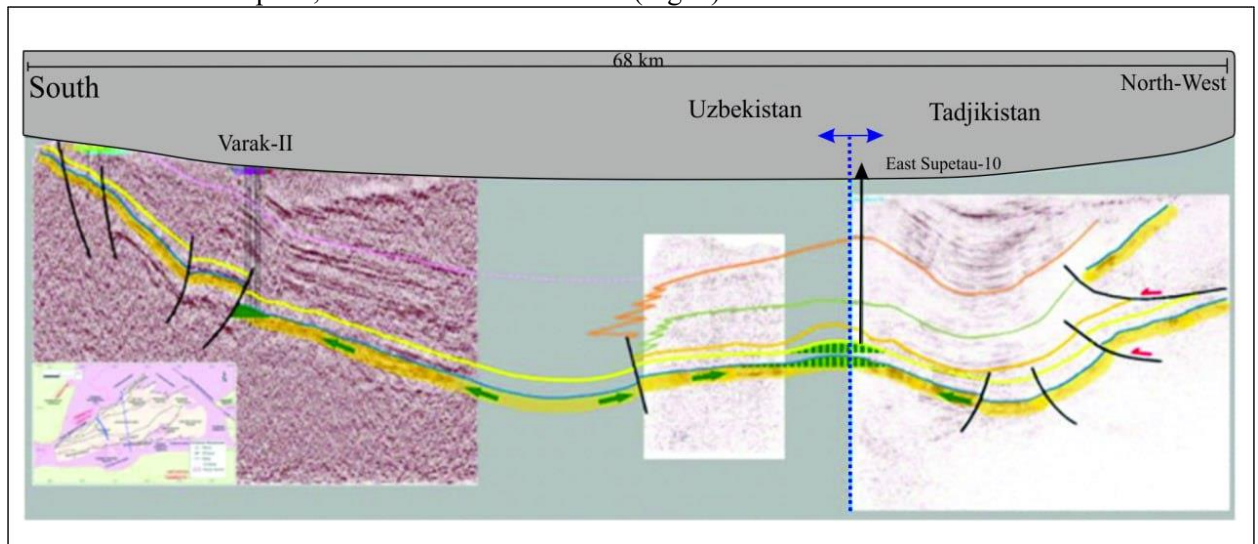


Figure 3. The exaggerated structure of the northern and southern shores of the Fergana basin

In addition, during these studies, a well drilled in the Chust-Pop field on the northern side revealed the Paleogene Bukhara layer at a depth of 5835 m. On the southern side, the Variq-II structure exposed the Paleogene Sumar layer at a depth of 4980 m, while the exploration well in the Variq-I structure, located 10 km southeast of the Variq-II structure, exposed the Paleogene Sumar layer at a depth of 3390 m.

On the basis of 3D seismic survey data, a geodynamic model of the formation of the earth's crust in the Fergana depression was created, and these models also rely on and complement the presented data. In the block diagram in Fig. 2, the data of the Variq-II borehole and the Supetau-10 borehole from the north and the return horizons recorded by the CDP data of this area and the recorded wave phase breaks are reflected in the form of a relatively folded graben.

The analysis of this section, which reflects the depth structure of the Fergana basin, it is possible to come to such a conclusion. The regressive basal horizons associated with the Paleogene deposits are clearly captured, and large variations in the emplacement depth of this boundary are observed. The base horizon of the southern side is located close to the earth's surface, the Paleozoic and Meso-Cenozoic formations in the central part of the depression are located much deeper than the northern and southern parts (Radzhabov Sh.S, Sim T.V, 2018). A series of discontinuous faults and local anticlinal uplifts are observed along both sides. The structure of this area confirms the existence of a double compression, in which the northern flank is taken as the reference horizon. The depth structure of the Meso-Cenozoic layer within this profile allowed us to build a geological model of the development of this region (Fig. 4).

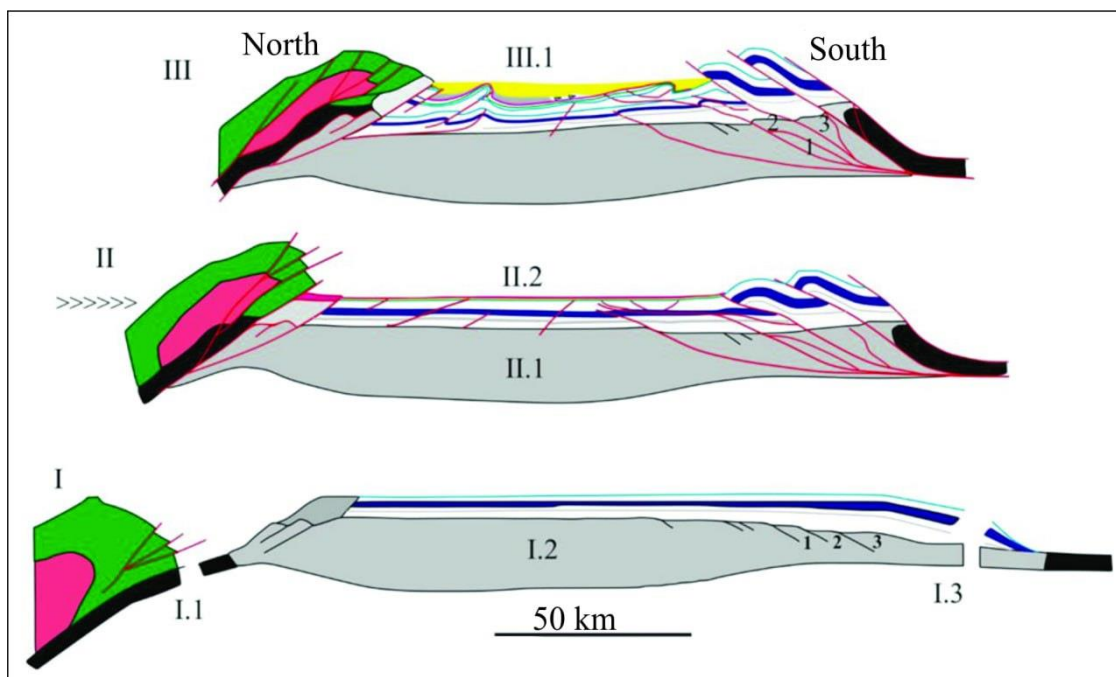


Figure 4 . Geological evolution of crustal formation in the Fergana Basin.

I -Carboniferous Permian, **I.1** -Volcanic arcs, **I.2** -Microcontinent, **I.3** -Passive border of the Carboniferous platform. **II** -Paleogene, Paleozoic compression is more than 100 km, **II.1** -Deformations on the edges of the microcontinent due to compression in the Paleozoic period formed blocks of Paleozoic deformations. Division within the Paleozoic. Silurian clays have changed into tectonic mélange. **III** - New period, P-N compression 7-10 km (within the basin), P-N compression 25 km (ocrain part of the basin), **III.1** - Due to the concentration of deformations, several overthrusts were formed in the deep part of the Northern board and frontal basin.

The platform stage of crustal development began after the end of the Hercynian orogeny and significant erosion of mountain ranges. As a result of the Hercynian folding, the western Tien-Shan and Fergana region represented a relatively dry platform, its relief was complicated by the remains of the opening of the Upper Paleozoic layers; stable peaks and troughs are identified (Akramkhodzhaev A.M., Saydalieva M.S, 1971). At the same time, the intermountain depression of Fergana was formed. By the end of the Permian period, the Fergana depression was part of the Pangea supercontinent. The platform development of the Fergana basin, its deposits and thicknesses, facies changes have been effectively studied as a result of geological and geophysical research (Akramkhodzhaev A.M., Saydalieva M.S, 1971; Kosygin Yu.A, 1952). In general, the stage of platform development lasted from the beginning of the Permian-Triassic period to the Eocene.

The beginning of the Jurassic period is characterized by a decrease in the mode of crustal expansion, and a change from a marine mode of sedimentation to a continental mode . During the Jurassic period, differential tectonic movements took place on the earth's faults, which occurred on the boundaries of folded bases in the Paleozoic, various structural-formational complexes. It is noted that the thickness of the deposits is maximum in the regions where the South and East Fergana depressions were formed. By the end of the Jurassic period, a change of the continental regime of sediment accumulation to a mainly marine and coastal-marine regime occurs. It is during this period that the relative uplift of the area and breaks in sediment accumulation are noted (Akramkhodzhaev A.M., Saydalieva M.S, 1971).

The Cretaceous deposits transgressively and stratigraphically overlie the Jurassic deposits. During the Cretaceous period, the region of the Fergana Basin underwent general subsidence more actively than in its eastern part and during the Jurassic period, but it was affected by subsidence at a slightly different level. According to the stratification scheme (Dickenstein G.F,1965), the approximate thickness of the chalk deposits in the bent central part of the Fergana depression reaches 2000 m. The Cretaceous period is characterized by the lagoon-marine character of sediment accumulation after tectonic stability. At the end of the Cretaceous period and in the Paleocene (Bukhara layer), there were large lagoonal basins connected

to the Afghan-Tajik sea basin in the central, western and southern parts of the Fergana Basin. The Paleogene deposits mainly formed during the stage of platform development, and the depression of the Fergana mountain range represents a carbonate-terrigenous formation formed in the relatively gulf-marine basin of the Paleo-Tethys, which is occasionally in contact with the Turanian Sea (Dickens G.F., 1965; Polyansky B.V., 1986; Urmanov A.Kh *et al.*, 2007]. This basin, which is related in size to the Aral Sea, is surrounded by a land with fine sandy relief composed of Paleozoic rocks.

The orogenic stage of geological development, which began at the end of the Upper Eocene, is characterized by the gradual activation of the Alpine orogeny, which continues to this day. The Fergana graben began to actively form during the collision of the Indian continent with Asia. Strong tectonic stresses have led to the wide development of the earth fault zone, which separates the Fergana depression from the north and south in the current structural plan, the strong amplitudes of horizontal and vertical movements confirm the existence of large-scale thrust zones. The thickness of Meso-Cenozoic deposits in the central part of the depression is 11 km. Geologists who have studied this area have different opinions about the history of tectonic development of the Fergana basin, especially about the new tectonic stage. However, based on the analysis of geological and geophysical data, it was noted that all of them are large-scale manifestations of tectonic dislocations associated with vertical and horizontal stress (Radzhabov Sh.S., Sim T.V., 2018).

The Oligocene period is characterized by global sharp differential movements. In the platform valleys in the southern part of Central Asia, rapid uplifts have developed, especially in the Tien-Shan region. Pamir was represented by low mountains instead. The sea retreated from the region at the beginning of the Oligocene, and a closed Fergana compressional bay existed. In the large intermontane marine basin, accumulation of red, fine-grained continental molasse deposits took place, the size of the basin gradually decreased in the surrounding alluvial-delta plain. Coarse-grained rocks were deposited by rivers directly near mountain peaks, near continental islands, and in land basins. The amount of gypsum in the layers is related to the periodic drying of the climate.

At the end of the Eocene, the processes of mountain formation, which caused the compression of the Earth's crust, began on the edges of the Fergana Depression. In the Chotkal-Kurama region, the uplift of the earth's crust began at this stage, which was sharply manifested in the initial phase of tectonic tension at the beginning of the Eocene-Oligocene. At the same time, conditions of sediment accumulation and formation composition of sediments in the Fergana basin have changed dramatically.

At the beginning of the Miocene, the current mountainous hills in the form of an island system were formed in wide valleys filled with red fine-grained continental molasses.

At the end of the Paleogene and the beginning of the Neogene, the Chatkol-Kurama, Fergana, Turkestan-Alay ridges were actively formed. They formed a series of red terrigenous molasses during early and late Miocene growth by rapid erosion and displacing clastic material. Local breaks in the formation of sediments are noted in the upper part of the Turkestan and Sumsar layers. Local unconformities are clearly noted only in the outer zone of mountains and foothills.

Southern Fergana, Talas-Fargana, and Darvoza earth faults are actively developed along the borders of uplifts and depressions. The wave of general uplifts covering Tien-Shan spread from the east. Relative tectonic stability of the area in the eastern part of the region, starting from the Talas-Fergana fault, is noted, where lignite is widespread in the section of the Zansan Depression.

In the late Miocene, uplift of mountains and foothills began at the edges of the depression. As the uplift area increased, the red soft molasses gave way to lighter and coarser grained rocks.

In Pliocene (Bactrian series), Turkiston-Oloy, Fargona and Chotkol-Quram ridges are rapidly rose. In the entire history of the Neogene, the most powerful uplift of the alluvial plain mountain range took place. Alluvium, lacustrine limestones and marls are deposited near the mountains in the lowlands of the Fergana intermountain basin. At the end of the Pliocene, the high peaks of the Tien-Shan probably became a mountain region covered with ice. The depression is covered with proluvial and alluvial-lake deposits, the central region becomes the valley of the Syrdarya river (Urmanov A.Kh *et al.*, 2007).

At the end of the Late Quaternary period, along with the crossing of mountains and steep slopes by rivers, there was a stronger uplift (up to 400-500 m), the total height of the ice-covered hills reached 2500-3000 m, in some places it reached 5000 m. After that, it is noted that the ascents slow down and the relief flattens [6]. According to geomorphological observations, it has been established that tectonic movements in the form of formation of disjunctive folds continue in Southern Fergana even now.

Kosygin Yu.A. and a number of other scientists have noted that it has been proven that the folds in the Fergana depression developed continuously during the Neogene and Quaternary periods. The location of the earthquakes with varying magnitude, was created based on the DEM (Digital elevation model) image of the Fergana basin and the catalog of earthquakes that occurred during the years 1978-2023 (Fig. 5).

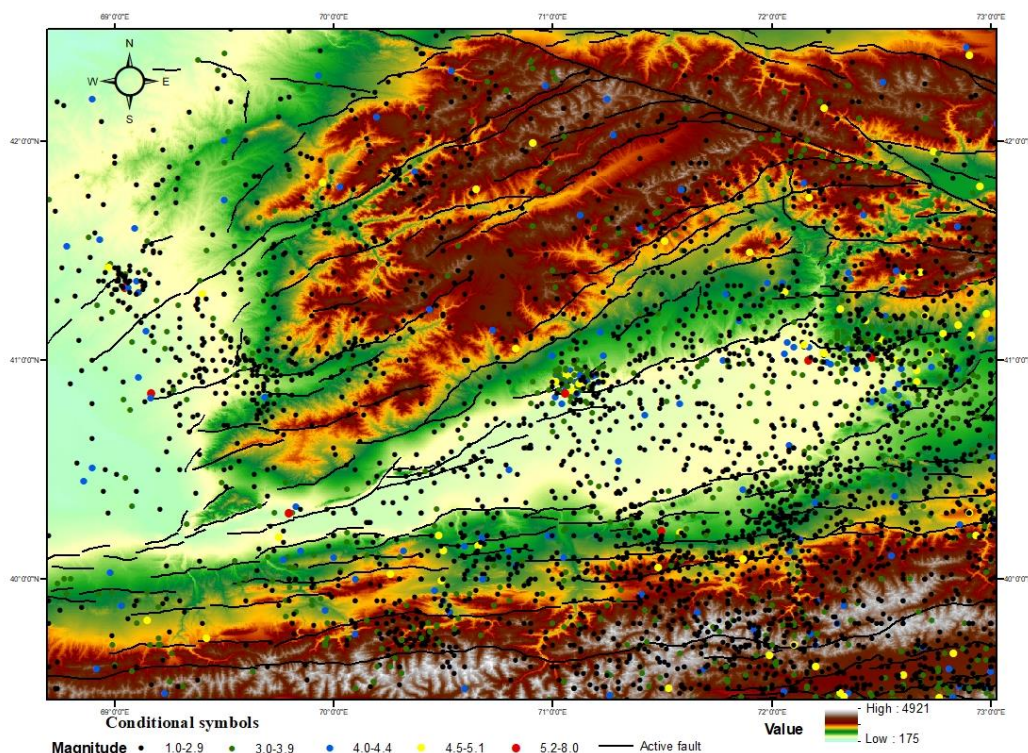


Figure 5. The map of the magnitude of the earthquakes of the Fergana basin that occurred during the years 1978-2023.

It has been determined by several local and foreign scientists that the Fergana Depression is a geodynamically active region, and these movements have shaped the current modern shifts of the earth's crust, especially in the southern part of the Fergana Valley. From a theoretical point of view, the scientific basis of these researches was obtained through the measurements of modern navigation satellite systems (GPS). However, in order to create a model related to the earthquakes occurring in the regions where the blocks are intersected by faults, the earthquake catalog data obtained from the USGS earthexplorer site was placed in the ArcScene program in 3D spatial distribution by depth. The main focus was on the magnitude distribution of earthquakes and the depth of their location on the Z axis, and when the radiolocation height image of the earth's surface was superimposed on the active earth faults separated by Bachmanov et al. (Bachmanov D.M *et al.*, 2017) in the resulting 3D model, the catalog of earthquakes corresponded to the zones located in the region of active earth faults.

The analysis of the location depth of the hypocenters of the earthquakes shows that it varies from 5 to 85 km in the studied area. Spatial distribution is approximately as follows: depth 25-30 km in the south and southeast of the region, 15-20 km in the central part, depth 5-10 km - almost everywhere, in mountainous areas the depth increases to 75-85 km.

Based on the catalog of earthquakes that occurred during the years 1978-2023, we can see the location of the plate movement by arranging its spatial location by magnitudes in the ArcScene program (Fig. 6).

Based on the catalog of earthquakes in the Fergana depression, we can say that the Fergana depression occurred as a result of the Middle Tien-Shan and Southern Tien-Shan movements, and it is no exaggeration to say that this depression was caused by the collision of the Himalayan and Eurasian plates. Based on the movement of the South Tien-Shan, the Fergana depression can be observed gradually submerging zones under the Middle and South Tien-Shan plates, pushing the depression and the Middle Tien-Shan.

The amount of displacement and subsidence can be estimated based on the data of modern GPS measurements of the horizontal and vertical movement of the earth's surface (A. Zubovich *et al.*, 2016).

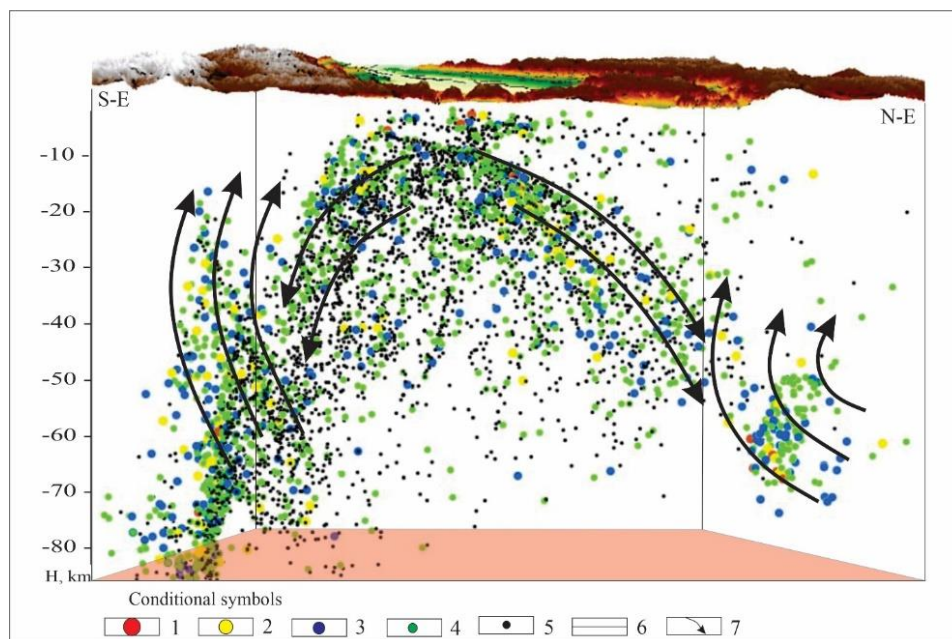


Figure 6. Depth model of the Earth's crust in the Fergana basin based on the catalog of earthquakes (view from the South-East and North-East sides). Legend. M-magnitude: 1) 5.2-8.0; 2) 4.5-5.1; 3) 4.0-4.4; 4) 3.0-3.9; 5) 1.0-2.9; 6) active earth faults 7-direction of movement of geodynamic processes;

The magnitude of large earthquakes is expressed in the southern and northern parts of the Fergana basin. The formation of small earthquakes is reflected in the central parts of the graben structure and on its sides. Such a manifestation of earthquake energy is observed in a partially brittle and dislocated granite layer. However, with increasing depth, the occurrence of high-energy earthquakes increases as the energy storage capacity of the upper mantle-influenced and highly altered rocks increases. In this process, a series of strong earthquakes are observed together with the folding of the basalt floor. This is related to the modern geodynamic movement of the Talas-Fergana flexural thrust fault that passes through the northeastern part of the Fergana depression. Due to the forces acting on the Fergana basin from the west and south, horizontal and partly vertical (subsidence) movements are distinguished by partial proportionality to the thrust direction of the Talas-Fergana flexure zone.

The earthquakes with hypocenters of 40-50 and 70-80 km correspond to deep structures or structural complexes of the earth's crust, which, as a result of the sustainability of development, preserved the level of serious tectonic movement not only in the platform stage, but also in the new period when the reorganization of platform structures began. Earthquakes with a depth of 5-10 km are mainly associated with the formation of young structures located near the surface of the earth, whose technical activity is still intensively manifested at the present time. At the same time, most of the focus of earthquakes have a local appearance and do not cause vibrations in large areas. For example, according to A.T. Konkov, the 5-point earthquake with its epicenter in the city of Namangan on January 11, 1955 was not recorded by seismic stations in Andijan and Fergana, and the 5-point earthquake that occurred in Andijan on May 10, 1955 was not recorded by seismic stations in Namangan and Fergana. Many such examples can be cited.

These earthquakes occurred within the flexural-tension zones of Northern Fergana and Southern Fergana, where seismic stations are located. Their focuses are not very deep and are related to the location of the covering deposits in an inconsistent structure. Here, on the one hand, the zone of faults blocking the seismic energy is connected with the complex structure of the surface, and on the other hand, with the extensive development of the crushing zone due to the accumulation of tectonic stresses and the possibility of strong earthquakes. An inverse relationship is also not excluded: earthquakes themselves make the way for the next ones. Thus, the inhomogeneity of the earth's crust, the presence of large earth faults in it, as well as the activating effect of new tectonic faults, causes not only the differentiation of the structure of the region, but also its high seismicity.

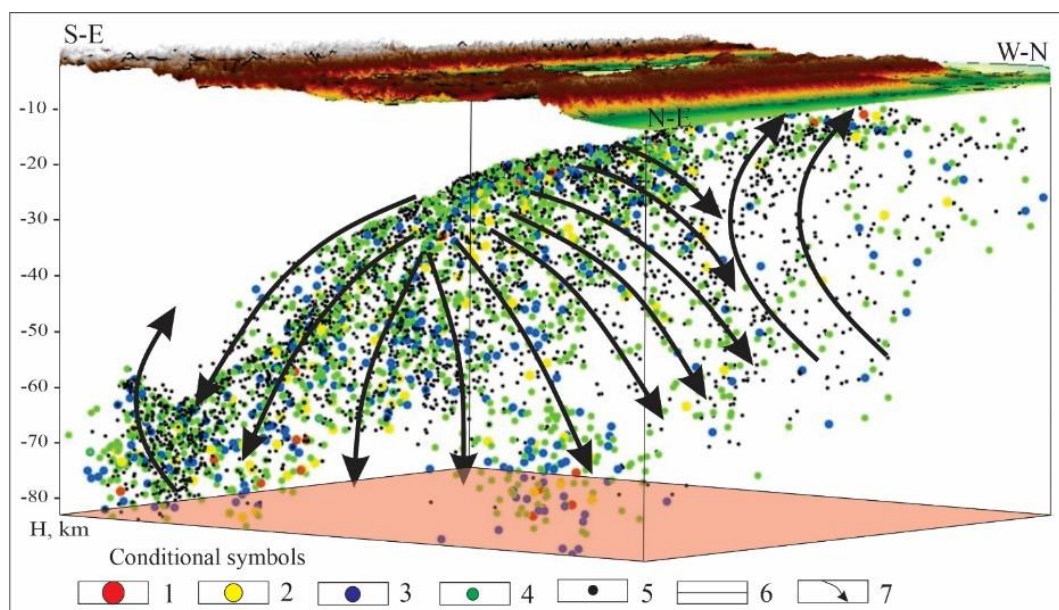


Figure 7. The depth model of the earth's crust of the Fergana basin created on the basis of the catalog of earthquakes (view from the South-East and North-West sides). Legend. M-magnitude: 1) 5.2-8.0; 2) 4.5-5.1; 3) 4.0-4.4; 4) 3.0-3.9; 5) 1.0-2.9; 6) active earth cracks; 7) direction of geodynamic movement.

The Fergana intermountain depression is from the north and northwest Kurama, Chotkal, in the east - Fergana, in the south - Aloy and Turkistan uplifts, sometimes bordered by regional faults that protrude to the surface of the earth. The depth of settlement of the Paleozoic surface increases from the edges of the depression and gradually sinks towards the center. Folds, flexures and discontinuities are widely developed in the section of the steps and merge in the flexure zones (Fig. 7).

As a result of the analysis of the spatial distribution of hypocenters of strong earthquakes, specific aspects of the structure of the earth's crust have been revealed: firstly, the focus of earthquakes correspond to the fault zones that separate the fold-block structures, secondly, most of these disturbances are not reflected in the surface relief of Mokhorovichich, and thirdly hypocenters are mainly located in granite and sedimentary layers (Ismailov V.A *et al.*, 2025; Ismailov V.A *et al.*, 2025).

Most of the earthquakes occurring in the Fergana basin reflected the development of the orogenic stage under the influence of geodynamic processes. The neotectonic movement of the Indian plate from the southern part is creating a reverse-discontinuity graben structure in the Fergana depression due to deformational compression. This is represented by the repetition of earthquakes in short periods during the mountain formation process.

CONCLUSION

Based on the analysis and generalization of published scientific research on the studied area, it was noted that though the horizontal compression intensity in the Chatkal-Kurama region, which is considered an orogenic region, is small when viewed from the side of the Indus Plateau, a sharp increase in the thickness of the earth's crust has been noted for the Pamir and Tibet regions.

In the geodynamic model for the Chatkal-Kurama region, which is a seismically active region, built by earthquake catalog, northern Fergana and southern Fergana appeared as an active subduction zone and formed tectonically active gorts and graben structures. In the area of Chatkal complex, mostly high-magnitude earthquakes correspond to earth faults and have created a tectonic mélange.

At the present stage, along with the increase in the intensity of high-level horizontal compression in the study area, active erosion processes continue on the mountain tips, and due to this, sediment accumulation is characterized by the accumulation of sediments in the intermountain basins in the regions of the Tien-shan folded mountain region. This process is not directly related to the movement of the lithospheric plate, but to local geological processes. As reflected in the geodynamic model of the earth's crust constructed for

the Fergana Valley and Chatkal-Kurama region, it describes the occurrence of earthquakes in the active fault zone and folded boundary parts of high-density layers.

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