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Assessment of fault activity by geophysical methods

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ABSTRACT

This article presents the results of complex geophysical and seismotectonic studies in the Navoi region. The article consists of 2 parts. The first part summarizes the geological and seismotectonic conditions. The analysis of seismotectonic features of Western Uzbekistan and adjacent territories has shown that the latest tectonic movements have formed the modern spatial distribution and correlation of tectonic structures of the territory. In addition, this study presents the results of the analysis of the geomagnetic and radioactive fields in the study area, which may be associated with geodynamic processes in the earth's crust. The second part discusses active faults associated with geomagnetic and radioactive fields.

KEYWORDS

Seismotectonics; Active fault; Deep fault; Neotectonics; Earthquakes

ARTICLE HISTORY

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Introduction

The region of the Beltau mountains and the western part of Kuljuktau are low mountains (absolute relief marks 500-800 m), composed of Paleozoic deposits (Ordovician, Silurian, Devonian) and abundant intrusions of igneous rocks. These mountains are bordered by younger Cretaceous-Paleogene-Neogene sediments, forming a foothill plain.

The Paleozoic complex includes volcanogenic-terrigenous, partially carbonate formations of the Ordovician, a thick carbonate formation of the Silurian, Devonian, Lower Carboniferous, volcanic-terrigenous and molasse sequences of the Middle and Upper Carboniferous. The sections of the Cretaceous (with the exception of the Aptian, Middle Upper Albian), Paleogene and Miocene are represented by marine facies; rocks of the Aptian stage, middle-upper Albian substages and Quaternary age were formed in continental conditions [1-4].

The middle - upper undivided sections and the upper part of the Upper Ordovician represent the Ordovician system. Deposits are distributed along the northern slopes of the Beltau and Kuljuktau mountains in a strip up to 1-1.5 km wide and up to 40 km long within the region. Interbedded shales and sandstones represent the section with interlayers of conglomerates, gravelstones, and siltstones, effusive and siliceous rocks. Siliceous-chlorite- sericite, micaceous-chlorite-quartz, micaceous-quartz, and clayey shales predominate. Interlayers of plagioclase porphyrites and quartz porphyrites, felsic tuffs are noted in the middle part of the section. Interlayers of conglomerates, siltstones, and siliceous rocks are confined mainly to the lower part of the section. It is assumed that Lower Ordovician deposits, which, in turn, overlie Upper Proterozoic deposits, build up the rocks of this suite from below. The most complete section of deposits is traded on the northern slope of Beltau, where their thickness reaches 500 m. In the remaining parts of the area under consideration, rocks are exposed in the form of scattered outcrops, which are separate sections of the section. The latter as a whole is composed of interbedded shales and sandstones with interlayers of conglomerates, gravelstones, and siltstones, effusive and siliceous rocks. Shales dominate the section. The Ordovician deposits are distributed in the central and western parts of Kuljuktau, where they are exposed in the form of narrow bands of sublatitudinal strike, often limited by faults, mainly on the wings of anticlinal folds. Peculiar lumpy argillaceous limestones with inclusions of siliceous rocks, quartz sandstones and shales represent the deposits. On the southern slope of the Beltau Mountains and to the west of the Shaidaraz well, among shales and limestones, there are lenses up to 30 cm thick of bluish tuffs of quartz porphyry [5-10].

Lower Devonian deposits in the form of separate elongated sections of sublatitudinal and latitudinal strike are widely developed east and southwest of the Tozbulak intrusion, west and southeast of the Darvaza mountains, on the southern slope of Beltau and in the eastern part of the Kyngyrtau mountains (Southern Kuljuktau). The base of the section is predominantly composed of black and dark gray limestones with intercalations of dolomites. White and spotty limestones with dolomite lenses ubiquitously represent the middle part of the section. Patterned conglomerate limestones of light gray color occur at the top of the section. The occurrence with the underlying deposits is consistent, with a gradual transition. In some places, this boundary is expressed tectonically. The total thickness of deposits is up to 700 m [11-13].

The deposits of the Upper Devonian are exposed in a single point, 2 km southwest of the Shaidaraz well, in an area 250x400 m in size. The rocks are represented by marmorized banded limestones with a stripped thickness of up to 100 m. The lower part of the section is not exposed by erosion, and its relationship with the underlying formations is unknown, overlapped or transgressively terrigenous sequence of the Middle Carboniferous.

Mesozoic (Cretaceous) and Cenozoic (Paleogene, Neogene) deposits are widespread in the foothills of the region, in the beds of temporary streams. Among the formations of the Cretaceous system, sediments of the Aptian, Albian,

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Cenomanian, Turonian stages and the Senonian superstage were distinguished. They lie on the Paleozoic folded basement and are represented by conglomerates, gravelstones, sandy-argillaceous rocks, limestones, and dolomites. The thickness of the deposits varies from 200 to 800 m.

The sediments of the Cretaceous system are overlain by a sequence of Paleogene and Neogene clays, marls, siltstones, sandstones and shell rocks with a total thickness of 350-400 m. The Quaternary deposits are divided by genetic type into eluvial-deluvial, proluvial and eolian. Conglomerates, pebbles, gravel, sands, loams and sandy loams with an admixture of clastic material represent them.

The total thickness of Quaternary deposits ranges from 0.5 to 150 m. The purpose of the study is to assess the activity of faults by geophysical methods and the seismotectonic situation.

Seismotectonic and Seismic Study of The Territory

The primary task of seismotectonic research is to identify the geological criteria of seismicity and, on their basis, identify the main sources of seismicity and assess the seismic hazard of the territory of the republic. At present, the genetic connection of earthquakes with zones of young ruptures and ancient deep faults, activated at the present stage, has been proven. Studies of the seismotectonic features of Western Uzbekistan and adjacent territories have shown that the latest tectonic movements have formed the modern spatial distribution and correlation of the tectonic structures of the territory. The main structures of the region are a chain of mountain structures, gradually plunging from east to west, intermountain and foothill troughs surrounded by structures of the Turan Plate. Both the amplitude and the velocity of neotectonic movements decrease in this direction. At the same time, the direction of tectonic movements was strictly controlled by regional faults and flexural-rupture zones. The scale of their manifestation is mainly related to the conditions for the formation of systems and zones of recent uplifts and subsidences, at the boundaries of which large faults became more active, subsequently leading to the generation of earthquakes of large magnitudes (Figure 1). The nature of the manifestation of the latest movements, their direction and scale made it possible to attribute the territory of Western Uzbekistan to the structures of modern activation (the territory of the Turan Plate) (Figure 1). An analysis of the features of the manifestation of the latest movements during the Quaternary period within both the orogenic and platform parts of the republic showed that at present the structures of the Tien Shan, plunging on the plain of the Turan Plate, do not fade, but tend to grow and further form. Based on this, the authors argue that the territory of the western subsidence of the Tien Shan belongs to the category of geotectonic structures of modern activation [14].

An analysis of the features of the fault tectonics of the region indicates that during the historical development of the territory, the zones of faults, which delimit different-scale tectonic structures, became more active several times. Therefore, with sufficient confidence it can be argued that intense mountain-building processes occurring in the latest stage of the tectonic development of the territory and continuing at the present time were accompanied by an increase in regional seismicity and the occurrence of strong and powerful earthquakes (Figure 1).

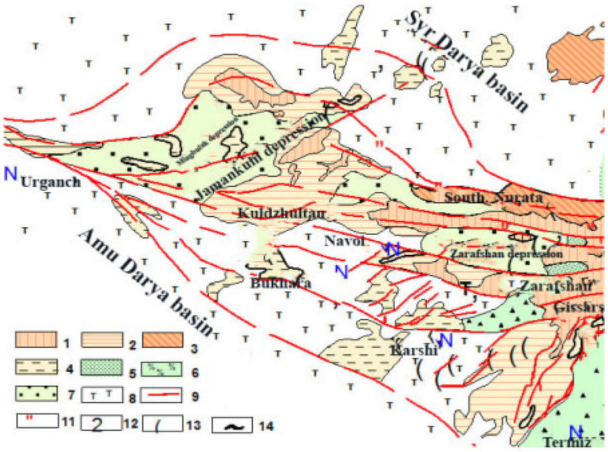

Figure 1. Extract from the map of seismotectonic of Uzbekistan [14]

1 - linearly elongated stable block uplifts of the Middle and Southern Tien Shan; 2 - fold-block uplifts of the western and southern subsidence of the Southern Tien Shan, composed of Paleozoic and Mesazoic formations; 3 - zones of anticlinal folds; 4 - local uplifts within the depressions; 5 - relics of the Mesazoic-Cainazoic troughs in the areas of uplifts; 6 - intermountain troughs; 7 - downhill troughs; 8 - Turan plate; 9 - active faults; earthquake epicenters with energy class: 10-K=17; 11-17; 12-15; 13,14.

Within the boundaries of Western Uzbekistan, faults of the northwestern strike are mainly distinguished. Faults of other directions appear episodically, not of great extent (Figure 2). On the surface, they are quite well represented by large crushing zones and hydrothermal manifestations. In the closed part of the territory, geophysical materials can trace faults. In a magnetic field, they are characterized by areas of a high horizontal gradient, a sharp shift in the axes of magnetic anomalies, and the presence of narrow, linearly elongated local anomalies. In the gravitational field, they correspond to bands of a high horizontal gradient (steps), a series of anomalies elongated along the strike [11]. According to the DSS (Deep seismic sounding) data, faults are expressed by a sharp change in the boundary velocity along the surface of the Paleozoic basement, and individual faults are at the Mokhorovichich boundary. Signs of activation of faults are observed in the Paleozoic, Paleogene, Neogene and Quaternary periods. There is a slight activation of them in the Alpine time (Figure 2) [11].

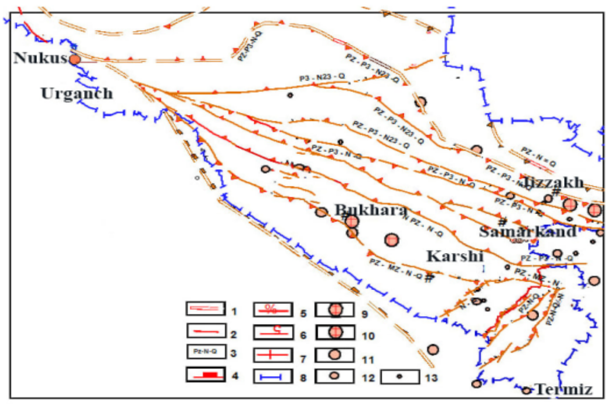

Figure 2. Schematic map of the main faults in Western Uzbekistan

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1 - faults separating geostructural areas traced on the earth's surface in the Mescainozoic deposits according to geophysics and space images; 2 - faults separating the main structural elements of folded systems traced on the earth's surface and Meso-Cenozoic deposits; 3 - stages of fault development; 4 - discharges (bergstrokes towards the lowered wing); 5 - uplifts; 6 - overthrusts (bergstreaks towards the autochthon); 7 - flexure-discontinuous zones; 8 - state border. Earthquake epicenters with M: 9 - ≥ 7.0; 10 - ≥6.5; 11- ≥6.0; 12 - ≤5.9.

A joint analysis of crustal faults with data from macroseismic surveys of the epicentral region of strong earthquakes, seismic intensity attenuation features, and the results of assessing the seismotectonic potential made it possible to identify the main seismogenic zones of Uzbekistan and evaluate their spatial and energy indicators. In total, more than 30 seismogenic zones have been identified for the territory of Uzbekistan (Figure 3), which are divided into three categories according to the seismotectonic potential.

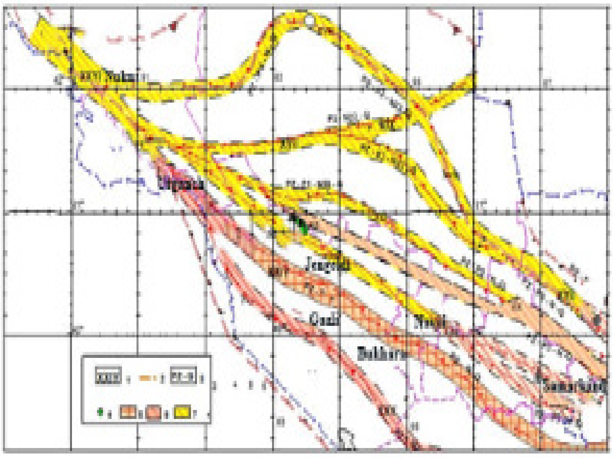

Figure 3. Map of seismogenic zones of Uzbekistan

1 - number of seismogenic zone; 2 - active faults of the earth's crust; 3 - periods of activation of the fault; 4 - WPP construction sites; Seismogenic zones in which earthquakes can occur with: 5 - M ≤ 7.5; 6 - M ≤ 6.5; 7 - M ≥ 5.0.

The first category of seismogenic zones, which are capable of generating earthquakes with M≤7.5 and I≤9 points, includes Gissar-Kokshaal (XXYII), South Tien Shan (XXIV).

The second category of seismogenic zones with seismic potential M≤6.5 and I≤8 points includes Mogoltau-Pistalitau (XYI), North-Kuljuktau-Turkestan (XX), Zarafshan (XXII), Bukhara (XXY), Sultanuizdag (XXYI). The third category of seismogenic zones with seismotectonic potential M≤5.5 and I≤7 points includes Besapano-North Nurata (XYII), Bukantau (XYIII), North Tamdy (XIX), North Kuljuktau-Turkestan (XX), South Auminzatau–Aktau (XXI), Pre-Kyzlkum (XXIII), Sultanuizdag (XXYI).

The Beltau and Kuljuktau mountains in the modern tectonic structure of the region are neotectonic uplifts of sublatitudinal strike, composed of rocks of the Paleozoic folded basement in the core, and deposits of the Meso-Cenozoic sedimentary cover in the wings.

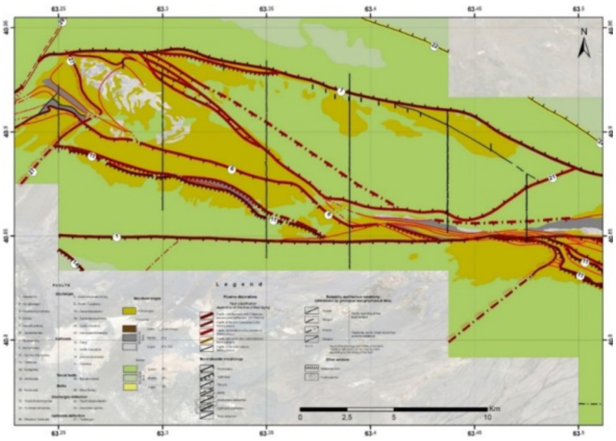

Figure 4. Tectonic map of the Beltau and Kuljuktau mountains (Compiled at the geological exploration expedition of the Ministry of Geology of Uzbekistan based on the materials of Ya.B. Aisanov (1973-83)) Scale 1:100000

Intensely dislocated sedimentary and igneous complexes corresponding to the geosynclinals stage of the region's development represent the folded basement. Relatively thin (up to 1200 m) deposits that arose during the platform stage of development form the cover.

Meso-Cenozoic deposits lie with azimuthal and angular unconformity on the uneven surface of various strata and intrusive formations of the Paleozoic basement (Figure 4).

It should be noted that Figure 4 shows faults up to the Paleozoic and Paleozoic ages. Not all of them are reflected in the modern relief. For example, fault number 7 spatially coincides with the North Kuljuktau fault in Figure 4. Similarly, fault number 11 coincides with the Central Kuljuktau fault. The western part of the Beltau fault with a diagonal scarp (3) in Figure 4. The South Kuljuktau fault (4) in Figure 4 is not reflected in Figure 4.

Methodology and Discussions

An important problem of modern exploration geophysics is the identification and study of low-contrast geological objects. These are understood as objects that are weakly manifested in physical fields recorded by geophysical equipment. The complexity of their study is because geophysical measurements take place against the background of interference of a completely different nature. The recent fundamental changes in the hardware of almost all types of geophysical work associated with increased sensitivity and resolution of instruments make these studies even more relevant [13,14]. Examples can be:

Spatial inhomogeneities in the upper part of the geological section, deep fault zone, poorly differentiated by magnetic properties from the host medium;

Deep extended geological bodies;

Artificial magnetic objects that are small in size, which makes it difficult to detect them in hiding environments;

The cultural layer changed as a result of human activity.

At the field stage, magnetometric and radiometric observations were carried out at the construction site of the Dzangeldy wind power plant. Magnetometric studies were

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carried out on embedded profiles in increments of 50 m using a high-precision GSM-19T magnetometer. The coordinates of each observed point were obtained manually using a GPS receiver (Garmin eTrex 22x).

The GSM GSM-19 magnetometer (Overhauser) is the main standard for mineral exploration, research of fault zones, tectonic disturbances, etc.

Radiometry is based on natural radioactive radiation in the study of the composition of rocks. In radiometry, the intensity of the studied natural radioactive zone depends on the radioactivity of rocks. The SRP-88 search radiometer is designed to measure radioactivity by gamma radiation during the examination of the radiation situation and the identification of radiation sources. In practice, the device is used for the search and exploration of minerals, the study of fault zones, tectonic disturbances and other purposes.

In the course of field research, magnetometric and radiometric observations were carried out on pre-planned profiles covering the area of construction of the Dzangeldy wind power plant.

Results

The Kuljuktau uplift belongs to one of the least geologically studied areas of Central Kyzylkum. A systematic study of it began in 1956-60. L.N. Kotlyarovsky conducted an aeromagnetic survey on a scale of 1:50,000, because of which positive magnetic anomalies with an intensity of up to 200 nT were detected against the background of a calm magnetic field, confined to intrusive arrays (Figure 5) [14].

The early sixties covered almost the entire area covered by gravimetric, magnetic and aeromagnetic surveys, electrical exploration of the VES and seismic exploration. The studies of these years were of a regional nature and were carried out mainly on a scale of 1:200,000 for the purposes of geological mapping in areas overlain by Mesozoic-Cenozoic formations.

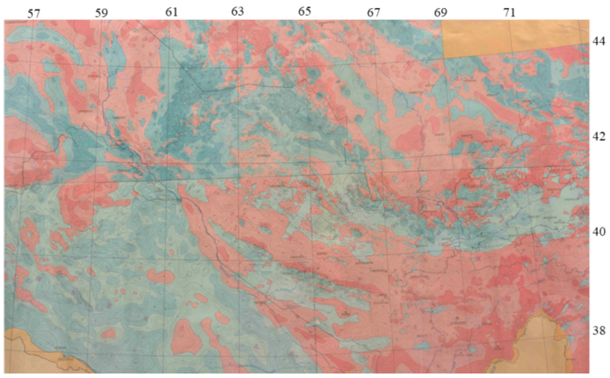

Figure 5. Map of the anomalous magnetic field Scale 1:500 000

In 1960, geological and geophysical studies on a scale of 1:50,000 gamma-ray surveys and schematic geological mapping were carried out on the entire area of Paleozoic formations under the leadership of S.I. Lukyanov in order to search for deposits of non-ferrous, rare and radioactive metals.

On the territory of the Paleozoic outcrops of the Kuljuktau mountains, a relatively calm magnetic field and negative gravity anomalies were noted. These features are associated with the low magnetic susceptibility of rocks, including gabbroids, and the widespread development of granitoids, limestones and shales with low density.

The magnetic survey was carried out on an area of about 200 km², with sides of more than 7.5 km in the latitudinal and more than 27 km in the meridional direction. The survey was carried out with absolute magnetometers "GSM-19T" the sensitivity of the magnetometer is 0.0221 nT. A reference magnetic station to account for the daily variation was installed at a distance of about ≈5 km to the southwest of the research site. The error of the abnormal field allocation does not exceed 0.3-0.4 nT. Measurements were carried out on profiles applied in the meridional direction, the distance between the profiles is 4 km² and the step is 50 m. In total, 6 regional profiles and intermediate profiles (200 m long) were laid in the amount of 12 pcs. The number of measurement points is 894.

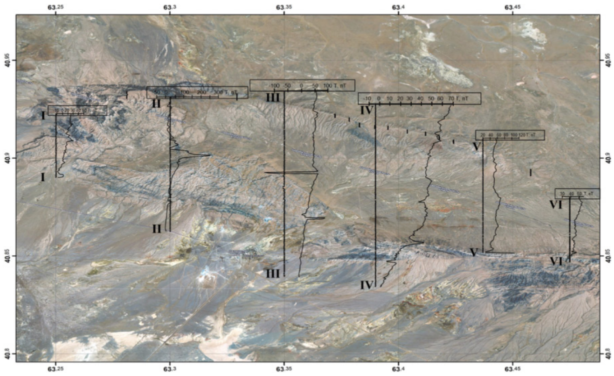

Figure 6. Variations of the geomagnetic field along the profile II, II-II, III-III, IV-IV, V-V, VI-VI of the Kuljuktau mountain.

As can be seen from Figure 6, the background value of the magnetic field is about 20-30 nT. Against the background of this field, an anomalous zone of the magnetic field of the sublatitudinal strike was revealed. The anomalous field has positive maxima and negative minima. The extreme value of the minimum has minus 130 nT and the maximum of the field has a value of 254 nT.

The first stage of high-precision magnetic surveys was carried out on the territory of mountains Kuljuktau. The obtained results show that the value of the monotonic background field is about 20-30 nT. Against the background of this field, an anomalous zone of the magnetic field of the sublatitudinal strike was revealed. The extreme value of the minimum is minus 130 nT and the maximum of the field has a value of 254 nT. Thus, the results of the analysis of magnetometric observations carried out within the selected wind power plant construction site show that it is characterized by a high intensity of the magnetic field. Fault zones are characterized by positive and negative anomalous variations of the observed field. It is not possible to assess the current activity of fault zones based on a single observation cycle.

The radiometric survey was carried out on an area of about 200 km², with sides of more than 7.5 km in the latitudinal and more than 27 km in the meridional direction. Geophysical instruments using the SRP-88 radiometer carried out the survey, the sensitivity of the radiometer is 0.3 microrentgen/hour. The error in the allocation of an abnormal field does not exceed 0.3-0.4 microrentgen/hour. Measurements were carried out on profiles applied in the meridional direction, the distance between

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the profiles is 4 kilometers and the step is 50 m. In total, 6 regional profiles and intermediate profiles (200 m long) were laid in the amount of 12 pcs. The number of measurement points is 894 (Figure 7).

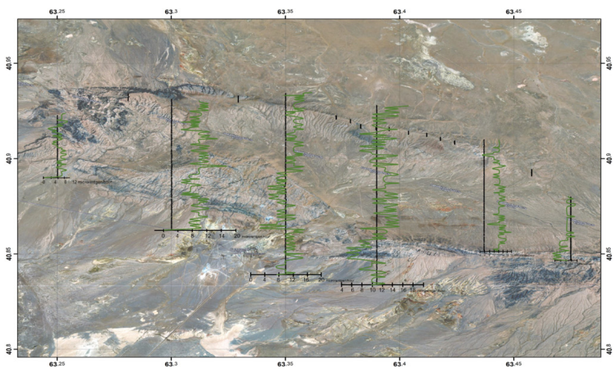

Figure 7. Variations of the radioactive field along the profile II, II-II, III-III, IV-IV, V-V, VI-VI of the Kuljuktau mountain

As can be seen from Figure 7, the background value of the radioactive field is about 2-4 microrentgen/hour. Against the background of this field, an anomalous zone of the radioactive field of the sublatitudinal strike was revealed. The anomalous field has positive maxima. The extreme value of the field has a value of 2-17 microrentgen/hour.

The first stage of radiometric studies was carried out on the territory of mountains Kuljuktau. The obtained results show that the value of the monotonic background field is about 2-4 microrentgen/hour. Against the background of this field, anomalous zones of the radioactive field of the sublatitudinal strike were revealed. The extreme value of the field is 17 microrentgen/hour.

Thus, the results of the analysis of radiometric observations of the influence of large fault zones show is characterized by high intensity. In most cases, the areas of anomalous variations of the radioactive field coincide with the fault zones. In some cases, abnormal variations are observed on the charts that do not coincide with fault zones or are slightly shifted to the side.

Results of complex analysis

The results of a comparative analysis of magnetometric and radiometric observations are presented on the profile I-I to VI-VI. As can be seen on the profile I-I of anomalous variations, the observed fields coincide well with each other. In contrast, in the second profile there is some discrepancy in the nature of the manifestation of fields. Within the third profile, there is a good coincidence of anomalous variations confined to fault zones, only now there is some antiphase of magnetic and radiation fields. In the fourth and fifth profiles, the coincidence of the general trend is common for both fields. No significant variations of the radiation field are observed. In the sixth profile, there is again a coincidence of the sections of the anomalous fields of both fields and the fault zone of the territory.

Thus, the results of a comparative analysis of the behavior of the observed fields show that in most cases the areas of anomalous variations of magnetic and radiation fields well reflect the existing fault zones of the territory. There are some shifts of the areas of anomalous variations of the gamma field away from the fault zones. Areas of intense manifestation of the gamma field of unknown nature have been identified, which may be associated with local features of the rocks of the Earth's crust or its stress states (Figure 8).

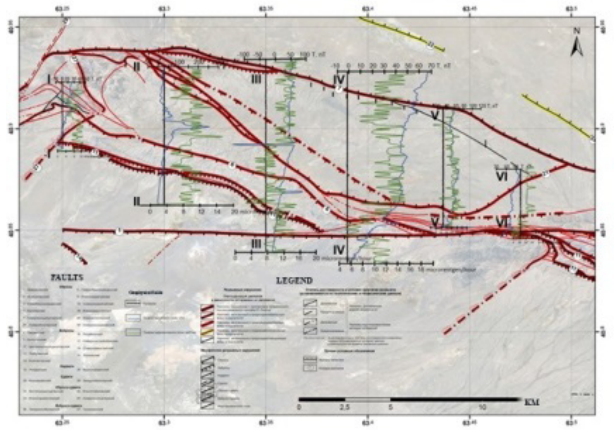

Figure 8. Variations of geomagnetic and radiation fields in profile II, II-II, III-III, IV-IV, V-V, VI-VI Kuljuktau Mountains

Conclusions

According to the estimates of previous authors, the seismic potential of the Prekizilkum seismogenic zone is I≤7 points, whereas the North-Kuljuktau-Turkestan I≤8 points.

According to the results of deterministic seismic zoning, the seismic intensity of the selected site is estimated to be equal to 7 and 6 points. However, it should be noted that the values of seismic intensity are calculated because of the old version of seismogenic zones given. After the occurrence of a strong earthquake in 2013 in the North-Kuljuktau-Turkestan (XX) zone with M=6.2, the seismic potential of the zone was increased to M ≤6.5 and I≤8 points. Based on this, the initial seismic shaking in the interseismogenic zone can also reach up to 7 points.

The Beltau and Kuljuktau mountains are projections of Paleozoic (PZ) rocks, on which Cretaceous (K) and Quaternary deposits, as well as numerous magmatic (intrusive) intrusions, have been preserved in the form of remnants and patches;

The velocity of vertical movements for the village of Dzhankeldy and Beltau uplift is characterized by a zero velocity value. For the Kuljuktau mountains, the speed of movement reaches +2 mm/year, which probably creates tension at the junction of the Beltau and Kuljuktau mountains. Moreover, the tense zone probably extends in a northeasterly direction.

Based on the first stage of high-precision magnetic surveys, it is shown that the fault zones of the study area are characterized by a high intensity of positive +274 nTl and negative -150 nTl anomalous magnetic field variations. It is not possible to estimate the current activity of fault zones on the basis of one observation cycle.

The results of radiometric observations show a monotonous change in the background field, which is 2-4 microrentgen/hour. Against the background of this field, anomalous zones of the radioactive field of sublatitudinal strike were revealed. The extreme value of the field is 17 microrentgen/hour. In most cases, areas of anomalous variations in the radioactive field coincide with fault zones. In some cases, the graphs show anomalous variations that do not coincide with the fault zones or are slightly shifted to the side.

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Thus, the results of a comparative analysis of the behavior of the observed fields show that in most cases, areas of anomalous variations in the magnetic and radiation fields well reflect the existing fault zones of the territory. Some shifts of areas of anomalous variations of the gamma field away from the fault zones are observed. Areas of intense manifestation of the gamma field of unknown nature were identified, which may be associated with local features of the rocks of the earth's crust or its stressed states.

Disclosure statement

No potential conflict of interest was reported by the authors.

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