https://doi.org/10.33271/nvngu/2023-4/018

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TECTONICS AND GRAVITY FIELD STRUCTURE OF CENTRAL KAZAKHSTAN

Purpose. Identification of the nature of the manifestation of tectonic elements of different ages in Central Kazakhstan in gravitational fields based on the results of the calculation of regional, intra-crustal and local transformants.

Methodology. Synthesis and analysis of the data on integrated interpretation and modeling of gravitational, geomagnetic, geothermal fields, the latest movements of the Earth's crust and parameters of the seismic regime, tectonics and stratigraphy of rocks.

Findings. Regional, intra-crustal and local heterogeneities in the lithosphere manifest themselves differently in blocks of Precambrian rocks, Early and Late Caledonides, Early and Late Hercynides. They may be associated with the processes of Paleozoic intracontinental rifting, with the rise of mantle matter and its emplacement into the Earth's crust, followed by the manifestation of Late Paleozoic orogenesis, doubling of the thickness of the Earth's crust, outpourings of magmatic formations.

Originality. It is established that large gravitational minima are distinguished in areas with Hercynian folding, characterized by abnormally high amplitudes in the movement of the Earth's crust. In the regions of the Caledonian folding, the values of gravity field anomalies of intermediate intensity and increased amplitudes of the latest movements of the Earth's crust are manifested. Areas with Pre-Paleozoic folding have relative maxima of gravitational anomalies and minimum values of the latest movements of the Earth's crust. Earthquake sources are concentrated in the consolidated crust at the junction of areas with different ages of basement consolidation, in gradient zones of geothermal, geomagnetic and gravitational anomalies. According to the variations of the intra-crustal transformant, it was found that a wide range of changes in the values of the gravitational field corresponds to areas with minimal temperature values, whereas in areas with increased temperature values, the range of changes in the values of gravity anomalies is reduced. The distribution of the local transformant of the gravitational field indicates the existence of highly variable anomalies, which reflects the high-frequency gravitational effect of near-surface objects of the Earth's crust.

Practical value. The distribution of inhomogeneities in the lithosphere with various density, geomagnetic and geothermal anomalies of geophysical fields, the nature of the seismic regime and the latest movements of the Earth's crust predetermined the formation of geostructures with different types of mineralization, each of which is recommended to be searched and explored by a specific rational set of geophysical methods.

Keywords: *gravitational field, geothermal field, geomagnetic field, regional transformant, intra-crustal transformants, local transformant, tectonic faults, seismicity*

Introduction. Central Kazakhstan is a region of Paleozoic riftogenesis, whose formation began with the Proterozoic on different-age folded basement [1, 2]. The tectonic development of the structures of this region is characterized by great diversity. However, the Paleozoic sediments are crumpled into intensely deformed folds [3, 4].

The study on the tectonics and deep structure of Central Kazakhstan according to gravity exploration opens up opportunities for understanding the ore-forming processes occurring in it, patterns of distribution of minerals in the Earth's crust and has access to a direct search forecast, which makes the topic of the article very relevant. The significance of the studies carried out is enhanced by the fact that, according to gravity survey data with the involvement of materials from geological surveys, drilling and other geophysical methods, it is possible to:

- determine the material composition of the Earth's crust and the upper mantle; establish direct correlations between the results of interpretation of gravity fields with various types of mineralization, which contributes to an active study on the geological nature of the anomalies of these fields;
- identify structural positions, features of the deep structure and conditions for the formation of solid minerals deposits, systematize them according to the type of deep structures;
- construct physical-geological models of the deep structure of ore clusters, areas and deposits and, on this basis, to develop deep criteria for localization of mineralization. The choice of methods for exploration of mineral deposits in Central Kazakhstan depends on the objectivity and correctness of the above procedures.

Tectonics. According to the existing schemes of tectonic zonation of Central Kazakhstan, there are five different-age structural-folding regions – the Pre-Paleozoic high of the metamorphic basement, Early- and Late-Caledonian folding, Early- and Late Hercynian folding [4, 5].

The area of Pre-Paleozoic folding is the Ulutau high of the metamorphic basement. It is composed by Precambrian formations (Fig. 1). Here, in relatively large areas, ancient Early Precambrian crystalline schists are outcropped, as well as sedimentary-effusive formations metamorphosed in the greenschist facies of the late Early Precambrian time. Late Precambrian marine sedimentary and sedimentary-volcanogenic deposits are of considerable thickness and are typically rifted [5, 6].

Areas with Early Caledonian folding (Kokshetau-North Tien Shan folding system) – Zhezkazgan and Teniz depressions, Sarysu-Teniz zone of block foldings, Betpakdala, Maikain and southern part of Aktau-Moiyntinsky anticlinoriums, southern and northwest parts of Devonian marginal volcano-plutonic belt, Zhalair-Naiman synclinorium [7].

During the Paleozoic, and partly during the Mesozoic-Cenozoic, longitudinal and transverse strike-slip, thrust displacements occurred here, consistently complicating the original structural plans that emerged in the evolution of tectonic structures.

This Caledonian system includes more than fifty separate structural-formational zones (anticlinoriums and synclinoriums), the stratigraphic section of which is characterized by diversity and great complexity [8].

The axial part of the Kokshetau-North Tian-Shan folded system in big areas is overlain by the Hercynian structural complex, which forms the largest Chu-Sarysu-Teniz belt of superimposed Middle-Upper Paleozoic depressions in Kazakhstan.Therefore, speaking about the geology of the structures of the Kokshetau-North Tien Shan fold system, we note only its individual distinctive features:

- structures of the western and central part of this system were consolidated in the Late Ordovician time, so they belong to the early Caledonides (or Taconides); in these structures

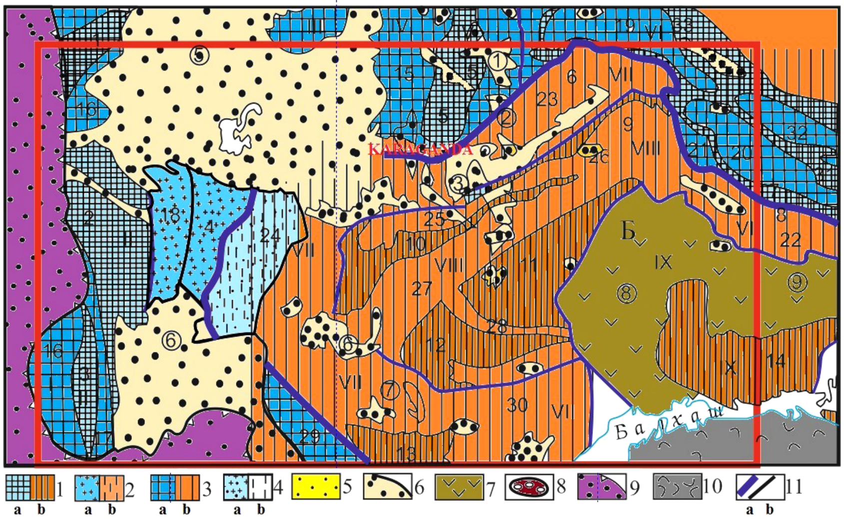

Fig. 1. Tectonic zonation and the main folded structures of Central Kazakhstan (*compiled using data from G. Lyapin, 1972 with copyright changes*):

1 – anticlinoriums (*a – areas with Caledonian consolidation*; *b –Hercynian consolidation*); *2 – anticlinoriums overlain by younger structural complex* (*a – areas with Caledonian consolidation*; *b – Hercynian consolidation*); *3 – synclinoriums* (*a – areas of Caledonian consolidation*; *b –Hercynian consolidation*); *4 – synclinoriums overlain by younger structural complex* (*a – areas with Caledonian consolidation*; *b – areas with Hercynian consolidation*). *The largest superimposed structures*; *5 – Anticlines, composed by Middle-Upper Paleozoic formations*; *6 – Synclines, composed by Middle-Upper Paleozoic formations*; *7 – Synclines, composed by Upper Paleozoic volcanogenic formations*; *8 – Syncline composed by Mesozoic formations*; *9 – Areas of continuous spread of the platform cover*; *10 – Neotectonic depressions*; *11 – borders between*: *a*) *folded systems and b*) *structural-formational megazones. Folded systems*: *A – Kokshetau-North Tian-Shan*; *B – Jungaro-Balkhash. Structural-formational megazones*: *I – Ishim-Karatau*; *II – Kokshetau-Ulutau*; *III – Stepnyak-Jaksyk*; *IV – Ermentau-Boschekol*; *V – Betpakdala*; *VI – Chingiz-Tarbagatai*; *VII – Mointy-Karaganda-Predchingiz*; *VIII – Agadyr-Karkaralinsk*; *IX – Pribalkhash*; *X – North-Dzhungar. Anticlinoriums*: *1 – Jarkainagach*; *2 – Ulutau*; *3 – Maitobye*; *4 – Kerey*; *5 – Ermentau-Niyaz*; *6 – Kyzyltas-Ekibastuz*; *7 – Akchatau*; *8 – Akbastau*; *9 – Spassk*; *10 – Atasu-Tekturmas*; *11 – Jaman-Sarysu*; *12 – Atasu-Mointy*; *13 – Buruntau*; *14 – Northen –Balkhash*; *17 – Karsakpai*; *18 – Arganata-Kypshak*; *19 – Bayanaul*; *20 – Abraly*; *21 – Koksengir*; *22 – Shubartau-Urdzhar*; *24 – Atasu-Konski*; *25 – Nury*; *26 – Aynasu*; *27 – Uspensk*; *28 – Akzhal-Aksoran*; *29 – Jalayr-Naiman*; *30 – West Balkhash*; *31 – Chingiz*; *32 – Chunay*; *33 – Alkamergenov. Superimposed Middle-Upper Paleozoic depressions* (*numbers in circles*): *1 – Teniz-Koruzhunkul*; *2 – Ekibastuz*; *3 – Maytobe*; *4 – Akzhar*; *5 – Kuu-Chekinskaya*; *6 – Karaganda*; *7 – Zhailma*; *8 – Bogumbay*; *9 – Teniz*; *10 – Dzhezkazgan*; *11 – Miykainar*; *12 – Tokrau*; *13 – Bakanas*; *15 – Seletyn*; *16 – Baykonur*; *28 – Akzhal-Aksoran*; *29 – Jalair-Naiman*

Silurian deposits are absent at all. The eastern structures belong to the Late Caledonides, because in these structures, the consolidation of the continental crust took place in the Late Silurian [8, 9];

- the presence of structural-formational zones of "intensive and weakened riftogenesis" is noted. The first ones are characterized by a big role of volcanogenic formations in the section and intensive dislocations of the deposits that make them up [9], whereas the second ones are characterized by absence or subordinate role of volcanogenic formations and relatively low dislocations of the composing mainly sedimentary rocks [10];

- Devonian deposits in many structures are represented by molasse formation, indicating the onset of the orogenic stage of evolution of these structures by this period. Outcrops of Carboniferous-Permian deposits, as a rule, are limited and compose small troughs on folded Early Paleozoic formations [4];

- intrusive magmatism is well represented. The most important milestones of its manifestation are the Cambrian period (stratified peridotite-gabbro-norite the Zlatogorsky complex, alkaline-ultramafic the Krasnomaysky complex), Late Ordovician-Early Silurian (large massifs of granites, granodiorites and diorites of the Zerenda and Kyrykkuduk complexes) and Devonian periods (the Ishimsky and Orlinogorsky complexes) [3, 8].

Areas with Late Caledonian folding – Ermentau, Boschekol and Chingiz megantiklinoriums, eastern part of Devonian Marginal Volcano-Plutonic Belt, Bayanaul and Seletinski synclinoriums, Karazhal trough; areas with superimposed Hercynian structures on caledonides (northern part of the Karasor synclinorium, Shedertinskaya depression, northern parts of the Karaganda depression, Hercynides of the Dzhungar-Balkhash system).

Yeremetau-Boschekol megantiklinorium is located on the border of the Kokshetau-North Tien Shan and Chingiz-Tarbagatai folding systems and combines the Yeremetau-Niyaz and Boschekul anticlinoriums, Seletinskaya and Olentinskaya synclinoriums (Fig. 1). This megazone is one of the typical Salair rift zones of the Kazakhstan Paleozoids with powerful underwater effusive and intrusive magmatism [7, 8].

Here, Upper Precambrian sedimentary-effusive strata are relatively well represented as well as complete sections of the Cambrian deposits, represented mainly by volcanics, or terrigenous-siliceous and terrigenous rocks. The Ordovician formations are exclusively terrigenous marine ones, their section in synclinal zones is continuous (from the Upper Cambrian to the Ashgilian Stage) and rather thick.

Chingiz-Tarbagatai megazone stands out in the extreme east of Central Kazakhstan, within the mountain massifs Bayanaul, Murjik, Chingiz, Tarbagatai [1, 8]. In the southwest, the system is in contact with the Caledonides of the Kokshetau-North Tian-Shan system and the Hercynides of the Dzungar-Balkhash system in the central and southwestern parts.

The megazone consists of several structural-formation zones contacting each other along deep faults. At the northwestern end of the system, the Kindykty and Bayanaul structural-formation zones are differentiated, whereas in the central and southeastern parts of the system, the Akshatau, Kan-Chingizs, Abralinskaya, and Akbastau structural-formation zones, parallel in length and replacing each other from southwest to northeast, are isolated [4].

The Devonian Marginal Volcano-Plutonic Belt is considered a borderline between the Caledonides and Hercynides and is a Hercynian structure that stabilized at the end of the Late Paleozoic. From the north, west and south this belt is surrounded by outcrops of Caledonids of Kokshetau-North Tian-

Shan folded system, from the east and northeast it meares with Caledonides of Chingiz-Tarbagatai system. Formation of Devonian Marginal Volcano-Plutonic Belt is considered to be the final event of Caledonian tectonic epoch [5].

At the same time this belt is the superimposed tectonic-magmatic zone and in the most part enters the areas which have undergone folding much earlier, in some places being located directly on Precambrian massifs [9].

Areas with Early- and Late Hercynian folding (Dzhungar-Balkhash system) – Nurinsky, Karasor, southern part of Uspenskiy, Zhaman-Sarysu synclinoriums, Tokrau, Kalmakemel, Bakanas depressions, Aktau-Mointinskiy, Atasu, Tekturmas, Spaskiy and North Balkhash anticlinoriums.

The Dzungar-Balkhash Hercynian folded system fits smoothly into the Caledonian structural plan (Fig. 1) and combines about two dozen dislocated structural-formation zones and several large depressions, listed above, overlain by Mesozoic-Cenozoic sediments [3, 6].

Within this system, the sections of the Precambrian continental crust are not outcropped on the ground surface, although the presence of their blocks and massifs in the deep horizons is not excluded. The oldest rocks in the stratigraphic section of the system are Vendian-Cambrian deposits; the Ordovician-Silurian formations are also well represented [1, 4].

There are two types of Lower Paleozoic formations, which differ drastically according to the composition of their rock assemblage. The first type of the section is found in relatively stable blocks and is represented mainly by sedimentary deposits with a subordinate role of volcanogenic ones. The second type is characteristic of anticlines, where the Lower Paleozoic section of structural-formation zones (Itmuryndy-Tyulkulamskiy and Tekturmas) is characterized by predominantly volcanic and sedimentary-volcanic composition and intense dislocations [3, 6].

Devonian deposits within the Dzungar-Balkhash folded system are widely spread. Lower Devonian is represented here by tuffogene-terrigenous deposits with marine fauna and subordinate role of volcanites. In Middle Devonian in a number of zones there appear red-colored and sand-colored sediments, in some places with volcanites of andesite-basalt composition. Upper Devonian sediments are formed, most commonly, by marine limestones, siliceous-carbonate and marly rocks, and siliceous siltstones [2, 5].

Carboniferous formations are formed by both sedimentary and purely volcanogenic rocks, which are characterized by a great variety of composition (basalt-andesite-dacite-rhyolite and their subalkaline varieties (trachybasalt-trachyandesite-trachydacite-ayulite, etc.).

North Balkhash megazone. During the whole pre-Mesozoic history, it did not undergo significant inversion uplifts, which probably resulted in a limited scale of granitoid magmatism distribution. Zhivetian-Francian deposits are everywhere represented by substantially terrigenous, gray or variegated strata, containing a certain amount of carbonate and coarse gravelite material, and in the Tokrau brachysynclinorium, even ground effusives of this time are known [6].

Vintage data. The first gravimetric studies on the territory of Kazakhstan were carried out in the period 1929–1932. The results of gravity determinations were used to solve problems of regional geology and tectonic zonation.

In 1953, a gravity map was compiled by D. Kazanly, which for the first time showed the Regional Central Kazakhstan Gravity Minimum (hereinafter referred to as CKGM), covering areas of ferruginous-manganese, lead-zinc and rare-metal mineralization. The latter circumstance led to an active study on the geological nature of this anomaly.

In 1984, under the editorship of T. Akishev and I. Shneider a set of maps were published of the gravity field and its components, which was the result of the digital conversion of the raster version of the gravity field map of scale 1 : 1,500,000 in the Bouguer reduction. The published maps were accompanied by maps of gravity field transformations: regional and local component, vertical and horizontal derivatives of Bouguer anomaly [11, 12].

The transformation procedure consisted in creating a linear rectangular matrix of gravity field values, which ensures its smoothing in relation to a scale of 1 : 5,000,000, in binding this matrix to the selected grid of geographical coordinates, and dividing the observed field into orthogonal components.

In studying the features of the gravity anomalies of Central Kazakhstan as the basis, gravity maps were taken of the observed field in a scale of 1 : 500 000 and 1 : 1,500000, because they contain the most complete information about this region as a whole and its individual segments [12].

Results. ***Regional transformant of the gravity field.*** The scheme of the regional transformant of the gravity field in combination with the data on other potential fields and structural-tectonic schemes formed the basis for the formation of ideas about the nature of the distribution of heterogeneities in the lower part of the Earth's crust and upper mantle, in the depth interval from 30 to 150 km [13, 14].

The regional transformant of gravity field integrally reflects all the diversity of the geological structure of the lithosphere of this large region laterally and at depth.

The scheme of the regional transformant of the gravity field, combined with the earthquake sources, shows isoanomalies with a contour interval of 10 mGal. The range of changes in the values of the gravity field anomalies varies from –115 to +45 mGal (Fig. 2).

At the same time, despite the fact that the regional gravity field well reflects the block (in plan) structure of the lithosphere, the attraction of independent data on magnetotelluric, seismic, seismological, seismic tomographic, geological, geotectonic and geodynamic studies is required to tie the identified heterogeneities at different depth levels [15, 16].

Only with the use of a combination of these data, it seems possible to identify deep magma pockets, submerged blocks of a sialic (with fragments of a mafic) basement, bodies of granulites of basic-intermediate composition, increments of the basalt layer (crust-mantle mixtures), tops of mantle plumes, etc.

Central Kazakhstan gravitational minimum (further in abbreviation CKGM) covers the territory of more than 300 thousand km^2 and has the form of an oval, stretched in a northeasterly direction.

From the surface of the territory of the CKGM, heterogeneous geological structures occur: in its marginal parts are distributed Early Caledonides of Northern Kazakhstan, Late Caledonides of Chingiz-Tarbagatai, in the central part – Early and Late Hercynides of Dzhungaro-Balkhash system, in the southwestern part – Aktau-Dzhungarian terrane of Precambrian rocks (according to Mazarovich, 2006), in the eastern part – the superimposed Late Paleozoic Balkhash-Ili ground Late Paleozoic volcanic-plutonic belt (as part of the Tokrau, Bakanas and Kalmakemel depressions [5].

The CKGM is characterized by a highly rugged, medium intensity negative gravity field, which is traced polygonal and linearly elongated Δga anomalies with intensity from –80 to –300 mGal and more (Fig. 2).

The deepest gravity minimum is confined to the Uspenskiy, Zhaman-Sarysu and Akzhol-Aksoran synclinorium, where the areas of development of thin (up to 10 km) active mantle are isolated [17, 18].

From the north, west and north-east the CKGM is bounded by Devonian marginal volcano-plutonic belt with negative anomaly intensity Δga up to –90 mGal. Spatially, high-gradient zones of change in the regional transformants of the gravity field gravitate to it (Fig. 2).

Further to the north, a large area of intermediate values of sign-variable gravity field anomalies is isolated, spreading over the Caledonian folding zones (within the Ermentau, Boschekul and Maikain anticlinoriums and the Baikonur, Seletinskiy, Dzhalair-Naiman, and Bayanaul synclinoriums),

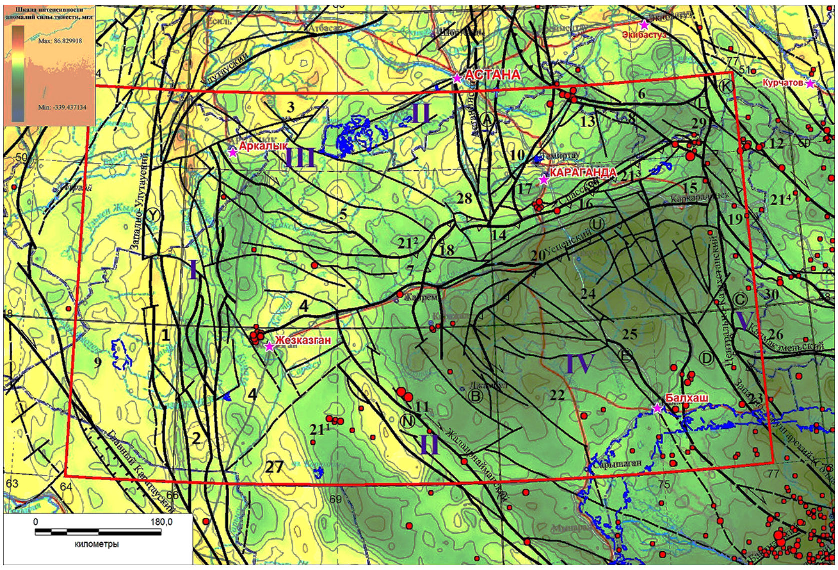

Fig. 2. The scheme of regional transformant of the gravity field, combined with earthquake sources (according to Nusipov E., Belousov N. P., Shatsilov V. I. – 2007; Mazarovich A. O. – 2006):

I – Highs of the metamorphic basement; II – Caledonian folded zones; III – Superimposed Hercynian structures on the Caledonides: IV – Hercynian Dzungar-Balkhash system; V – Balkhash-Ili Late Paleozoic volcanic belt. 1–33. Tectonic elements (Fig. 1). Red circles are sources of earthquakes, black lines – tectonic faults. The red line is the contour under study

as well as superimposed Hercynian structures on Caledonides(Teniz and Zhezkazgan, Shiderty, Karazhal and Karaganda depressions). Here the intensity of anomalies Δ*ga* of variable sign is +15÷ –60–70 mGal (Fig. 2).

Further to the west within the field of the regional component of the gravity field there appears a chain of intense linearly-elongated maximums, extending in the meridional direction and controlling the Ulutau structures. The intensity of anomalies of the regional transformant of the gravity field here reaches +25÷+40 mGal [15].

In the east, the CKGM borders with of Chingiz-Tarbagatay fold systems (–30–45 mGal), eastern margin of Devonian Marginal Volcano-Plutonic belt (–25–30 mGal) and structures of Balkhash-Ili Late Paleozoic volcano-plutonic belt (Kalmakemel and Bakanas depressions) with intensity of anomalies Δ*ga* to –110 mGal (Fig. 2).

Intracrustal transformant of the gravity field. The map of the intracrustal transformant of the gravity field (the residual component of the first order) allows us to separate intracrustal heterogeneities by density and rank the zones of tectonic faults by depth of penetration (Fig. 3). It is presented in isolines with a contour interval of 10 mGal and characterizes the internal structure of the consolidated crust to a depth of 20 km [14, 15].

The map was compiled as a result of the recalculation of the observed gravitational field into the upper half-space and used to identify anomaly-forming bodies in the structure of the granite-metamorphic and granulite-basite layers. The CKGM is differentiated only in its northern part within Nurinskiy, Karas, Uspenskiy (–60 mGal), Zhaman-Sarysu (–40÷–60 mGal) synclinoriums and Aktau-Montiny anticlinorium (–20÷–30 mGal) (Fig. 3).

Outside the CKGM contour, the negative anomalies of the intracrustal transformant of the gravity field are observed in some areas of the Zhezkazgan and Bayanaul depressions, the Sarysu-Teniz zone of block folds, the Devonian Marginal Vol-

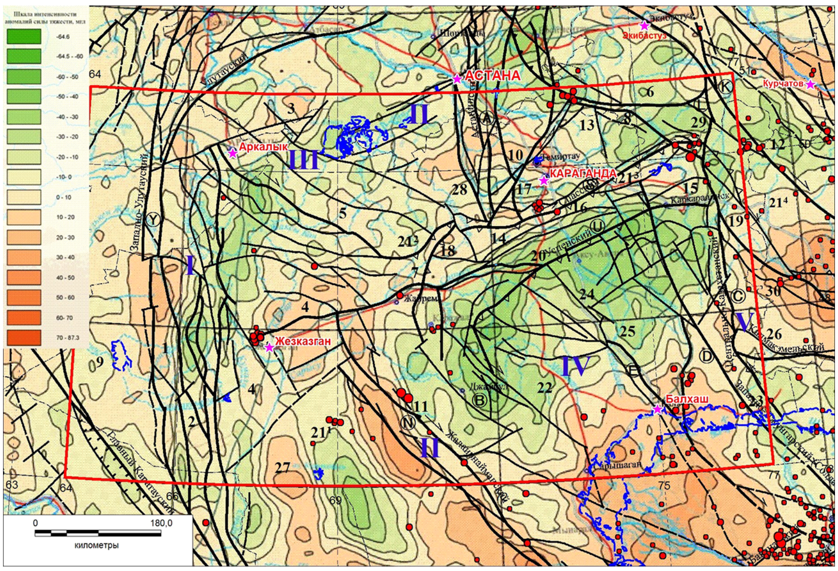

Fig. 3. The scheme of intracrustal transformant of the gravity field, combined with earthquake sources (according to Nusipov E., Belousov N. P., Shatsilov V. I. – 2007, Mazarovich A. O. – 2006). Legend: symbols in Figs. 1 and 2

canic-Plutonic Belt and the Ulutau massif with a negative gravity anomaly intensity of –5÷–40 mGal [15].

In the rest parts of the Kazakh Shield, the distribution of the intracrustal transformant of the gravity field fixes the excess of density masses, manifested in differently directed, highly indented anomalies of positive sign with the field intensity +20÷+70 mGal (Fig. 3).

The configuration and sizes of these anomalies vary in complex dependence on the details of the internal structure and composition of the folded basement.

Local transformant of the gravity field. The distribution of the high-frequency transformant of the gravity field describes the gravity effect from local objects of the Earth's crust with a depth of up to 5–7 km.

The map is presented in isoanomalies with an isoline interval of 5 mGal and is intended for spatial detailing of destruction zones or local density inhomogeneities on the day surface using a complex of geological and geophysical data (Fig. 4).

On this map, the local transformant of the gravity is manifested by a complex combination of positive and negative anomalies, whose intensity varies from –55 to +18 mGal with background reading of ±10 mGal [15, 18].

The form of local anomalies Δ*ga* varies from isometric, polygonal to arc-shaped or linearly-elongated, with some prevalence of the latter (Fig. 4). The peculiarity of the morphology of Δ*ga* anomalies probably has a neotectonic content.

The greatest contrast and informativeness of the anomalies of the local transformation of the gravity field is observed above the outcrops on the day surface of the Pre-Mesozoic basement, where the structure of these anomalies clearly manifests such elements of geological structure as magmatic formations, deep faults, blocks of sedimentary-volcanogenic formations, places where secondary changes in rocks appeare.

Linear-elongated anomalies. They form extended zones/systems of linear-elongated or arc-shaped anomalies. However, it is not uncommon for these zones to contain anomalies of isometric or polygonal shape with increased or decreased values of Δ*ga*, located in an echelon-like or oriented along the faults.

A characteristic feature of the line-elongated anomalies Δ*ga* is their complete coincidence with the structural plans of the anticlinoriums and synclinoriums and the deep faults separating them.

Displacements of tectonic blocks on the planes of these tectonic faults caused the formation of negative gravity steps in the band of Spassk-Ⓢ, Chingiz-Ⓛ, Kalba-Chingiz-Ⓕ thrust faults, as well as the Zhalair-Naiman, West-Balkhash-Ⓑ-Kounrad-Borlin-Ⓔ, West-Jungar-Ⓓ, and Uspensk-Ⓤ faults (Fig. 4).

The Uspensk and Nurinskiy synclinoriums in the gravity field of the local transformant represent a relatively narrow band of sublatitudinal orientation, confined to the Uspensk fault and the Chingizsky thrust, respectively, with anomalies Δga intensity –25÷–50 mGal.

In the band of the Spassk fault, the negative gravity field anomalies of the Spassk, Tekturmas and Atasu anticlines are oriented in the northeastern direction, and their intensity varies in the range –10–15 mGal (Fig. 4).

Within Devonian Marginal Volcano-Plutonic Belt negative anomalies are oriented arc-shaped. On southwest and east flanks of this belt their northwest orientation is observed, on northern – northeast orientation, and their intensity varies in a range – 5–10 mGal.

At Zhezkazgan depression there are contrastingly expressed negative anomalies, stretched in meridional direction with intensity up to –10–15 mGal, correlating with structural position of this depression (Fig. 4).

Ulutau crystalline basement high and Betpakdala anticlinorium, Zhalair-Naiman synclinorium correlate well with the positive gravity field and are genetically connected with intrusives and effusives of the basic to medium composition and/or blocks of ultramafic rocks.

Positive gravity field anomalies here are oriented submeridionally, and their intensity varies in the range of +10÷+15 mGal. In places, sporadically developed linear gravitational fields of negative sign (from –5 to –10 mGal) are observed.

Isometric and oval gravity anomalies. They are grouped in the form of isometric or oval, polygonal anomalies, which are confined to arched uplifts of the Earth's crust, saturated with intrusive bodies or their erupted analogues, including stocks, batholiths, paleovolcano vents and other local geological formations located en echelon or beaded.

A characteristic feature is inconsistency of orientations of gravity field anomalies with the spatial location of tectonic elements, including faults (Fig. 4). In some way, this indicates the manifestation of some phases of tectogenesis after the completion of the geomagnetic field formation of these tectonic elements.

The exception is the Karaganda depression, where the correlation of structures with the orientation of anomalies Δ*ga* is observed.

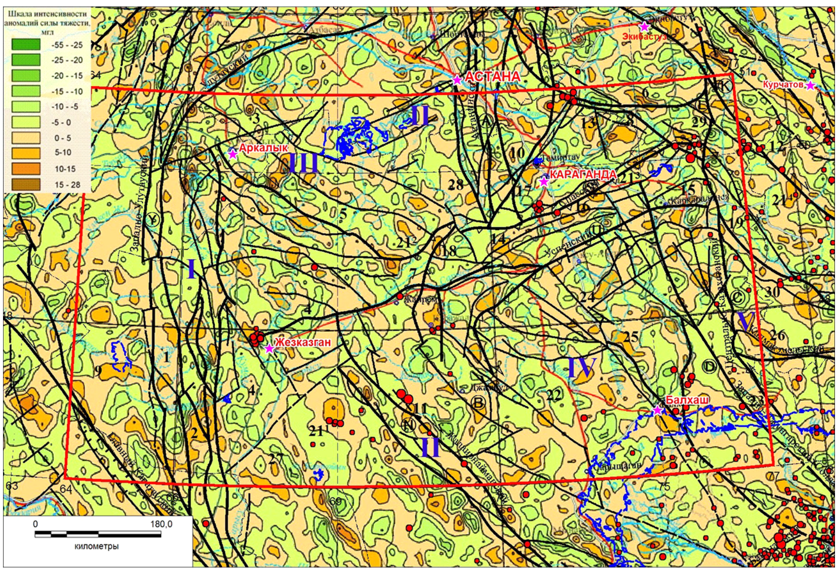

Fig. 4. The scheme of local transformant of the gravity field, combined with earthquake sources (according to Nusipov E., Belousov N. P., Shatsilov V. I. – 2007). Legend: symbols in Figs. 1 and 2

Here, high-relief, polygonal anomalies of the local transformant of the gravity field with intensity up to –5÷–10 mGal are predominantly developed (Fig. 4), presumably associated with shallow post-Carboniferous intrusions, which may be represented by granodiorite outcrops.

Anomalies of the negative gravity fields of the Aktau-Mointy anticlinorium are oriented in the northwestern direction. Their intensity varies within –20–25 mGal, and their shape is polygonal with implicit zonation.

Ermentau (0÷–10 mGal) anticlinorium is differentiated isometric or polygonal weakly expressed negative anomalies. In places, the intensity of anomalies here decreases up to –15 mGal (Fig. 4). The genesis of anomalies is associated with stocks and massifs of Lower Permian syenodiorites. The orientation of the anomalies can be grouped into northeastern, northwestern and meridional directions, inconsistent with the general orientation of the Ermentau anticlinorium.

Teniz depression is differentiated by the presence of large subisometric maxima of the local transformant of the gravity field with intensity of +15÷+25 mGal.

Mosaic systems of alternating geomagnetic field anomalies. They form a set of isometrics (including circular, polygonal), irregularly shaped chaotically located positive and negative anomalies of different intensity (Fig. 4).

At the Boschekol and Maikain anticlinoriums, Seletinskaya, Shederty and Bayanaul synclinoriums low-intensity alternating anomalies Δga, confined to mapped stocks and massifs of Lower Permian syenodiorites, alaskites, granodiorites were distributed [16].

The North Balkhash anticlinorium, Zhaman-Sarysu and Tokrau synclinoriums are differentiated by a complex character of the local transformant of the gravity field. Here, the intensity of this transformant is –10–15 mGal with a consistent decrease in the southeastern direction to 0 + 5 mGal. The nature of these anomalies is associated with intrusions of the North Balkhash (Kounrad) and Sayak structural-formation zones.

To the East and Northeast of the Central-Kazakhstan and Chingiz deep faults in the gravity field there is a region of poorly differentiated mosaic anomalies with intensity –10–15 mGal, which spatially tend to the Chingiz anticline, Kalmakemel and Bakanass synclinoriums.

The area with Dzungar-Balkhash of Hercynian folding is differentiated by the complex character of gravity field with intensity of anomalies of both signs from –10 to +20 mGal (Fig. 4). The orientation of these anomalies here weakly correlates with the orientation of tectonic elements of the Dzungar-Balkhash folded system.

Discussion. The nature of the transformations of the gravitational field of Central Kazakhstan for the past 60 years has repeatedly become the subject of the closest attention from the leading scientists of Kazakhstan, near and far abroad.

For example, in the opinion of D. N. Kazanly (1959), I. P. Benevolenskiy, E. I. Patalakha (1975) and other researchers, a drastic decrease in the intensity of the regional component of the gravity field in the central part of the CKGM is caused by low density of the upper layer of the consolidated crust, composed by widely represented intrusions of granitoids and volcanoplutonic complexes of the Balkhash-Ili belt of lower density. In its northern part, the CKGM is compensated by the calculated gravitational minimum, which coincides with the troughs of the surfaces of the granite-metamorphic, granulite-mafic layers and the Moho discontinuity [20].

In retrospective, the geological nature of the CKGM was also linked to other factors: a) the trough of the Moho discontinuity (Brodovoy V. V., Bekzhanov G. R., Kolmogorov Yu. A., 1963); b) manifestation of the Late Paleozoic orogenesis (Benevolensky I. P., 1968); c) the arch effect of the Earth's crust during the subsidence of the surface of the upper mantle (Bekzhanov G. R., Lyubetsky V. N., Polevaya L. P., 1975); d) doubling the thickness of the Earth's crust during large-scale thrusts (Koshkin V. I., 1991).

In the last two decades, the concept of the relationship between the CKGM and the processes of rifting has become more and more popular. According to the ideas of Lyubetsky V. N., Lyubetskaya L. D., Naumenko A. V., et al. (1989, 2016), Akylbekov S. A. (1996), Shabalina L. (2005), Istekova S. A. (2007), the CKGM fixes the areas of intracontinental riftogenesis, which were formed in the conjunction area of several lithospheric microplates with the ancient sialic basement: Northern Kazakhstan from the north, Aktau-Jungar (Balkhash) from the south, Issykkul-Moinkum from the southwest, Chingiz-Tarbagatai from the north-east [21].

In our opinion, territorially, the CKGM corresponds to the area of the paleorift system, covering Nury, Karasor, Uspensk, Zhaman-Sarysu; Tokrau, Kalmakemel and Bakanas synclinoriums, Spassk, Tekturmass, Atasu, Aktau-Mointy, Nortern-Balkhash anticlinoriums (Fig. 2).

Similar gravity minima of high intensity are characteristic of many intracontinental rift systems, e. g. East African, Baikal, etc. The diversity of the above points of view indicates that the problem of further study of the nature of the CKGM remains relevant [5, 20].

According to [13,16], the results of modeling of the deep structure of Central-Kazakhstan paleorift system by the complex of geological and geophysical data indicate that in its southeastern part the character of gravity anomalies is probably related to the rise of mantle substance and its intrusions into the Earth's crust. These processes were accompanied by flows of mantle fluid, opening of rift zones, and outpourings of basalts of increased alkalinity.

The results of the authors' studies show that in the field of the regional component of gravity, large minima (up to –105 to –270 mGal) are distinguished in the areas with Hercynian folding. Intermediate values (from +15 to –70 mGal) appear in the areas of the Caledonian folding. Relatively, the maximum values of the anomalies Δ*ga* (up to +25÷+40 mGal) appear in the areas of pre-Paleozoic folding [18].

In addition, along the periphery of the CKGM and at the suture zones with different age of basement consolidation, earthquake sources are concentrated, most of which are lumped in the gradient zones of geothermal, geomagnetic and density anomalies of the consolidated crust [22].

It is of interest that there is no obvious geospatial relationship between the morphology of the Moho discontinues and the distribution of regional gravity anomalies. For example, the structure of the Moho discontinues exhibits a well-defined submeridional zoning of the linearly-elongated tectonic elements (highs and troughs), whereas the regional field of gravity anomalies has developed polygonal, mosaic forms, with a limited role of linearly-elongated forms [16, 18].

At the level of intra-crustal heterogeneities there is a complication of the pattern of distribution of gravity field anomalies, the degree of their differentiation in morphology, size, strike and tension increases, which reflects heterogeneities and a wide variety of geological bodies in the granite-metamorphic and granulite-mafic layers.

At the same time, in the field of the intra-crustal transformant, the area of distribution of gravity anomalies has significantly decreased in size. The presence of uplifts was revealed in the structure of the consolidated crust. Some of them are confined to the top of the granite-metamorphic layer with a thickness up to 15–20 km and excessive density of 0.05 g/cm^3. Another part is associated with the surface of the granulite-basite layer with a thickness of 20–25 km and an excess layer density of 0.1 g/cm^3 [16, 18].

In order to compensate the actually observed parameters of the gravity field, steeply dipping column-shaped bodies – diapirs with a density deficit of 0.063 g/cm^3 [19], were implemented into the subcrustal layer at depths from 45 to 170 km and conventionally identified with the deep mantle plume, whose tops are intruded in the lower crust.

Petrographic composition of these diapirs from top to bottom presumably changes from plagioclase to spinel and garnet peridotites [20].

In accordance with the results of the authors' studies, the CKGM and adjacent areas are differentiated by reduced values of thermal fields on the slices of the consolidated crust 10 and 30 km [23].

From here, westward, towards the Ulutausky high of the metamorphic basement, the consolidated crust density and geothermal anomaly values increase, which is directly related to the different thermal conductivity of the rocks composing the consolidated crust [23].

It is important to add to this that areas with minimum temperatures correspond to a wide range of changes in the value of the gravitational field, while in the direction of areas with increased temperatures, the range of changes in the values of gravity anomalies reduces. This petrophysical phenomenon is yet to be studied.

The distribution of the local gravity field transformants shows strongly laterally varying gravity anomalies, whose intensity values vary within a relatively narrow range of ±10 mL. This reflects high-frequency gravity effect from local near-surface crustal objects up to 5–7 km deep [15].

In the field of local gravity transformants anomalies are characterized by different sizes and orientations, with high-relief, polygonal to arc-shaped, linear-elongated and isometric shapes and not amenable to zoning, often not controlled by faults. The genesis of these anomalies is associated with shallow geological heterogeneities that have no "deep roots" However, it is possible that this feature probably has a neotectonic content [24].

In continuation of this paradigm, according to the results of the authors' studies, it was found that areas with Hercynian folding are isolated by extremely high amplitudes of the latest crustal movements (+600+1000 meters). The orientation of the anomalies is consistent with the strike of the tectonic faults [24, 25].

Areas with Late Caledonian folding in the field of latest crustal movements are differentiated by high values of amplitudes (+400+800 meters and more). The anomalies are characterized by polygonal forms and in plan repeat the geometric forms of tectonic elements.

In areas with Early Caledonian folding, the amplitudes of the latest crustal movements are +300+600 meters. Areas with Pre-Paleozoic folding are differentiated by minimal values of the latest crustal movements, which have a block-mosaic character, and their amplitudes increase from west to east from +100 to +400 meters [25].

Conclusion. The studies carried out on tectonics and structure of gravitational fields of Central Kazakhstan give the reason for the following conclusions:

In the field of the regional transformant of gravity anomalies three large lithospheric blocks are isolated, bounded by zones of high gradient steps: a) Central Kazakhstan Gravity Minimum; b) area of variable values of gravity field anomalies; c) Ulutau relative gravity maximum.

From the ground surface, these blocks correspond to different-age geological structures: blocks of Precambrian rocks, Early and Late Caledonides, Early and Late Hercynides, and Upper Paleozoic volcanic-plutonic belts.

At the early stages of the study on Central Kazakhstan, the genesis of gravity anomalies was associated with a trough along the Moho surface, the manifestation of the Late Paleozoic orogenesis, the doubling of the crustal thickness during large-scale thrusts and other concepts. At the later stages of the study, the concept of relationship between gravity anomalies and the processes of Paleozoic intracontinental riftogenesis dominate.

In the field of the regional component of gravity field, large minimums are differentiated in the areas with Hercynian folding. Intermediate values are manifested in the areas with Caledonian folding. Relatively maximum values of the anomaly Δga – in areas with pre-Paleozoic folding.

Along the periphery of the CKGM and at the junction of areas with different age of basement consolidation, the earthquake sources are concentrated; most of them stand apart within the gradient zones of geothermal, geomagnetic and density anomalies of the consolidated crust.

At the level of intra-crustal heterogeneities there is a complication of the pattern of distribution of gravity field anomalies, their degree of differentiation on morphology, extension and intensity increases, which reflects a wide variety of geological bodies at the level of granite-metamorphic and granulite-basite layers. At the same time, the area of distribution of negative gravity anomalies significantly decreased in sizes.

The CKGM and adjacent areas are differentiated by reduced values of thermal fields at the slices of the consolidated crust 10 and 30 km [22]. From here, westward, towards the Ulutau high of the metamorphic basement, the density of the consolidated crust and the values of geothermal anomalies increase, which is directly related to the different thermal conductivity of the rocks composing the consolidated crust.

Regions with minimum temperature values correspond to a wide interval of changes in the gravity field values, whereas towards regions with increased temperature values, the diapason of changes in the values of gravity anomalies is reduced.

The distribution of the local transformant of the gravity field shows the existence of anomalies, highly variable in a relatively narrow range, which reflects the high-frequency gravity effect from local near-surface objects of the Earth's crust to a depth of 5–7 km. The shape of local anomalies varies over a wide diapason and, in all likelihood, has a neotectonic content.

The areas of Hercynian folding are differentiated by abnormally high amplitudes of the latest crustal movements. The Late Caledonian folding areas are differentiated by increased values of these amplitudes. The orientation of the anomalies is consistent with the strike of tectonic faults. These anomalies are characterized by polygonal forms and in plan repeat the geometric forms of tectonic elements.

In areas with Early Caledonian folding, the amplitudes of the latest crustal movements take reduced values, whereas areas with Pre-Paleozoic folding are differentiated by minimal values of the latest crustal movements and have a block-mosaic character.

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Тектоніка та структура гравітаційного поля Центрального Казахстану

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Мета. Виявлення характеру прояву різновікових тектонічних елементів Центрального Казахстану у гравітаційних полях за результатами розрахунку регіональної, внутрішньокорової та локальної трансформантів.

Методика. Синтез і аналіз даних з комплексної інтерпретації й моделювання гравітаційних, геомагнітних, геотермічних полів, новітніх рухів земної кори й параметрів сейсмічного режиму, тектоніки та стратиграфії гірських порід.

Результати. Регіональні, внутрішньокорові та локальні неоднорідності в літосфері по-різному проявляють себе у блоках докембрійських порід, ранніх і пізніх каледонідів, ранніх і пізніх герцинідів. Вони можуть бути пов'язані з процесами палеозойського внутрішньоконтинентального рифтогенезу, з підйомом мантійної речовини та впровадженням їх у земну кору з подальшим проявом пізньопалеозойського орогенезу, подвоєнням потужності земної кори, виливами магматичних формацій.

Наукова новизна. Установлено, що великі гравітаційні мінімуми виділяються в районах із герцинською складчастістю, що характеризуються аномально високими амплітудами нових рухів земної кори. В областях каледонської складчастості проявляються проміжні інтенсивності значення аномалій гравітаційного поля, збільшені амплітуди нових рухів земної кори. Області з допалеозойською складчастістю мають відносні максимуми гравітаційних аномалій і мінімальні значення нових рухів земної кори. На стику областей із різним віком консолідації фундаменту, у градієнтних зонах геотермічних, геомагнітних і гравітаційних аномалій, у консолідованій корі концентруються вогнища землетрусів. За варіаціями внутрішньокорової складової встановлено, що областям із мінімальними значеннями температур відповідає широкий спектр змін значень гравітаційного поля, тоді як в областях зі збільшеними значеннями температур інтервал змін значень аномалій сили тяжіння скорочується. Розподіл локальної трансформанти гравітаційного поля свідчить про існування дуже мінливих аномалій, що відображає високочастотний гравітаційний ефект від приповерхневих об'єктів земної кори.

Практична значимість. Розподіл неоднорідностей з різними щільнісними, геомагнітними і геотермічними аномаліями геофізичних полів, характером прояву сейсмічного режиму та нових рухів земної кори зумовили формування геоструктур з різним типом зруденення, на кожному із яких рекомендується провести пошукові й розвідувальні роботи специфічним раціональним комплексом геофізичних методів.

Ключові слова: *гравітаційне поле, геотермічне поле, геомагнітне поле, регіональна трансформанта, внутрішньокорова трансформанта, локальна трансформанта, тектонічні розломи, сейсмічність*

The manuscript was submitted 05.03.23.