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STRUCTURE OF THE GRAVITATIONAL FIELD AND GRAVITY-DISTURBING OBJECTS OF THE SOUTH TORGAY SEDIMENTARY BASIN

Purpose. Study of the distribution of density heterogeneities at various slices of the Earth's crust in the South Turgay sedimentary basin (STSB). Identification of the correlation relationships of these heterogeneities with the structure, geodynamic processes, and tectonic evolution of this basin.

Methodology. Geological interpretation of regional, intracrustal, and local gravity field anomalies, incorporating data from seismic and magnetic surveys, geothermal studies, and neotectonic dislocations.

Findings. The spatial distribution of density heterogeneities at different lithospheric slices of the STSB has been identified, along with the locations of gravity-disturbing mass centers, as well as the extent, shape, and intensity of anomalous bodies and their burial depths. In the depth range of 30–150 km, a pronounced block heterogeneity of the STSB's lithosphere is observed, revealing significant differences in the intensity, morphology, polarity, orientation, and gradient variations of the transformed gravity anomaly (Δg_{reg}) compared to the adjacent areas of the Lower Syrdarya Horst and the Shu-Sarysu Depression. At depths of up to 25–30 km in the consolidated crust, manifestations of horizontal shear deformations have been established, along with the internal structure and contrast of intra-crustal interblock boundaries. No significant differences between the STSB and the Lower Syrdarya Horst have been identified in the intra-crustal gravity transform field, while distinctions from the Shu-Sarysu Depression have been observed. At depths of up to 7 km, local gravity-disturbing objects show a clear correlation with the depth to the top of Paleozoic formations, effectively tracing fold belts concealed beneath Mesozoic-Cenozoic deposits.

Originality. For the first time, assumptions have been made for the region about significant differentiation in the depths and ages of major faults, which indicates amplitudes of shifts at the level of regional, intracrustal and local heterogeneities of the lithosphere. At the base of the earth's crust of the STSB along the Moho discontinuity, a trough is recorded, under which an active mantle zone is observed, increased horizontal gradients of the base of the earth's crust are fixed. A unique geological phenomenon has been revealed, according to which the main geonomic boundaries of the earth's crust are conformable, which clearly confirms the rift nature of the STSB.

Practical value. The obtained data can be utilized for developing new approaches to geological exploration, its planning and assessing the oil and gas potential of the STSB; as well as to optimize the location of exploration and appraisal wells and design wells targeting new oil and gas prospective formations within the complexes of the quasi-platform structural level. The research results will contribute to a better understanding of the distribution patterns of deep-seated density, structural, geomagnetic, and geothermal heterogeneities at various levels of the lithosphere, their correlation with modern tectonics and the geological evolution history of the STSB. Moreover, they can serve as a foundation for future scientific research aimed at studying geodynamic processes in this basin as well as for adapting the proposed methodology to other oil and gas basins.

Keywords: *gravitational field, transformants, heterogeneities of the lithosphere, seismic surveys, magnetic surveys, geothermal studies, neotectonic dislocations*

Introduction. Structurally, the South Torgai sedimentary basin (STSB) is bounded to the east and southeast by the submeridionally oriented Ulytau meganticlinorium and the mountain-fold structures of the Greater Karatau, which separate it from the Shu-Sarysu Depression (SSD). To the west and southwest, this depression borders on the subsidence of the Lower Syrdarya Horst (LSH).

Its northern boundary is conventionally defined by the Zhylyanshyk depression, while to the south and southwest, it is delimited by the Greater Karatau Fault (abbreviated hereafter as GKF).

The modern structural plan of the subsurface horizons of the STSB has been well studied through seismic surveys. Based on this data, the depression is divided into the Zhylyanshyk depression in the north and the Aryskum depression in the south, separated by the Mynbulak saddle (Fig. 1).

The origin and formation conditions of the crystalline basement rocks of the STSB remain a subject of considerable scientific debate.

According to [1, 2], the basement of the STSB is composed of a variety of deep metamorphosed Precambrian rocks similar to the Bekturgan and Maitobe series of Ulytau of Proterozoic, in some places of Lower Paleozoic (Cambrian-Ordovician).

Pre-Paleozoic formations of the Aryskum Trough were encountered during drilling in well Aryskum 2-P, where they are represented by gneisses of quartz-biotite-plagioclase composition. In the basement of the Zhylyanshyk Trough, amphibolitised gabbros were found in the Uzynshik structure in well 1-G at depths of 2,924–2,931 m [2].

Based on pre-Mesozoic deposits, the STSB was recognized as an independent geostructural unit in the early 1980s. According to some researchers, this basin is composed of Meso-Cenozoic formations in two struc-

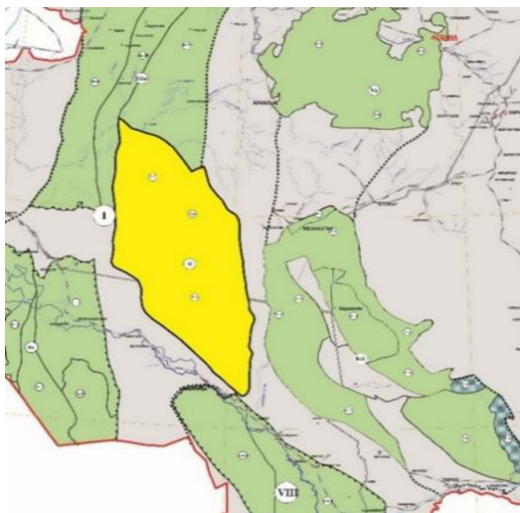


Fig. 1. Location scheme of the South-Torgai oil and gas bearing region (modified from U. Akchulakov, et al., 2012):

Symbols: PP — petroleum province, PR — petroleum region, PPD — potential petroleum district, GD — gas bearing district. Numbers: III-Aralo-Torgay OGP: III-7 Zhylyanshyk PPD, III-b South-Torgay PR, III-6 Aryskum OGP, III-8 Mynbulak district, V Teniz-Shu OGP, Vb-Shu-Sarysu PR: V-4 Zhezkazgan NGD, V-5 Kokpansor GD, V-6 Tasbulak GR, V-7 Suzak-Baikadam GD, V-8 Moinkum GD, Va Teniz PR: V-1 North-Western NGD, V-2 North-Eastern NGD, V-3 Teniz PPD

tural levels: the Jurassic system taphrogenic (riftogenic) and the platform Cretaceous-Paleogene [3, 4].

Alternatively, other researchers distinguish three structural levels within the STSB: the lower level representing the basement, the middle level as quasi-platform, and the upper — orthoplatform [5].

The lower structural level is characterized by significant rocks dislocation, including highly metamorphosed effusive and intrusive formations disrupted by a series of fault systems.

The middle — quasi-platform level is distinguished by a pronounced angular and stratigraphic unconformity.

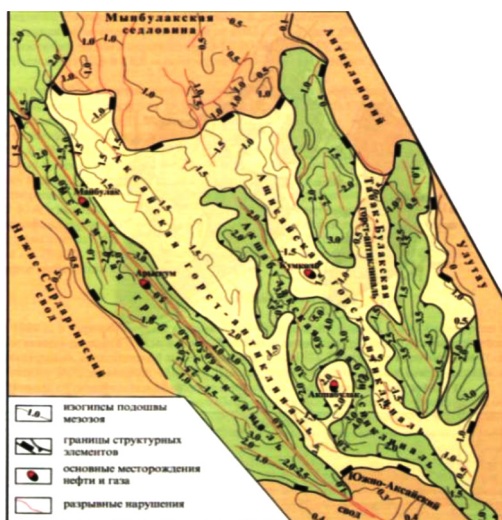


Fig. 2. Aryskum depression. Pattern of geological oil and gas zonation of the sedimentary cover (according to Abilhasimov H. B., 2007)

The Mesozoic-Cenozoic sediment strata forming the upper structural level of the sedimentary cover is divided into two levels: rifted in its lower part and epirift (orthoplatform) in its upper part.

This level is well studied by deep drilling and geophysical exploration methods. Its structural differentiation is quite well-defined, which makes it possible to identify a system of submeridionally oriented linear grabens separated by horsts (Fig. 2) [2, 4, 6].

Within the Aryskum trough, the Aryskum, Akshabulak, Sarylan and Bozingen grabens are clearly distinguished from west to east, separated by the Aksai, Aschisai and Tabakbulak horsts. The boundaries between these structural elements are faults in most cases (Fig. 2).

Deep drilling, conducted with consideration of the structural features of Mesozoic formation, allows for the identification of several characteristic sections that most accurately reflect the geological parameters of the STSB.

For example, the Aryskum, Sarylan, Akshabulak, Bozingen and Mynbulak type sections.

Geological-structural factors controlling the distribution of gas and oil fields across the area and stratigraphic section allow the identification of a Jurassic-Neocomian regional oil and gas-bearing play in the STSB and a zonal oil and gas-bearing play associated with the weathering crust of pre-Mesozoic formations.

In the STSB, 17 fields have been discovered to date. Among them, the Arysskoye and South Konys fields are gas-condensate, while the others are oil and gas-condensate. Among the largest in terms of oil reserves are the Kumkol, Akshabulak, and Konys fields.

Vintage data on gravimetric survey. In the STSB systematic gravimetric surveys have been conducted since the early 1950s during the stages of regional, prospecting, and detailed geophysical studies by various organizations and authors to address a wide range of geological objectives.

From 1952 to 1986, during the regional stage of geological exploration, gravimetric surveys were conducted at scales of 1:500,000 and 1:200,000 using GKA-NIIGR gravimeters. The surveys were performed by the Jezkazgan, Turlan, Amangeldy, and Burchogur geophysical expeditions, as well as the Kazakhstani Aerogeological and Geophysical Expedition, involving advanced researchers such as V. I. Burtman, N. Y. Kunin, A. V. Lapin, N. I. Durnev, K. K. Kakhramanov, Y. A. Popov, Y. G. Khromov, and others.

Based on the results of these efforts, maps with a contour interval of 2 mGal were constructed, and the following geological objectives were resolved:

1. Tectonic, lithological and petrographic zoning of major tectonic elements — uplifts and depressions in the relief of the folded basement — was carried out, areas of accumulation of thick sedimentary layers, boundaries of large tectonic elements, and deep crustal faults were highlighting.

2. Geological zoning was carried out with the aim of creating oil and gas geological maps and identifying areas for more detailed seismic exploration and deep drilling.

In the late 1950s and early 1960s, a prospecting gravimetric survey at a scale of 1:100,000 was carried out in

the STSB (by V. E. Evsyukov, A. I. Volkov, and others), based on the results of which a map with a contour interval of 1 mGal was created.

From 1961 to 2002, prospecting gravimetric surveys at a scale of 1:50,000 continued in the areas of this sedimentary basin, carried out by the Jezkazgan, Krasnoholm, Turlan, and Kustanai Geophysical Expeditions, Azimut Energy Services, Agadyr Complex Geological and Geophysical Expedition, Geophysical Expedition "Geofizservis" (Zhurbitskiy B. I., Stashevskiy N. L., Beznedelnyy B. D., Glushkovskaya D. I., Ibragimov V. G., Amireshev K. S., Alexeev L. A., Rezenko G. A., Bozhok N. I., Ryzhenko G. E., Ivanov M. V., Shkolnikov I. Kh., Miroschnichenko S. N., Turmagambetov R. E., Bichevoy M. G., Rekalo V. P., and others).

Based on the results of these studies, maps at a scale of 1:50,000 with sections of 0.2, 0.25 and 0.5 mGal were created. The following geological objectives were addressed during the prospecting stage:

1. Study of the tectonic structure of separate areas of the STSB and mapping of the crystalline basement for subsequent investigations with other geological and geophysical methods to identify areas prospective for oil and gas.

2. Detection of significant hydrocarbon accumulations within the host rocks.

The gravimetric survey during the prospecting stage was carried out using the following gravimeters: SN-3, Norgard, GAK-3M, GAK-4M, GAK-PT, KVG-1M, GAK-7T, GAK-VT, GAK-PTM, GNU-K2, GR/K2, GR/K1, KVG-1M, GAK-4V, Delta-2, GR/K1, GNU-KS, GAG-2.

Between 1974 and 1992, detailed gravimetric surveys at a scale of 1:25,000 were conducted by the Turlan Geophysical Expedition (Mametov K. M., Amireshev K. Sh., et al.) and the Aero-geological-Geophysical Expedition of the Kazgeophysics State Production Geological Association (PGA) (Akhmetov A. A., Zolotrubov A. V., et al.). The resulting work produced a map at a scale of 1:25,000 with a contour interval of 0.2 mGal.

From 1968 to 1992, detailed gravimetric surveys at a scale of 1:10,000 were carried out by the Amangeldy and Kustanai Geophysical Expeditions, as well as the Aero-geological and Geophysical Expedition of the Kazgeophysics PGA (Beznedelny B. D., Popova G. S., Ivanov V. M., Nichipurenko A. M., Akhmetov A. A., Zolotrubov A. V., et al.). The outcomes of these efforts include maps at a scale of 1:10,000 with contour intervals of 0.1 and 0.2 mGal.

Between 1979 and 1982, gravimetric surveys at a scale of 1:5,000 were conducted in the STSB by the Kostanay Geological and Geophysical Expedition (S. E. Yesinalinova and V. D. Nemenushchaya). Based on the results of the study, a map at a scale of 1:5,000 with a contour interval of 0.1 mGal was created.

Detailed gravimetric surveys were conducted using gravimeters such as GNU-KV, GNU-KS, GNU-K2, GR/K2, Delta, GAK-7T, GAK-PTM, Delta-2, GNU-K1, and GAK-PT at scales of 1:25,000, 1:10,000, and 1:5,000. These surveys aimed to address the following objectives:

- identification of local structural forms favorable for hydrocarbon accumulation and faults tracing;

- determination of the shape, size, and orientation of gravity-disturbing objects and their lithological and petrographic differentiation.

In addition, a large volume of gravimetric exploration was carried out in profile variants: gravimetric surveys (1961–1981), surveys along seismic profiles (1958–1965), and gravimetric surveys along interpretational profiles (1959–1991).

Findings. STSB is characterized by a high degree of gravimetric study, therefore deep structures are a priori adequately supported by gravimetric data.

Gravimetric studies have made a significant contribution to understanding the geological evolution of the STSB, despite the complexity of tectonics of this basin. According to calculations by separate researchers [1, 6], the gravitational effect from the main layers of the Earth's crust accounts for 91 % of the observed gravity field.

Based on the maps and graphs of Δg_{obs} (Δg_{loc} and Δg_{reg}), using the solution of direct gravity exploration objectives, qualitative conclusions were made about the density inhomogeneities that create these anomalies. The locations of the centers of gravity-disturbing masses were determined, the extents and shapes of anomaly-causing bodies were identified, and conclusions were drawn about the depth of these bodies.

Positive anomalies correspond to the location of rocks with excess density, while negative anomalies correspond to rocks with a density deficit, as well as changes in the position of the boundary where there is a sharp density contrast in the rock formations.

Regional gravity field transformant. The regional transformant of the gravity field represents the total effect from various combinations of lower crustal and upper mantle high- and low-density inhomogeneities located at different depths. The method of analytical extrapolation of the observed field into the lower half-space was applied to correlate them with depths.

The regional gravity field transformant effectively highlights the block structure of the lithosphere within the depth range of 30–150 km.

A set of gravity field maps and its components, created through digital transformation of the raster version of the gravity field map at a scale of 1:1,500,000, published in 1984 under the editorship of T. A. Akishev and I. Yu. Schneider [6], became the basis for the calculation of the regional transformant.

The transformation procedure itself involved creating a linear rectangular matrix of gravity field values, ensuring its smoothing according to the 1:1,500,000 scale; correlating this matrix with the chosen grid of geographical coordinates, and separating the observed field into orthogonal components [6].

The resulting regional transformant map of the gravity field, supplemented with other geophysical data, is compiled with contour lines of anomalies at intervals of 10 mGal, and the values of the transformant itself range from –160 to +55 mGal. At the same time, the sizes of the identified regional gravity anomalies significantly exceed the areas of the tectonic elements delineated on the surface of the folded basement (Fig. 3).

The STSB is characterized by weakly intense minima of the regional transformants Δg_{reg} with intensity values ranging from –10 to –125 mGal, with anomaly morphology that does not correlate in shape, strike, and localization.

tion with tectonic elements on the Paleozoic surface, except for: a) Tabakbulak horst and the Sarylan graben; b) The southern periphery of the STSB in the GKF zone.

In these regions – particularly in the northeast, southeast, and south (along the GKF) of the STSB – large, weakly intensive linear gravity maxima with a submeridional orientation are observed in the transformants field Δg_{reg} . These features are characterized by intensity values reaching +10 to +15 mGal or higher (Fig. 3).

In the LSH, located to the west, positive Δg_{reg} anomalies of a different configuration are observed. These anomalies are predominantly polygonal in shape, with intensities reaching +5 to +25 mGal and dimensions of up to 230×60 km. Moreover, they are weakly susceptible to zoning (Fig. 3).

In contrast, in the SSD, situated to the east of the STSB, the Δg_{reg} transformant field is characterized by negative, linear, meridional gravity minima, with intensities ranging from -120 to -160 mGal and sizes of $22-58 \times 28-32$ km [7].

To the west of this depression, in the zone of the Ulytau Fault, the sharp gravity steps is observed, associated with deep faults that serve as natural tectonic barriers, within which there is a reversal of the sign of the regional transformant of the regional gravity field (Fig. 3).

Since the Ulutau fault directly influences the distribution of the transformant Δg_{reg} , it is recognized as a lower crustal or upper mantle level of its origin, with functions to delineate large-scale lithospheric density heterogeneities.

A right-lateral horizontal shift with an amplitude of up to 30 km is observed along the Ulutau fault (Fig. 3).

It is assumed that the formation time of this fault (of

a strike-slip nature) dates back to the pre-Paleozoic or Lower Paleozoic, as the petrographic composition of Lower Paleozoic and Precambrian rocks to the west and east of the fault shows significant differences. After its generation, the Ulutau fault has been reactivated multiple times (for example, in the Early and Middle Paleozoic).

The chaotic orientation of anomalies of the regional transformant of the gravity field within the GKF zone (except for its southeastern fragment), along with the absence of evidence indicating the influence of this fault on the morphology and intensity of the Δg_{reg} anomalies, suggests that it does not affect the heterogeneities of the lower crust and upper mantle (Fig. 3).

Therefore, it can be asserted that in STSB:

1. The field of the regional gravity transformant significantly differs from the LSH to the west and the SSD to the east in terms of morphology, sign, orientation, and gradients variations of Δg_{reg} anomaly.

2. Weakly intensive minima of the regional gravity transformant are distinguished, while in the LSH, predominantly polygonal maxima of Δg_{reg} anomalies are observed, which are difficult to zonation. In contrast, the SSD is characterized by intensive, linear, meridionally elongated minima of Δg_{reg} .

3. The depth of origin and age of major faults are significantly differentiated. While the Ulutau fault is recognized as having an upper mantle level of generation and is dated to the Early Paleozoic or Precambrian, faults such as the GKF and Sevastopol show no manifestation in the field of the regional gravity transformant, suggesting a shallower level of its formation.

Intracrustal transformant distribution. The intracrustal transformant distribution enables the characterization of structural and density heterogeneities of the Earth's crust down to depths of 20–25 km. It allows for identifying density variations and ranked tectonic faults at various depths, as well as characterizing the internal structure and contrast of intracrustal interblock boundaries.

The intracrustal transformant map, constructed with a contour interval of 10 mGal (Fig. 4), was compiled by recalculating the observed gravity field into the lower half-space. The resulting map provides objective information about the distribution of anomalous density bodies within the granite-metamorphic layer of the Earth's crust [7].

In addition, it provides the capability to classify intracrustal heterogeneities based on density characteristics and to rank tectonic fault zones according to the depth of their penetration [6].

In the intracrustal transformant field, the STSB is characterized by an excess of density masses (+15 to +30 mGal), with a deficit of density masses (up to -30 mGal) observed only in its southern and western peripheral areas (Fig. 4).

At the same time, areas with positive anomalies of the intracrustal transformant have expanded compared to the regional component of the gravity field, reaching exceptionally large sizes (over 52,500 km²).

The range of variations in the intracrustal gravity transformant within the STSB fluctuates from +30 to -25 mGal. The number of linearly elongated anomalies has also increased compared to the transformant anomalies of Δg_{reg} (Fig. 3).

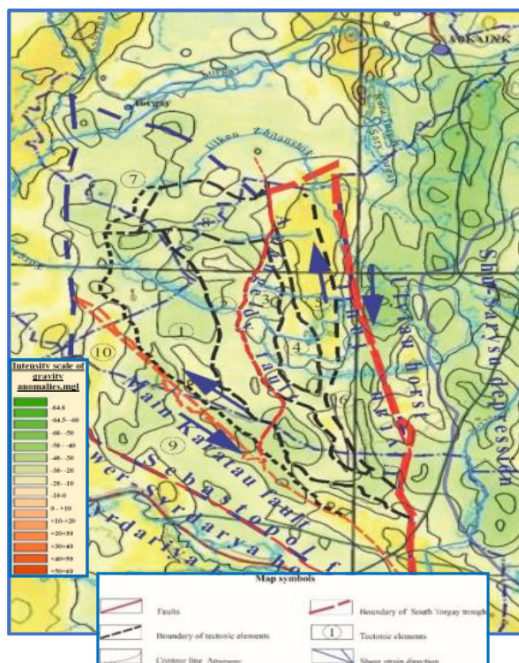


Fig. 3. Map of the regional transformant of the gravity field in the STSB and adjacent regions. Modified after Nusipov E.N., Shatsilov V.I., Uzbekov N.B. (2007) [6]:

Symbols: 1 – Aksai horst; 2 – Besoba-Terensai graben; 3 – Ashchisai horst; 4 – Sarylan graben; 5 – Tabakbulak horst; 6 – Bosingen graben; 7 – Zhylyanshyk trough; 8 – Mynbulak saddle; 9 – Aryskum graben

In the eastern part of the STSB, including the Tabakbulak horst, as well as the Sarylan and Bozingen grabens, linear anomalies with submeridional orientation are identified, exhibiting intensity values of +5 to +18 mGal.

For example, the Tabakbulak positive anomaly (associated with the eponymous horst) has expanded in size and now occupies almost the majority of the STSB (Fig. 4).

Based on the comprehensive interpretation of the regional, intracrustal, and local transformants (below) of the gravity field, it can be concluded that the Tabakbulak horst is likely to be the only feature where heterogeneities with excess density are traceable across all levels of the lithosphere.

To the north, the Tabakbulak intracrustal positive anomaly extends into the Mynsualmas Step and across large areas of the Zhylyanshyk Trough, while to the south, it reaches the Bozingen Graben (with intensity values of +5 to +20 mGal).

Exceptions include the Aryskum Graben, certain areas of the Aksai Horst, and the southern part of the Bozingen Graben, where the intensity of the intracrustal transformant decreases to -15 mGal.

In the Aryskum Graben, in the GKF line, two large linearly elongated negative anomalies with increased intensity (-30 to -20 mGal) and a northwestward orientation are isolated in the negative intracrustal transformant field.

One of these anomalies is located in the center of the Aryskum graben (with sizes 73×35 km), while the other is in its northeastern part (with dimensions 51×10 km). Rel-

ative to each other, they are displaced up to 43 km, thereby confirming the concept of right-lateral block displacement in the upper part of the Earth's crust along the GKF.

In the southeastern continuation of this deep fault, in the northern parts of the Fergana and Naryn depressions, the amplitude of displacement along Paleozoic deposits increases and, according to [8–12], reaches 200 km.

In the southern part of the Bozingen Graben, a large submeridional negative intracrustal transformant anomaly of oval shape is fixed, with sizes of approximately 70×28 km and an intensity of -20 to -30 mGal (Fig. 4).

In contrast, the SSD located to the east, negative linear-elongated anomalies with intensity of -40–50 mGal dominate, and characterized by large sizes (up to 176×67 km).

To the west of the SSD, in the northern part of the Ulytau horst, a significant gravitational minimum is observed with dimensions of 275×66 km in meridional extent and an intensity ranging from -55 to -40 mGal (Fig. 4).

In the LSH, the intracrustal transformant of the gravity field is dominated by big areas of alternating negative and positive anomalies (+5 to -15 mGal), which do not conform to zonation.

Based on the morphology and intensity of intracrustal anomalies, it seems possible to predict the depth of fault penetration. According to the compiled map of the intracrustal transformant (Fig. 4), the GKF, Sevastopol, and Ulytau faults can be traced, which influence the morphology and intensity variations of the intracrustal transformant anomalies.

At the same time, this influence manifests to varying degrees. The contrast and expression of the Ulytau fault have improved in the intracrustal transformant field compared to the transformant Δg_{reg} . This deep fault separates big meridional anomalies of the intracrustal transformant with some horizontal displacement of these anomalies relative to each other, indicating the varying tectonic activity of the Ulytau fault at different levels of the lithosphere in the STSB (Fig. 4).

The obvious contrast in morphology and the intensity of the intracrustal transformant is also observed in the GKF. The possible time of formation of this fault is the Late Carboniferous–Early Permian, based on datings obtained from the continuation of the GKF in the Fergana and Talas Ranges [8, 12].

Thus, based on the above, the following conclusions can be formulated regarding the intracrustal transformant of the observed gravitational field in the STSB:

1. No differences are observed in the morphology and intensity of the intracrustal transformant of the gravitational field between the STSB and the LSH, whereas significant differences are present between this basin and the SSD.

2. The horizontal displacements of linear anomalies of the intracrustal transformant (projections of upper crustal density heterogeneities) on either side of the planes of the Ulytau Fault and GKF likely indicate the potential manifestation of right-lateral horizontal shear (strike-slip) deformations.

3. Compared to the regional transformant, the anomalies in the field of the intracrustal transformant

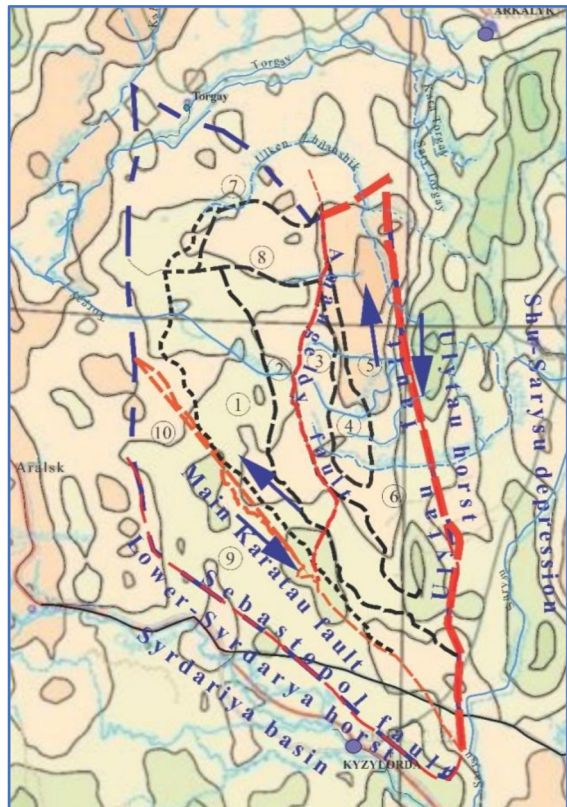


Fig. 4. Map of the intracrustal transformant of the gravity field in the STSB and adjacent regions (modified after Akishev T.A., Shneider I.U., et al., 1984). For other symbols, refer to Fig. 3

have changed their sign and intensity – from a weakly expressed negative gravitational field to contrasting positive anomalies, indicating the presence of rocks with increased basicity in the upper part of the consolidated crust. Additionally, the dimensions of the anomalies in the intracrustal transformant also exceed those of the regional transformant.

4. The number of linear anomalies in the field of the intracrustal transformant has increased compared to the regional transformant, suggesting that folding processes and dislocations have developed more extensively in the upper part of the consolidated crust, down to depths of 25 km. Therefore, it can be concluded that, since linearity is a criterion for folding processes, diastrophic processes were more intense in the upper part of the consolidated crust of STSB and less intense in its lower part.

5. Major deep faults (GKF, Sevastopol, and Ulytau faults), which determine the fragmentation of the South Turgai Depression, are distinguished in the field of the intracrustal transformant of the gravity field with varying degrees of contrast.

The local transformant of the gravity field. The local transformant of the gravity field was evaluated by recalculating the observed gravity field into the lower half-space, as well as by computing higher derivatives of the gravity field. Using maps and graphs of Δg_{loc} , it is possible to determine the location of density heterogeneities causing gravitational disturbances, as well as the direc-

tion of extension and the shape of anomalous objects. Furthermore, the intensity of anomalies allowed for an assessment of their burial depth and the formulation of qualitative conclusions about the density heterogeneities responsible for these anomalies.

Areas with increased Δg_{loc} gradients coincide with sharp contacts between rocks of differing densities, i.e., with deep faults [3, 4].

The Aryskum graben is located within the field of negative Δg_{loc} transformants, with values ranging from +8 to –14 mGal. In the central part of the graben, a small positive isometric anomaly with scalloped edges stands out, measuring 42×19 km and having an intensity of +4 to +8 mGal (Fig. 5).

The morphology and placement of the local transformant of the gravity field are entirely controlled by the GKF and Sevastopol fault (Fig. 5).

Big minima of the geomagnetic field ΔT_a with polygonal, isometric, and sub-isometric shapes are also observed in the Aryskum Graben [4, 9].

The Aksai horst can be characterized by gravity minima Δg_{loc} with values ranging from –8 to –12 mGal, which are consistent with the strike of the structure.

The eastern part of the Aksai horst is distinguished by an elevated background of anomalies Δg_{loc} (up to +4 mGal). In the central and eastern parts of this horst, a higher background of positive Δg_{loc} anomalies is observed, with values ranging from +4 to +16 mGal (Fig. 5).

It is assumed that a deep fault exists, which divides the Aksai Horst into western and eastern parts and forms differences in the geological structure of the horst in different sections. If this is indeed the case, the delineation of this horst within the contours of a single structure is not fully justified.

According to the existing data, the depth of Paleozoic formations in the Aksai Horst varies from 700 to 1,000 m, and in its western part, it deepens to 1,600–2,000 m [2].

The intensity and sign of the local transformant of the gravity field of this horst correlate with the geomagnetic field anomalies [6, 10].

The Besoba-Terensai horst is distinguished by the presence of weak gradient positive Δg_{loc} anomalies (with intensities ranging from 0 to +4 mGal) in a polygonal shape, weakly amenable to zoning. In its northeastern part, a negative anomaly of oval configuration with sizes of 23×32 km and a transformant intensity of Δg_{loc} ranging from 0 to –16 mGal is observed (Fig. 5).

It is assumed that the geological cross-section of the Bessoba-Terensai Horst is composed of less consolidated rocks than those in the adjacent Aksai Horst. Anomalies of both signs are characterized by oval and occasionally polygonal shapes. The structure of the gravity and magnetic fields, in the first approximation, correlates with each other.

The Ashchisai Horst – the gravity field of the transformant Δg_{loc} here is weakly differentiated and is characterized by positive anomalies, creating a background with slightly elevated intensity of +4 to +8 mGal. The northwestern and southeastern parts of the horst are characterized by increased values of the transformant Δg_{loc} , with values ranging from +8 to +12 mGal and dimensions of 43.2×11.5 km (Fig. 5).

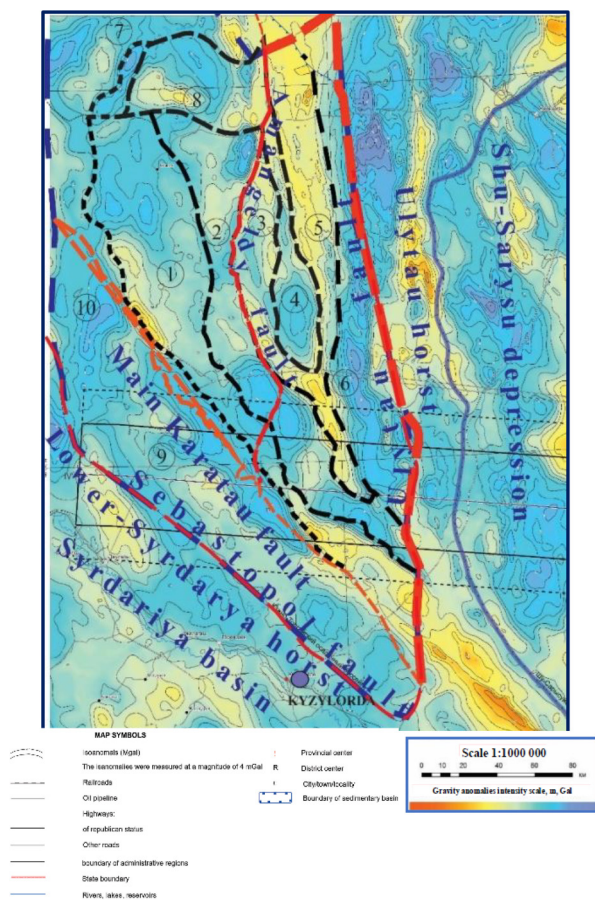


Fig. 5. Map of the local transformant of the gravity field in the STSB and adjacent regions (modified after Akishev T. A., Shneider I. U., et. al., 1984). For other symbols, refer to Figs. 2 and 3

In the center of the horst, negative anomalies of complex configuration are observed, with intensities ranging from -4 to -8 mGal and dimensions of 12×20 km.

Against this background, in the western part of the Aksai Horst, the correlation between magnetic and gravity anomalies is manifested [9].

The Tabakbulak horst is located in a zone of submeridional gravitational maxima with an increased intensity of Δg_{loc} ($+8$ to $+16$ mGal). Maximum intensity values of Δg_{loc} are recorded in the northern part of the horst. (Fig. 5)

Weak-gradient positive anomalies of the transformant Δg_{loc} do not correlate with the smooth field of geomagnetic anomalies [4, 13]. Reliable information on the depth of Paleozoic formations is available only in the southern part of the Tabakbulak horst, where it ranges from 0.4 to ≥ 1.5 km.

The Sarylan graben is located in the zone of gravitational minima. (Fig. 5). In the southern part of the graben, a big negative gravitational anomaly with dimensions of $5,432$ km² and intensity ranging from 0 to -8 mGal is observed. In the northern part of the structure, weak positive gravity anomalies of the transformant Δg_{loc} ($+4$ to $+8$ mGal) are fixed.

The anomalies of the local transformant of the gravitational field exhibit a meridional strike, linear-elongated shapes, and align with the stereomorphic features of the Sarylan graben.

A correlation between negative anomalies of the gravity and magnetic fields is observed [4, 11]. The depth of Paleozoic strata varies significantly, ranging from -100 m in the northern part of the graben to $-3,500$ m in its southern part. The structure is complex, fragmented by numerous faults.

Mynbulak saddle – located in the northern part of the Arysium Depression, is characterized by a negative Δg_{loc} transformant background (-4 to -8 mGal). The anomalies are big in size and polygonal in shape, with intensity values ranging from 0 to -12 mGal. In the southern and eastern parts of the Mynbulak Saddle, positive sub-isometric Δg_{loc} anomalies are distinguished by rugged, fragmented fields. The Δg_{loc} transformant intensity here ranges from $+8$ to $+12$ mGal, with anomaly dimensions in the southern part of the saddle measuring 44×14 km.

The Bozingen Graben is characterized by a negative gravity field with Δg_{loc} values ranging from -4 to -20 mGal. In the central part of the graben, a large minimum with a submeridional strike is observed, with a transformant intensity of Δg_{loc} and dimensions of 51.17×14.47 km. In the eastern part of the Bozingen Graben, a positive transformant anomaly Δg_{loc} with an intensity of $+4$ to $+12$ mGal is located, extending beyond the South Turgai Depression.

The depth of Paleozoic formations in the Bozingen Graben ranges from 300 to $2,000$ m (Li L. V., Petlenko S. V., 2017).

Based on the above, the following conclusions can be formulated:

1. Alternating systems of positive and negative transformant anomalies Δg_{loc} of low intensity have been distinguished, oriented generally in the meridional direction, which trace (immersed) folded Paleozoic belts

beneath the Mesozoic-Cenozoic sediments. To the west of the STSB, negative Δg_{loc} systems dominate, while to the east of this basin, positive systems prevail.

2. The transformant anomalies Δg_{loc} of low intensity are projections onto the daylight surface of immersed folded belts beneath the Mesozoic-Cenozoic deposits, the nature of which has not yet been fully understood. A clear correlation is observed between the intensity of the transformant minima Δg_{loc} and the depth to the top of the basement, which is confirmed by drilling results.

3. The stereomorphs and orientations of Δg_{loc} anomalies generally show similarities with the tectonic plan of the top of Paleozoic formations. However, in many cases, the morphology of the anomalies of transformant field Δg_{loc} does not correspond to the modern structural plan of the STSB at the top of these formations.

4. The placement of the transformant Δg_{loc} , in the first approximation, is controlled by the GKF and Sevastopol fault zones, while the Ulutau and Amangeldy faults do not have a significant impact on the distribution of the transformant Δg_{loc} . This geological phenomenon, to some extent, indicates the different scales of shifts at the regional, intracrustal, and local transformant levels.

Discussion. The correlation between gravitational and magnetic anomalies has provided additional insight into the geological structure of the STSB.

In the Aksai, Bessoba-Terensai, Ashisay, Tabakbulak horsts, and Bozingen graben, there is inconsistency in the orientation, shape, extent, and sign of large and intense gravity and magnetic anomalies. The depth of Paleozoic formations in these areas ranges from 300 to $1,700$ meters.

In the Arysium, Sarylan grabens, and Mynbulak saddle, there is a consistence of negative gravity and magnetic anomalies. Although, in the marginal parts (in the south and east) of these tectonic elements appear anomalies of the opposite sign [4, 13].

The orientation of gravity and magnetic anomalies is northwestward or submeridional. They are controlled by deep-seated faults. The anomalies measure 40×23 – 26 km, being linearly elongated with fragments of polygonal shapes. The depth of Paleozoic formations varies significantly from -100 m to $-3,500$ m [4, 11].

Thus, the long-term stepwise formation of magnetically and gravimetrically disturbing objects in the lithosphere of STSB has contributed to the formation of heterogeneities that, in scale, correspond to groups of structural and formational zones identified on the top of Paleozoic formations.

The deep structure of the Earth's crust in the STSB is unevenly studied using a set of geophysical methods (gravity, magnetic, seismic survey, MMTS).

However, deep seismic study has been limited to the Volgograd-Chelkar-Turgay Deep Seismic Sounding (DSS) profile (M. S. Erenburg, N. N. Belyashova, 1980), specifically the Turgay segment of this profile in the northern part of the Arysium Depression. The results obtained from this study have illuminated the structure of the Arysium Depression to depths of up to 70 km. [1, 14].

The Mohorovičić discontinuity (Moho) is one of the main geonomic boundaries of the lithosphere, separating

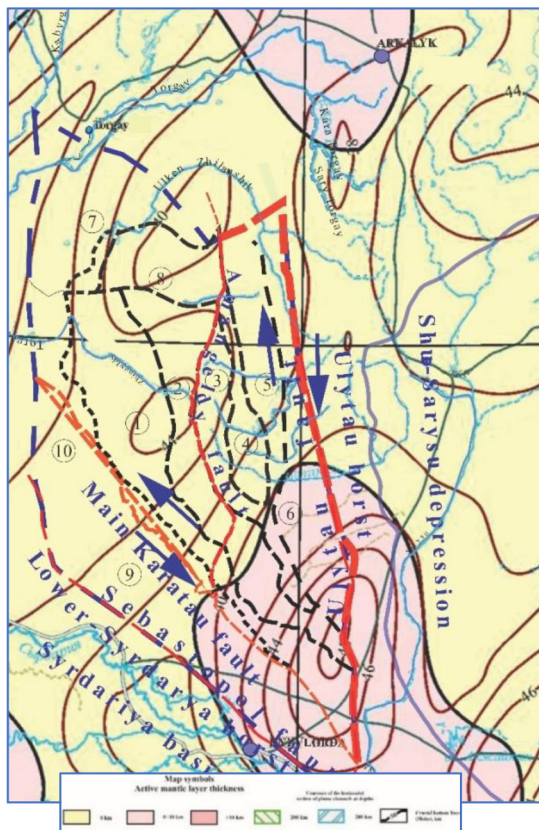


Fig. 6. Structural map of active mantle blocks against the background of the Earth's crustal base:

Modified after Nusipov E. N., Shatsilov V. I., Uzbekov N. B. (2007)

the structures of the Earth's crust and upper mantle. The depth of this boundary, with a refractor velocity of 8.1–8.2 km/s, determines the thickness of the Earth's crust.

At the STSB, the Moho discontinuity is identified at depths of 40–48 km. In the LSH, it ranges from 38–40 km, and in the SSD, its significance reaches 40–42 km. (Fig. 6).

Thus, the Moho discontinuity relief in the STSB reveals a depression, while the adjacent areas of the SSD and the LSH exhibit relative uplifts on the Moho discontinuity.

Therefore, it can be concluded that the STSB, in terms of the Moho discontinuity, separates the relative uplifts of the LSH and SSD (Fig. 6).

It can be assumed that in the structure of the earth's crust of the STSB, a significant place is occupied by plates of ancient Precambrian complexes. At the same time, sutures from former Vendian-Ordovician oceanic basins are also present, along with remnants of late Devonian-early Carboniferous marginal foreland deposits, fragments of the Devonian continental volcanic belt, and so on [3, 15].

It is also noteworthy that in the field of latest movements of the Earth's crust in the STSB, minimal uplift values (+50 to +100 m) are observed, while the LSH is characterized by maximum uplift values (+400 to +600 m or more). Intermediate values of the latest crustal movements (+200 to +500 m) have been recorded in the SSD [6, 14, 16].

As a result, a unique geological phenomenon is formed, according to which the main geodynamic

boundaries of the Earth's crust are conformably positioned (day surface, Paleozoic, Basement and Mantle surfaces), which clearly identifies the rift nature of the STSB.

Active mantle surface. The concept of the active mantle and its experimental validation have been substantiated in articles [6, 12]. Its presence has been established across most of the STSB [6, 7, 15]. The surface of the active mantle is characterized by $V_p < 8.2$ km/s and $\Delta g_{reg} = 3.25$ g/cm³ [7, 15].

Based on actual seismic data, a thickness map of the active mantle for Kazakhstan and adjacent territories was compiled [6, 12], a fragment of which is analyzed in the present study (Fig. 6).

A noteworthy geological phenomenon is observed in the STSB, where an active mantle with a thickness of up to 10–16 km is identified along the top of mantle (down to 48 km) (Fig. 6). Furthermore, areas with the maximum subsidence of the Moho discontinuity correspond to regions with an increased thickness of the active mantle (up to 14–16 km).

Further to the north, west, and east, the thickness of the active mantle layer decreases until it completely pinches out. This layer extends over the STSB in the form of a peculiar “tongue”, with sizes 225 × 161 km (Fig. 6). Thus, the boundaries of the tectonically active mantle wedge into the body of the Turan Platform and exhibit a northwest orientation.

An interesting observation is that the tectonically active mantle is not identified in the western part of the SSD or in the eastern areas of the LSH, i.e., in regions where the Moho discontinuity is relatively elevated [17, 18].

Seismic survey using the DSS (deep seismic sounding) method along the Volgograd-Chelkar-Turgai profile, specifically its “Turgai” fragment, has shown good consistency between the P-wave velocity model and the existing density model of the South Torgai Depression, constructed based on the results of seismogravity modeling [6, 14] (Fig. 7).

Available data for regional geophysical modeling have enabled comparative analysis and interpretation of depth-related features of the velocity structure of the Earth's crust and the crust-mantle transition zone.

This has significantly increased the informativeness and reliability of revealing petrophysical, geotectonic and geodynamic criteria in the study of deep inhomogeneities of the Earth's crust. The elements of the seismic-gravity model of the Earth's crust of the STSB are demonstrated as follows (Table):

1. The high-velocity layer with $V_p = 7.0$ –7.2 km/s and a density of 3.0–3.15 g/cm³ is characterized by a tendency to decrease (pinch out). It is interpreted as the Moho transition zone or a layer with a crust-mantle mixture, with a thickness of 3–15 km.

2. The granulite-basite layer, with a seismic velocity of $V_p = 6.6$ –7.0 km/s and a density of 2.95 g/cm³, has variable thicknesses ranging from 8 to 18 km and is inconsistent in petrographic composition. Its surface lies in an antiform pattern relative to the mantle surface.

3. The granulite-basalt layer with $V_p = 6.6$ –7.0 km/s and a density of 2.95 g/cm³ has variable thicknesses ranging from 8 to 18 km and is inconsistent in petrographic composition. Its surface lies in an antiform relative to the mantle surface.

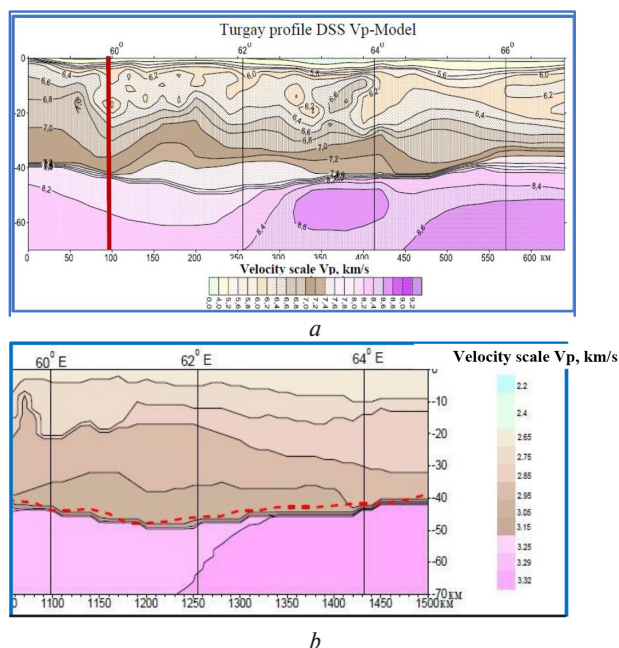


Fig. 7. *P*-velocity (V_p -a) and density (ρ -b) models of the Earth's crust and upper mantle of the Turgai fragment of the DSS Volgograd-Chelkar-Turgai profile. Modified from the data of Nusipov E. N., Kaidash T. M., Stepanenko N. P., Shatsilov V., 1981

4. The granulite-gneiss middle crustal layer with velocities of $V_p = 6.2\text{--}6.6\text{ km/s}$ and a density of 2.85 g/cm^3 forms bulges and lenses within the consolidated crust. It has a differentiated petrographic composition, is inconsistent in orientation, and shows variations in thickness (4–10 km). In places, its surface forms protrusions with amplitudes of 6–12 km.

5. The granite-gneiss layer with velocities $V_p = 5.6\text{--}6.6\text{ km/s}$. It consists of volcanic-metamorphic and metamorphic complexes of the Proterozoic.

Metamorphic complex. It consists of volcanogenic-metamorphic and metamorphic complexes of the Precambrian. The metamorphic complex has a density of 2.75 g/cm^3 and longitudinal wave velocity (V_p) of $6.0\text{--}6.6\text{ km/s}$. The volcanogenic-metamorphic

complex has a density of 2.65 g/cm^3 and V_p of $5.6\text{--}6.0\text{ km/s}$.

There is an opinion that, based on the approximately equal thicknesses of the sialic and basaltic layers, the consolidated crust in the STSB generally corresponds to the normal continental type [12, 19].

In our model of the consolidated crust of the STSB, the concept is different. The granulite-basaltic layer identified in the lower part of the consolidated crust is poorly ordered in terms of density and velocity characteristics, which indicates structural and petrographic heterogeneity and irregular thickness.

We assume that the upper part of the consolidated crust (the sialic layer) is formed by a complex lithostratigraphic association, including wedging, bifurcation, lenses, and tectonic mélange – blocks of fragmented, rolled, and mixed rocks associated with the displacement of tectonic nappes.

High-velocity inclusions are interpreted as cooled proto-plumes (slabs) currently undergoing subsidence under the influence of gravity, while low-velocity inclusions are interpreted as ascending flows (plumes) of heated mantle material (deep energy conduits). This interpretation aligns with variations in the Moho discontinuity relief within the study region.

As heated mantle material ascends, it gradually occupies the entire subcrustal volume of the lithosphere, forming low-velocity heterogeneities ($V_p = 7.6\text{--}8.2\text{ km/s}$) and high-temperature anomalies ranging from 1,100 to $1,400^\circ\text{C}$. These heterogeneities are attributed to the active mantle, characterized by an increased intensity of physicochemical transformations that drive a spectrum of geodynamic processes [14, 15, 18].

We support the concept according to which the thrusting of the Karatau structures onto the base of the South Turgai Depression occurred as a result of longitudinal right-lateral strike-slip displacement [20, 21].

According to [12, 22], in the boundary zones of the Arysium Graben and Aksay Horst, as well as the Akshabulak Graben and Tabakbulak Horst, migrations of mantle melts with basic and ultrabasic compositions occur within the section. These migrations are manifested by the frequent alternation of thin (2–6 km) layers, ex-

Table

Geophysical characteristics of Structural-Material layers of the Earth's Crust and Upper mantle (Belousova N. P., Shatsilov V. I., 2007)

Structural-material complexes of stratified and geophysical layers of the crust and upper mantle			Values of geophysical parameters	
			Velocity V_p , km/s	Density ρ , g/cm ³
Sedimentary cover	Phanerozoic eon		<4.0	<2.55
	Paleozoic complex		4.0–5.2	2.55
Consolidated crust	Granite-gneiss (sialitic) top crustal layer	Volcanogenic-metamorphic Palaeozoic complex	5.6–6.0	2.65
		Precambrian metamorphic complex	6.0–6.4	2.75
	Granulite-gneiss (basite) middle crustal layer		6.2–6.6	2.85
	Granulite-basite (ultrabasite) lower		6.6–7.0	2.95
	Moho transition zone (coromantium mixture)		7.0–7.2	3.05–3.15
Upper Mantle	Active		<8.2	3.25
	Normal		8.2–8.4	3.29

tending from 30 km to 200 km, and are characterized by P-wave velocity values ranging from 6.0 to 6.8 km/s.

This assumption is supported by the identification of restites – fragments of deep-seated rocks remaining after partial material extraction through anatexis, palinogenesis, and mantle melting, leading to the formation of basic and ultrabasic magmas – in the upper part of the consolidated crust of the Arys-kum Depression [23].

Another important channel of information is the values of horizontal gradients of the Earth's crust base. Increased values of these gradients indicate the presence of through-crust destructive zones with steep contacts between rocks of different densities, penetrating deeply into the upper mantle.

A large anomalous zone of sublatitudinal orientation, measuring 104×40 km, with horizontal gradients of the crustal basement ranging from 0.25 to 0.45 km/km, is delineated within the Arys-kum and Bozinger Grabens, as well as in the Aksay Horst [7, 14].

Southwest of STSB is distinguished by minimal values of horizontal gradients at the base of the Earth's crust (0–0.15 km/km). SSD can be characterized by intermediate gradients of 0.20–0.25 km/km in its eastern part and 0.35–0.40 km/km in its western part [12, 24].

The SSD can be characterized by intermediate values of this parameter, ranging from 0.20–0.25 km/km in the east to 0.35–0.4 km/km in the western part [12, 24].

Using this criterion as a basis and conducting a comparative analysis with the Moho discontinuity, another geological phenomenon has been identified: areas with an increased horizontal gradient at the base of the Earth's crust coincide with regions of active mantle development and depressions at the base of the crust.

It can be hypothesized that the spatial distribution of density heterogeneities in the STSB is determined by its geodynamic evolution, in which the Vendian–Early Paleozoic and Jurassic stages of riftogenesis played a significant role [15].

The fundamental difference between these stages of riftogenesis lies in the fact that during the Vendian–Early Ordovician, they followed the classical model with intense subsidence and crustal extension in the early phases of development (resulting in the formation of molasse deposits, tillites, followed by siliceous-carbonaceous-terrigenous and siliceous-carbonate rocks), and subsequent compression, tectonic inversion, active dislocations, and widespread magmatism during the final stages [8, 9].

During the Jurassic stage of riftogenesis in the South Turgai paleobasin, intense tectonic dislocations occurred, leading to active movements along differently oriented Paleozoic and pre-Paleozoic faults. This caused the fragmentation of the ancient Proterozoic–Lower Paleozoic basement, resulting in the formation of grabens [8, 17].

However, the formation of the graben system was completed without the intrusion of magmatic bodies and intense tectonic deformations [1, 9, 17].

Thus, the STSB can be considered a zone of inherited riftogenesis – a tectonic structure that underwent two stages of rift evolution, in the Late Proterozoic–Early Paleozoic and during the Jurassic period.

It is important to note that there is a concept according to which, at the Late Early–Early Middle Devonian, a spreading zone formed in the Turkestan Paleoocean. Under its influence, an active continental margin developed along the southern edge of the Kazakhstan Palecontinent (Caledonian consolidation), with the formation of the Turgai Devonian marginal volcanic belt [8, 16, 19].

The Ulytau and Syrdarya microcontinents were fused into a single continental massif, collectively forming the southwestern edge of the Devonian Kazakhstan Continent [3, 17].

During this time, dacite-andesite-basaltic magma was erupted in a rift-like depression (within the contours of the STSB, bounded by a system of deep faults against the backdrop of the uplift of the Caledonian continent's edge. Some of the erupted material was carried to the western coastal zone, where it was buried under underwater conditions [8, 17].

Another perspective on the geodynamic evolution of the Turkestan Paleo-ocean is presented by V.S. Burtman, et al. [14] based on paleomagnetic data. According to their view, the spreading of the oceanic crust in the Turkestan Ocean occurred from the beginning of the Paleozoic to the Middle Devonian, while subduction of the oceanic crust beneath the Kyrgyz-Kazakhstan continent took place during the Ordovician, Silurian, and Early-Middle Devonian. In the Late Devonian, subduction ceased, but spreading continued. Therefore, by the Late Devonian, the Turkestan Ocean reached its maximum width [3, 9, 17].

Conclusion. The conducted studies have substantiated new views on the distribution of density heterogeneities at different levels of the lithosphere in the STSB, identified the locations of gravity-disturbing mass centers, and refined the strike, shape, and intensity of anomalous bodies, as well as their burial depth.

The regional transformant of the gravity field effectively displays the block heterogeneity of the lower part of the earth's crust and upper mantle in the depth range of 30–150 km.

In the structure of the regional transformant of the STSB, significant differences in morphology, sign, orientation and gradients of changes in the transformant Δg_{reg} from the Lower Syrdarya Arch and the Shu-Sarysuy Depression were established.

In addition, weakly intense minima of Δg_{reg} are common in the STSB, while in the LSH, maxima of polygonal anomalies of Δg_{reg} are observed, and in the SSD, intense negative linearly elongated minima of Δg_{reg} are observed.

Significant differentiation in the depth and age of deep faults was revealed. For example, the depth of the Ulytau fault is recognized as the upper mantle level, and the age as Early Paleozoic or Precambrian.

The granulite-basitic layer in the lower part of the Earth's crust is weakly ordered in terms of density and velocity characteristics, and thus in terms of structure and petrological composition, exhibiting inconsistencies in thickness. It can be assumed that the structure of this layer is significantly composed of plates from ancient Precambrian complexes and sutures of former oceanic basins of the Vendian–Ordovician period.

The upper part of the consolidated crust is formed by a complex lithostratigraphic association (wedging out,

bifurcation, lenses, tectonic mélange – blocks of fragmented, rolled, and mixed rock masses associated with the displacement of tectonic nappes). the base of the earth's crust of the STSB, a depression is recorded along the Moho discontinuity, while in the adjacent areas of the SSD and the LSH, relative uplifts of the Moho discontinuity are isolated.

An interesting observation is that, within the field of latest crustal movements, the STSB is characterized by minimal uplift values, while the LSH is marked by maximum values, and the SSD shows intermediate values.

Thus, a unique geological phenomenon is formed, according to which the main geonomic boundaries of the Earth's crust in the STSB lie conformably (e.g., the Earth's surface, the Paleozoic and basement surfaces, the Moho discontinuity), which visually confirms its rift nature.

Below the Moho discontinuity, the active mantle lies beneath most of the STSB. Outside of this basin, the thickness of the active mantle decreases, eventually pinch out. For example, in the northern part of the STSB, the western part of the SSD, and the eastern areas of the LSH, the tectonically active mantle is not determined.

The next geological phenomenon we identified is the coincidence of areas with increased horizontal gradients at the base of the Earth's crust with regions of active mantle, indicating active geodynamic processes occurring at the current stage of development of the STSB.

In this context, the LSH is characterized by minimal values of horizontal gradients of the crustal basement. The Shu-Sarysu Depression can be described by intermediate values of these gradients.

The intracrustal transformant of the gravity field has allowed for the characterization of density heterogeneities down to depths of 20–25 km, as well as the determination of the internal structure and contrast of intracrustal interblock boundaries.

In the field of the intracrustal transformant of the STSB: a) no differences from the LSH were identified, while differences with the SSD were established; b) horizontal shifts of linear anomalies of the intracrustal transformant were identified in the Ulytau fault and GKF, indicating the potential for horizontal shear deformations.

The nature of the intracrustal transformant of the gravity field has changed compared to the regional transformant. These changes are manifested in:

1. The spread of positive anomaly values, indicating the presence of rocks with increased mafic composition.

2. An increase in the number of linearly-elongated anomalies, suggesting that folding processes have actively developed in the upper part of the crust.

3. A contrasting distribution of intracrustal transformant anomalies near major faults (GKF, Sevastopol, and Ulytau faults) complicating the structure of the STSB. The age of their formation is Late Paleozoic–Triassic.

The upper part of the consolidated crust (sialic layer), responsible for forming the intracrustal transformant fault, is composed of a structurally complex lithostratigraphic association with significant thickness variations. It features widespread elements of wedging, bifurcation,

lens formation, and tectonic mélange. It is assumed that the structure of the sialic layer includes significant relics of the Devonian active continental margin with a coeval marginal volcanic belt.

The local transformant of the gravitational field made it possible to study gravity-disturbing objects down to depths of 7 km, determine the burial depth, and characterize the geological structures beneath the sedimentary cover. In the field of the local gravity transformant of the STSB:

1. An alternation of sub-meridional positive and negative anomalies of low intensity has been identified, tracing folded belts concealed beneath Mesozoic–Cenozoic sediments. Negative Δg_{loc} values dominate in the western part of the South Turgay Depression, while positive values prevail in the eastern part.

2. The spatial patterns and extent of the Δg_{loc} anomalies generally exhibit similarity to the tectonic framework of the Paleozoic formations' surface. At the same time, the morphology of the Δg_{loc} transformant often does not correspond to the modern structural plan of the STSB at the surface of the Paleozoic formations.

3. A clear correlation is observed between the intensity of the Δg_{loc} minima and the depth to the top of the Paleozoic formations, as confirmed by deep drilling.

4. In the west of the STSB, the placement of the Δg_{loc} transform is controlled by the BKR and Sevastopol fault. To the east of the STSB, the Ulytau and Amangeldy faults do not influence the placement of the Δg_{loc} transform. This geological phenomenon to some extent indicates different scales of displacements at the level of the local transformant of the gravitational field.

The correlation between gravitational and magnetic anomalies has provided additional insight into the complexity of the geological structure of the STSB:

1. In the Aksai, Ashisai, and Tabakbulak Horsts, as well as in the Besoba-Terensay and Bozingen Grabens, there is inconsistency between the large-scale anomalies of gravitational and magnetic fields in terms of orientation, shape, extent, and sign.

2. In the Aryskum, Sarylan Grabens, and Mynbulak Saddle, consistency between gravitational and magnetic anomalies has been observed in terms of extent, sign, morphology, and the controlling factor of deep faults.

3. The longtime multi-stage formation of magnetically and gravimetrically disturbing objects in the Earth's crust has allowed for the identification of heterogeneities that correspond in scale to groups of structural and formational zones manifested on the top of the Paleozoic formations.

The geodynamic factor – the distribution of density heterogeneities in the lithosphere of the STSB – is determined by its geodynamic evolution, including the Vendian–Early Paleozoic and Jurassic stages of riftogenesis processes.

The fundamental difference between these riftogenesis stages lies in the fact that in the Vendian–Early Ordovician, they manifested according to the classical scheme, with intense subsidence and stretching during the early phases of development, followed by compression, tectonic inversion, active dislocations, and widespread magmatism during the final stages.

During the Jurassic stage of riftogenesis in the South Torgai Paleobasin, intense tectonic dislocations occurred, along with active movements along variously oriented Paleozoic and pre-Paleozoic faults, and the splitting of the ancient Proterozoic–Lower Paleozoic basement, which led to the formation of grabens. However, the origin of these grabens ended without tectonic inversion, diastrophism, or the intrusion of magmatic bodies.

Moreover, there is a concept according to which, at the end of the Early Devonian–beginning of the Middle Devonian, a spreading zone formed in the Turkestan Paleo-ocean, under the influence of which an active continental margin developed along the southern and southeastern edges of the Kazakhstan paleocontinent, with the Turgai Devonian marginal volcanic belt.

Consequently, the STSB can be considered as a rift-ing zone inherited from the Paleozoic – a tectonic structure that has experienced stages of rift development three times: in the Late Proterozoic – Early Paleozoic, in the Middle-Late Paleozoic and in the Jurassic.

Thus, the integrated approach, which included gravimetric and geological-geophysical studies, provided valuable information on the distribution of deep density and structural heterogeneities at different levels of the lithosphere and linked them with the current tectonics and geological history of the STSB, as well as laid the foundation for further research on geodynamic processes in this region of Kazakhstan.

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Структура гравітаційного поля та гравізбурюючі об'єкти

Південно-Торгайського осадового басейну

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Мета. Вивчення розподілу щільнісних неоднорідностей у різних прошарках земної кори Південно-Торгайського осадового басейну

(ПТОБ). Виявлення кореляційних зв'язків цих неоднорідностей з будовою, геодинамічними процесами й тектонічною еволюцією даного басейну.

Методика. Геологічна інтерпретація регіональних, внутрішньокорових і локальних аномалій гравітаційного поля з урахуванням даних сейсморозвідки, магніторозвідки, геотермічних досліджень і неотектонічних дислокацій.

Результати. Були визначені просторовий розподіл неоднорідностей щільності на різних ділянках літосфери ПТОБ, розташування центрів маси, що заважають гравітації, а також протяжність, форма та інтенсивність аномальних тіл і глибини їх залягання. У діапазоні глибин 30–150 км спостерігається виражена блокова неоднорідність літосфери ПТОБ, що виявляє значні відмінності в інтенсивності, морфології, полярності, орієнтації та градієнтних варіаціях трансформованої гравітаційної аномалії (Δg_{reg}) порівняно із прилеглими районами Нижньосирдар'їнського вала та Шу-Сарисуйської западини. На глибинах до 25–30 км у консолідованій корі встановлені прояви горизонтальних зсувних деформацій, внутрішня будова й контрастність внутрішньокорових міжблокових меж. Не було виявлено суттєвих відмінностей між ПТОБ і Нижньосирдар'їнським валом у полі внутрішньокорової гравітаційної трансформації, тоді як відмінності від Шу-Сарисуйської западини спостерігалися. На глибинах до 7 км локальні гравітаційні об'єкти демонструють чітку кореляцію із глибиною до вершини палеозойських утворень, ефективно відстежуючи складчасті пояси, приховані під мезозойсько-кайнозойськими відкладеннями.

Наукова новизна. Уперше висунуте припущення про значну диференціацію за глибиною закладення та віком великих розломів, що свідчить про різномасштабні зсуви на рівні регіональних, внутрішньокорових і локальних неоднорідностей літосфери. В основі земної кори ПТОБ по розриву Мохо фіксується западина, під якою спостерігається активна мантийна зона, фіксуються підвищені горизонтальні градієнти основи земної кори. Виявлене унікальне геологічне явище, відповідно до якого основні геонамічні межі земної кори є згодними, що наглядно підтверджує рифтову природу СТБ.

Практична значимість. Отримані результати можуть бути використані для планування геологорозвідки та оцінки нафто-газового потенціалу ПТОБ; планування пошуково-оціночних робіт, оптимізації розміщення бурових майданчиків і проектування свердловин, спрямованих на перспективні об'єкти квазіплатформеного структурного ярусу. Результати досліджень сприятимуть кращому розумінню закономірностей розподілу глибинних, структурних, геомагнітних і геотермальних літосферних неоднорідностей, їхньої кореляції із сучасною тектонікою та геологічною історією ПТОБ. Окрім того, вони можуть стати основою для подальших наукових досліджень, спрямованих на вивчення геодинамічних процесів, а також для адаптації запропонованої методології до інших нафтогазоносних басейнів.

Ключові слова: гравітаційне поле, трансформанти, неоднорідності літосфери, сейсморозвідка, магніторозвідка, геотермічні дослідження, неотектонічні дислокації

The manuscript was submitted 06.10.24.