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COMPREHENSIVE ANALYSIS OF MAGNETIC AND GRAVITY DATA BASED ON VOLUMETRIC GRAVITY-MAGNETIC MODELING ALONG THE GEOTRAVERSE IN THE SHU-SARYSU SEDIMENTARY BASIN

(Представлено членом редакційної колегії д-ром геол. наук, проф. О.М. Карпенком)

The purpose of the studies presented in the article is to obtain the information of the deep structures along the Shu-Sarysu geotraverse, to determine the regularities in the distribution of mineral deposits and predictive assessment of the research area prospects for searching for hydrocarbons and other minerals. To achieve this purpose, a complex of high-precision gravitational and magnetometric measurements was used. There was shown a high efficiency of the integrated interpretation of 3D gravimagnetic modeling when studying the geological structure of the crystalline basement (assessment of the morphology of its surface, material-petrophysical mapping of the rocks that make up the basement) and the sedimentary cover (assessment of the morphology of the reference horizons, studying their material composition); when identifying and clarifying the position of discontinuous faults, conducting lineament analysis in order to decipher the block structure of the studied areas; when building 3D volumetric models of geophysical parameters; when substantiating predictive and search geophysical criteria for detecting oil and gas geological structures, both in the thickness of sedimentary formations and in the rocks of the crystalline basement. The progress of these methods is conditioned by the widespread introduction into practice of modern computer technologies for processing and interpreting data.

K e y w o r d s : ***geotraverse, gravity data, aeromagnetic, density properties of rocks, geomagnetic model, field transformations, gas, 3D modeling of potential fields.***

Background

The results of a systematic study by a complex of geological and geophysical methods in combination with regional studies have always served as the basis for the development of many topical problems of formation, localization of various industrial-genetic types of deposits and reassessment of prospects for mineral deposits at a new level. A large radius of study characterizes geophysical methods, and the main result of their application is three-dimensional representations of the earth's crust structure with its differentiation according to certain physical parameters: density, magnetic and electrical properties, velocity of elastic vibration propagation, etc. The use of geophysics leads to reducing the cost of the work. However, the use of one method does not provide an unambiguous solution to the tasks set, therefore, in order to achieve the goals, it is necessary to develop and to improve the complex of geophysical methods. As a result, a modern geophysical basis is formed that is obtained with high-tech and high-precision equipment and advanced software, which is the basis for building high-quality geological models of mineral deposits. The study area belongs to the little-studied, almost completely closed areas. As a result of the development of the geological exploration program for sedimentary basins, it was decided to study the Shu-Sarysu sedimentary basin by carrying out works along the Shu-Sarysu geotraverse.

According to the results of more than 40 years of exploration history, the Shu-Sarysu basin has a very complex geological structure, a tense geodynamic history, and the degree of geological and geophysical exploration of the basin does not allow assessing reasonably its generation potential in relation to hydrocarbons (Daukeev et al, 2002). All these data substantiate a complex of geophysical surveys along the Shu-Sarysu geotraverse. The proximity of the Shu-Sarysu basin to a number of large cities and industrial centers of Central and Southern Kazakhstan will make it an ideal source of Kazakhstan gas supply if sufficient reserves are discovered. Finally, according to the statistical calculations of specialists, the potential of the Shu-Sarysu basin is quite high. However, their reliability requires confirmation through a significant amount of complex geophysical work with the delineation of local objects and setting oil and gas prospecting drilling within them. All these facts substantiate the relevance of the studies presented in the article.

The information of studying the geological and tectonic structure, prospects for gas content along the Shu-Sarysu geotraverse, as well as the possibilities of modern aeromagnetic exploration and the range of geological tasks to be solved during regional work were considered in the article "Geoelectrical model of the Earth's crust along the Shu-Sarysu geotraverse according to magnetotelluric soundings" (Tleubergenova et al., 2023).

The purpose of this work is to study the deep structure of the basin, to identify structural and material complexes in the sedimentary cover and to assess the regional hydrocarbon potential of the territory based on the interpretation of gravimagnetic data using modern technologies of 3D modeling of potential fields.

The scientific significance of the presented studies is substantiated by the development of a modern three-dimensional geophysical model of the area, which makes it

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possible to clarify the geological structure of the Shu-Sarysu sedimentary basin, to change ideas of the tectonic activity of rocks and to find out the conditions for the formation of hydrocarbon deposits.

The practical significance lies in the use of complex 3D modeling technology for various regions, which makes it possible to compare models obtained at the early stages of research; building complex geodensity and geomagnetic models of the earth's crust on specific reference profiles; the possibility of regional forecasting of areas favorable for the accumulation of hydrocarbons in the redistribution of sedimentary basins and solid minerals within ancient platforms (Galuev, 2008).

The set goals were achieved through the solution of the following tasks:

- generalizing and integrating geological and geophysical criteria based on the features of the Shu-Sarysu sedimentary basin geological structure for a comprehensive interpretation of gravity and magnetic anomalies;
- studying the characteristic behavior of the gravitational field in order to separate the gravitational effects from various geological structures occurring in depth;
- identifying intrusive bodies lying at depth, tracing numerous faults using lineament analysis based on geodensity and geomagnetic models;
- predictive assessing the geological structures for prospects for hydrocarbons.

A full range of geophysics was performed on the Shu-Sarysu geotraverse, but this article shows a comprehensive analysis of magnetic and gravity data based on the results of the volumetric gravimagnetic modeling, since it is three-dimensional geological models that integrate all geological and geophysical information. The contours of the main elements of the structural-tectonic structure of the area obtained on the basis of generalizing stock materials of previously performed geological and geophysical studies are plotted on maps of horizontal sections of excess density and magnetization.

Materials and research methods. Here there is a brief description of the results of aeromagnetic reconnaissance. The observed magnetic field is associated with magnetization of the crystalline basement rocks of predominantly basic and ultramafic composition, and sedimentary rocks, as a rule, do not contain magnetized rocks in their composition (Tleubergenova et al., 2023).

The qualitative interpretation of the magnetic field is based on the following basic principles for interpreting magnetic anomalies:

- the areas of positive magnetic field are caused by magnetic basement rocks (Cambrian porphyrites) and large intrusions of medium-acidic composition;
- the Upper Ordovician granodiorites and diorites, as well as the Devonian volcanics, have anomalously high values of magnetic susceptibility and are characterized by positive magnetic anomalies with intensity up to 600–700 nT;
- the group of weakly magnetic granitoids and sedimentary-metamorphic rocks is marked by low magnetic fields with an intensity of 100–200 nT;
- the mosaic structure of the magnetic field corresponds to the vaults of structural elements with a shallow foundation;
- deep depressions are reflected in the magnetic field as low-gradient isometric anomalies;
- tectonic disturbances are expressed by zones of high magnetic field gradient. Deep basement faults that control the placement of structures in the sedimentary cover are characterized by linear chains of anomalies.

It is noted that under the platform conditions, the structures of the sedimentary cover correspond to the relief of the basement, therefore, it follows that by studying the structure of the basement by magnetic prospecting, it is possible to identify objects promising for oil and gas in the sedimentary cover.

As a result of the aeromagnetic survey we:

- characterized the relief of the Paleozoic base;
- identified intrusive bodies of different sizes and composition;
- traced tectonic faults. The most important deep faults include the Tastin and the Shusky ones that separate the Tasbulak trough from the Tastin uplift, the Tastin uplift from the Nizhne-Shu uplift and the Sozak-Baikadam trough;
- according to the characteristics of the magnetic field, the zoning of the territory was carried out;
- a buried part of the North Karatau anticlinorium was traced, and under the Syrdarya syneclise a continuation of the Turlan brachysynclinorium was found;
- the fold-block nature of the structures of the region, as well as the stepped structure of the basement surface, was confirmed;
- within the Leontief graben, where droplet oil was discovered in 2017, there is a linear decrease in the magnetic field values from plus 50 nT to minus 150 nT;
- identified local structures that are of interest for searching for a whole range of minerals (Tleubergenova et al., 2023).

The results of gravimetric studies carried out in potentially oil and gas areas testify to the high efficiency of using gravity exploration together with seismic exploration and other methods of geophysics in studying sedimentary basins, solving problems of petroleum geology at the regional-zonal and local level (Babayanc et al., 2003). The structural-tectonic structure of the sedimentary cover, the morphology of the basement surface are very clearly and reliably manifested in the gravitational field. Modern technologies of analyzing gravity measurements make it possible to identify new elements of the structural-tectonic structure, to supplement significantly the interpretation of seismic data, to expand existing ideas of the region geological structure features, to help clarify the structural position of areas, and to increase reliability of predictive estimates (Babayanc et al., 2004).

The gravimeters CG-6 AutoGrav Scintrex (Canada) were used during field gravity exploration along the Shu-Sarysu geotraverse. They are by far the most advanced instruments in the world for high-precision ground gravity surveys (Nazirova et al., 2019). In order to bring the gravimetric survey to the level of the State gravimetric network, as well as to take into account the offset of the zero point of the instruments in ordinary cruises, 4 points of the field reference gravimetric network were used. Ordinary gravimetric measurements were carried out according to a single method, flights began and ended at field strongholds.

The root-mean-square error in determining the observed values of gravity was ±0.02 mGal, the gravity anomalies in the Bouguer reduction were ±0.02 mGal.

The office processing of gravity data was performed using the Gravity and Terrain Correction module of the Geosoft Oasis MontajTM software package. The system includes all the functions of processing and reduction of gravity survey data, including the input of corrections for relief using digital elevation models (Nazirova et.al., 2016).

Based on the obtained materials, a digital model of the gravity field of 100 km of the Shu-Sarysu regional profile strip and its framing along a 500x500 m network was developed. Processing, interpretation and conditional visualization of

gravity data were performed using modern specialized software packages: the ArcGIS/ArcMap (ESRI, USA), the Didger (Golden Software, USA), the Surfer (Golden Software, USA), the Geosoft Oasis MontajTM, COSCAD 3D, the SIGMA-3D, the GM-SYS 2D, the ZONDGM2D.

The analysis of a priori information collected from the experience of geophysical research and the results of the geological interpretation of the gravity field in the region made it possible to form the following geological and geophysical criteria.

1. The gravity minima can be caused by deflections in the roof of the ancient folded basement made by thick strata of the platform cover and an intermediate structural stage, in the section of which low-density salt-bearing formations are likely.

2. The local gravity minima and maxima can be caused respectively by salt domes and local uplifts of dense rocks (P_1, C_1v, C_1t, D_3fm).

3. The gravity maxima are usually associated with uplifted blocks of the ancient basement, which are characterized by a reduced thickness of the intermediate structural stage, loss of some strata, including salt-bearing ones, from the section of the latter.

4. The anomaly-forming gravity field objects are the Middle Carboniferous, the Middle-Late Devonian, the Middle Devonian intrusive complexes. Basic and ultrabasic intrusions cause contrasting positive anomalies. Medium composition objects (diorites, granodiorites) are characterized by an increased gravity field. Acid intrusions are displayed in the gravity field as negative anomalies.

5. Tectonic disturbances are expressed by zones of a high gradient of the gravitational field. Correlating bends of isoanomalies, a sharp change in the strike of anomalies and linear boundaries of changing the nature of the field can correspond to them. On the map of local anomalies, they are fixed by steps of high gradients; on the map of the vertical gradient of gravity anomalies by chains of isolated, linearly elongated small negative anomalies stretching from the northwest to the southeast.

Results and discussion

To analyze the gravitational field, a map of gravity anomalies in the Bouguer reduction was used. The initial field (fig. 1,a) reflects the total gravitational influence of both the geological structures of the upper tiers (fig. 1,b) and the deep structures of the earth's crust and upper mantle. To separate gravitational effects from surface and deep structures, regional and residual gravity anomalies are calculated by means of recalculating the initial field into the upper half-space at different heights.

The observed gravitational field of the region is difficult to differentiate; its intensity varies from minus 215 mGal to plus 20 mGal. In the regional component, the range of anomaly intensity values is from minus 150 mGal to minus 15 mGal.

Decreasing of the intensity of the field from the northwest to the southeast characterizes the strike of structural elements in the regional plan. The complex nature of the gravity field of the region is caused by significant variations in the thickness of the sedimentary cover, presumably due to the density heterogeneity of the basement of the considered parts of the Shu-Sarysu sedimentary basin. The main largest and most distinct elements of the gravity field (from north to south along the geotraverse) are the Shu block, the Tasbulak trough, the Lower Shu uplift, the Tastin uplift, the Talas uplifted block, the Sozak-Baikadam trough, the Moiynkum trough, the Leontief graben, the Karatau ridge and the Arys trough (the latter is part of the Syrdarya basin).

Based on the gravi-magnetic data, the transformants were calculated and a three-dimensional geodensity model (fig. 2) and a magnetic magnetization model were built, which made it possible to interpret gravity and magnetic field anomalies along the entire Shu-Sarysu geotraverse strip.

A decisive role in the region structure is played by the Main Karatau Fault (MKF), the longest one, established according to geological data and well traced in physical fields along the gradient zones and a sharp change in the direction of isoanomalies. This Precambrian fault is a complex system of subparallel faults, which in all geological epochs served as a supply channel for magma and hydrothermal solutions. The MKF displacement plane has a southwest dip at an angle of 80°, the maximum amplitude is 1.5–2.0 km (Akchulakov et al., 2014).

The northern end of the Shu-Sarysu regional profile extends beyond the boundaries of the sedimentary basin and is limited by the Shu block.

The residual field calculated as the difference between the initial and recalculated upwards to the height of 15 km, is characterized by a strong irregularity of isoanomalies and reflects the structure of the upper tiers of the distinguished structures (fig. 3,a). Residual gravity anomalies are compared with the magnetic field normalized to the pole (fig. 3,b).

The use of the procedure makes it possible to carry out the automatic tracing of linearly elongated anomalous zones, to identify the epicenters of local anomalies, and to designate their axial lines. The obtained solution testifies to the high efficiency of this algorithm for detecting lineaments practically regardless of the intensity of anomalous manifestations in the initial field (fig. 4 and 5) (Bezukladnov et al., 2007).

The carried out gravimetric studies confirmed large blocks of the earth's crust, contoured the distribution areas of rocks of different composition, revealed intrusive bodies lying at depth, traced numerous faults of various directions, lengths and depths.

Based on the conducted gravity survey in the 100 km strip of the Shu-Sarysu regional profile:

- the block nature of the foundation structure was confirmed;
- the explanation of the gravitational effect within the limits of the Tastin and Nizhne-Shu uplifts, the Tasbulak and Moiynkum troughs was given;
- the development of anticlines and horsts with an increased thickness of the Carboniferous limestones and intrusive bodies of basic and felsic composition on the Tastin uplift was predicted.

Conclusions

The gravimetric work allowed obtaining additional information of the geological and tectonic structure of the almost completely closed region. Large blocks of the earth's crust differing in the history of development and geological structure were identified, the areas of distribution of rocks of different compositions, intrusive bodies occurring at depth were outlined. Local uplifts in the roof of the Paleozoic and its individual horizons were identified. Numerous discontinuous disturbances of various directions, lengths, depths and various roles in the formation of the structural plan of the region were traced.

As a result of gravity exploration in the 100-kilometer corridor of the Shu-Sarysu regional profile, the following conclusions were made:

1. The existing views on the block nature of the region structures that differ in the depth of the foundation, were confirmed.

The intense indentation of the gravity field, a lot of correlated bends of isoanomalies carry the information of the block

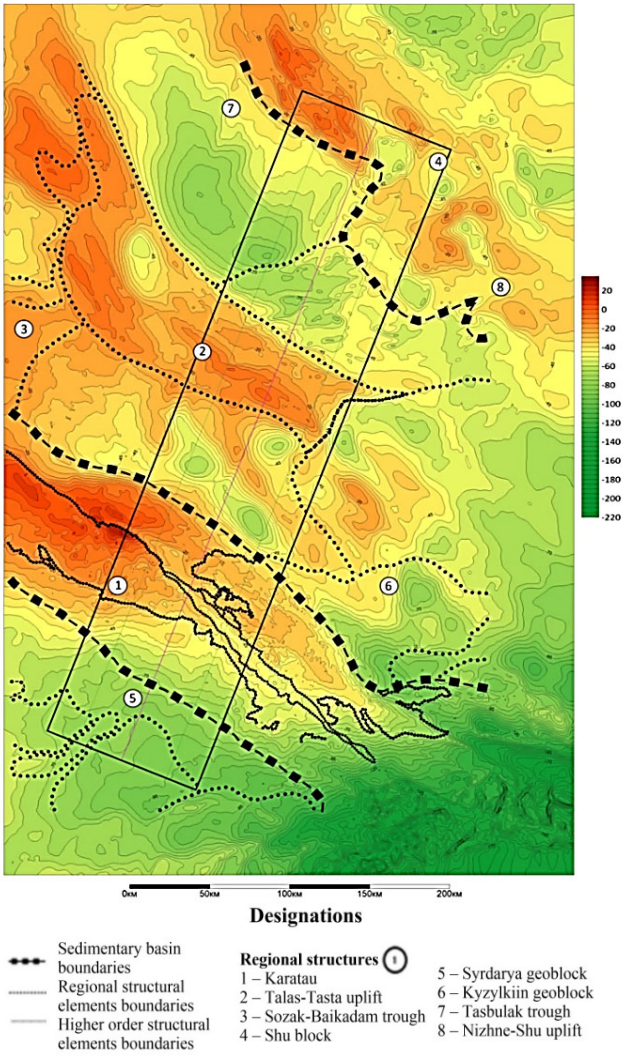
structure of the brachisynclinorium and trough submerged part. The blocks are bounded by small rapidly wedged-out faults of predominantly submeridional and northeast strike that feature extended faults of the northwest direction.

2. In the Tasbulak and Moiynkum troughs and within the areas of the Tastin and Nizhne-Shu uplifts, the gravitational effect uncompensated by the sedimentary cover is explained by the probable presence of lenticular layers of the Upper Devonian rock salt and acidic intrusions in the basement (in some areas, their total influence).

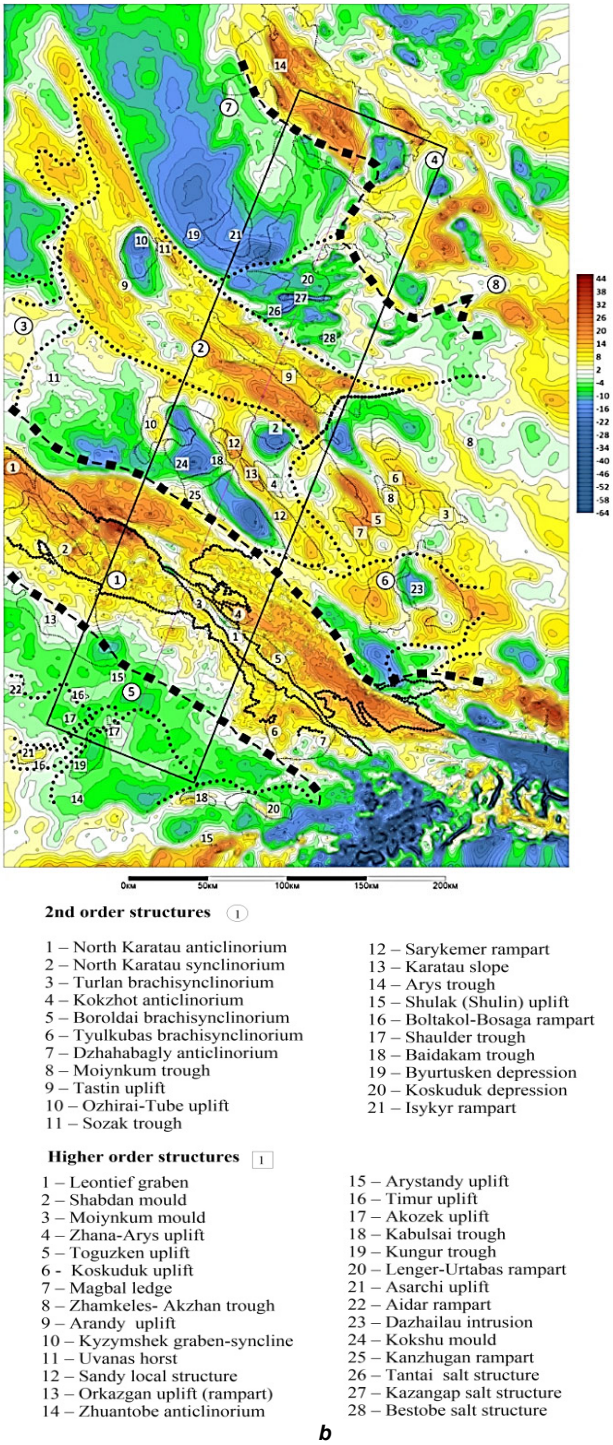
The development of anticlines and horsts with an increased thickness of the Carboniferous limestones and intrusive bodies of basic and felsic composition is expected on the Tastin uplift.

3. The Baikadam, the Kokshui, the Shabdan and the Moiynkum troughs can be of interest in the search for oil and gas.

Minor anticlinal structures and uplifts in the section of the cover can be of interest for exploration. All the presented figures serve as an illustration of the spatial confinement of the gas fields of the Shu-Sarysu sedimentary basin to local positive gravity anomalies.



a



b

Fig. 1. Gravity survey results:
a – map of gravity anomalies in the Bouguer reduction;
b – local component of gravity anomalies in terms of the upper half-space at 15 km

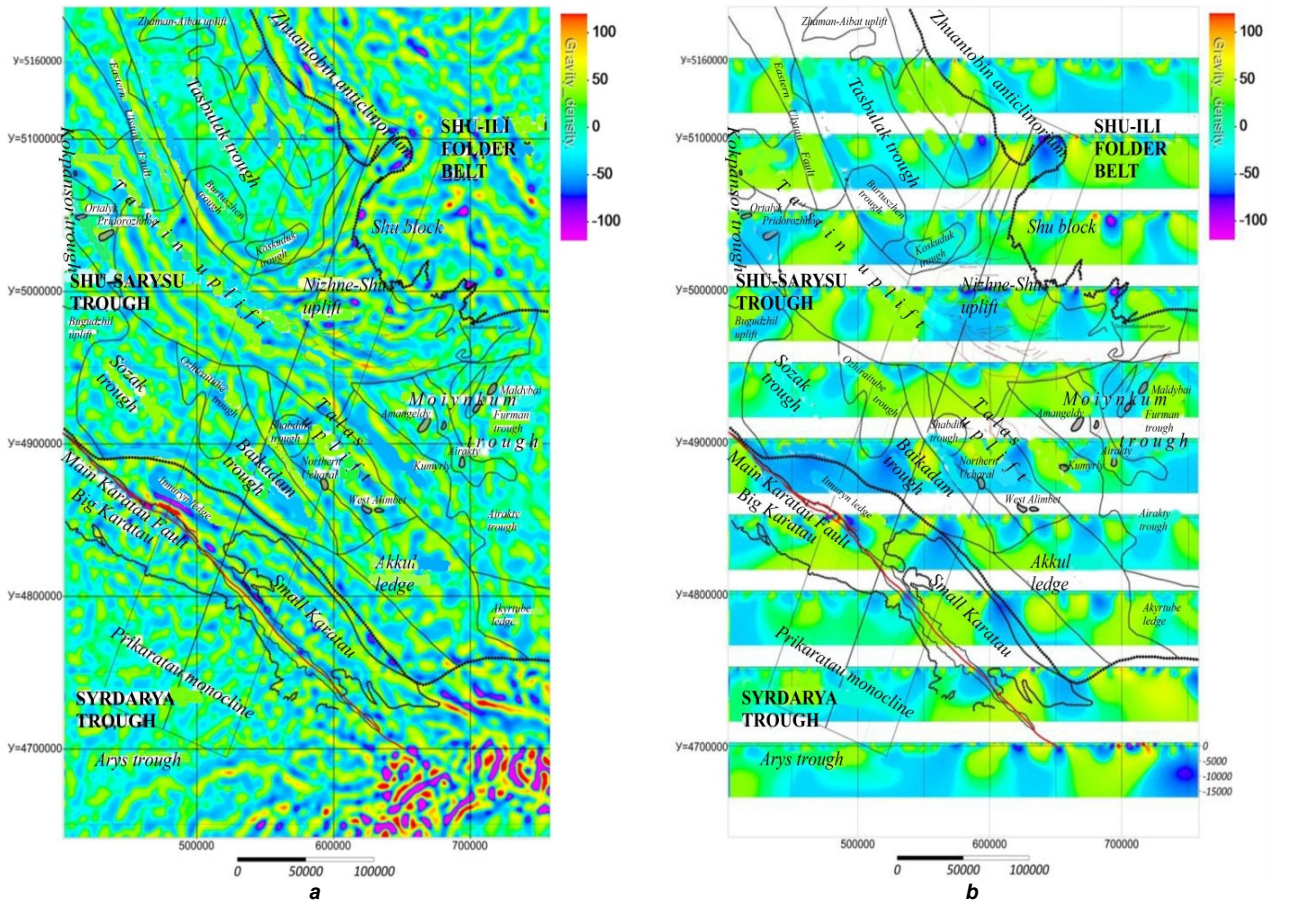


Fig. 2. Horizontal section at the depth of 2 km (*a*) and vertical latitudinal sections of the volumetric density model down to the depth of 17 km (*b*)

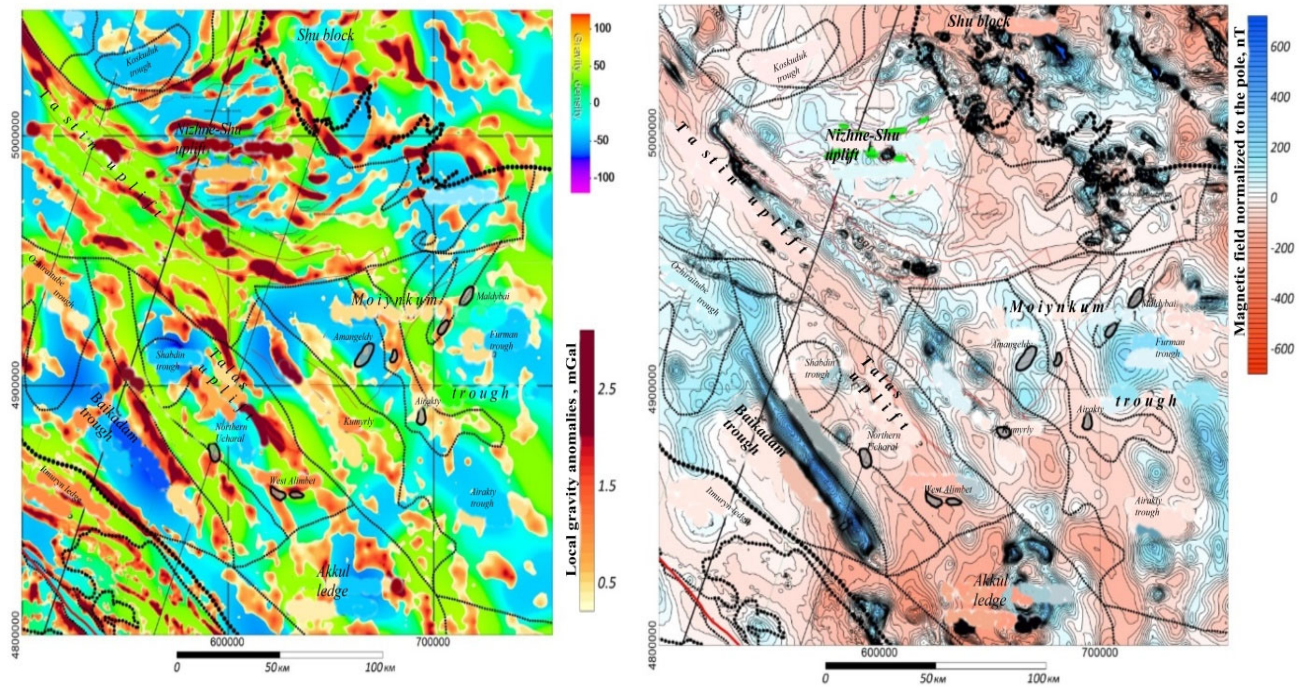
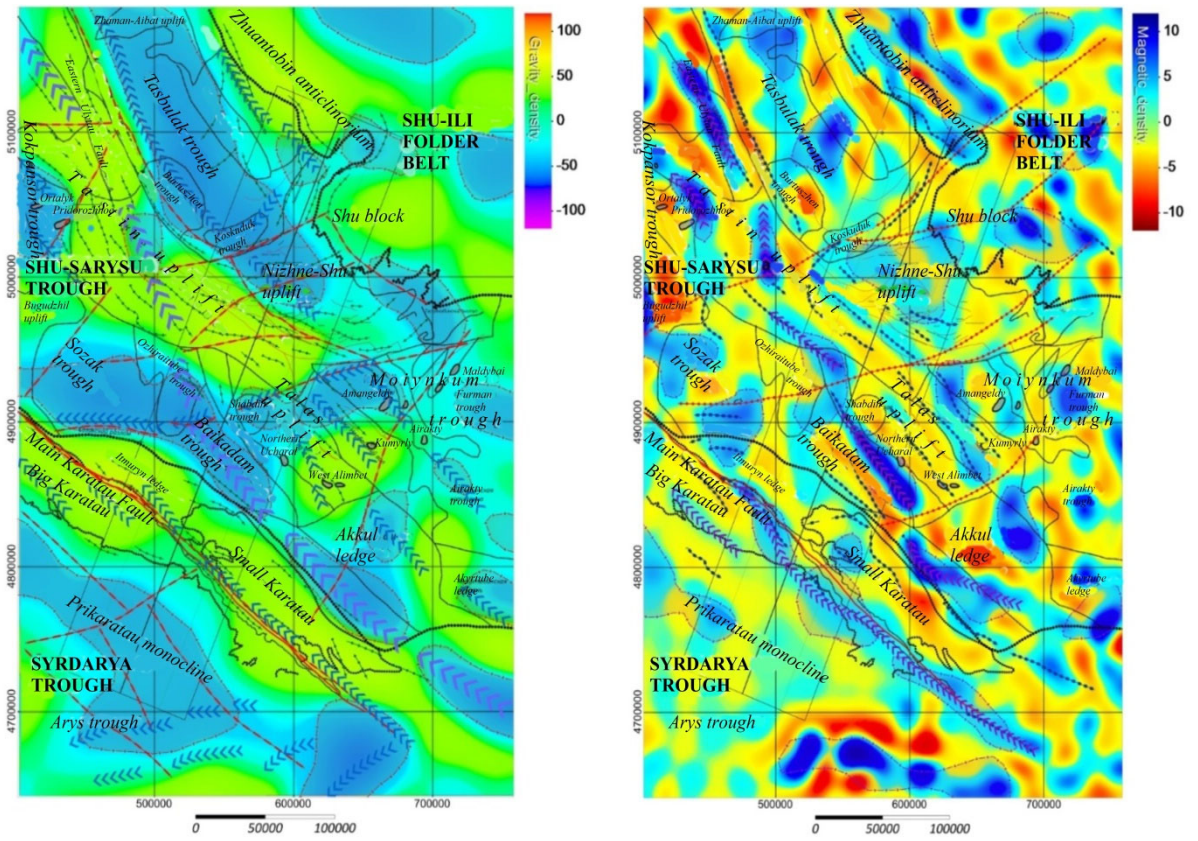
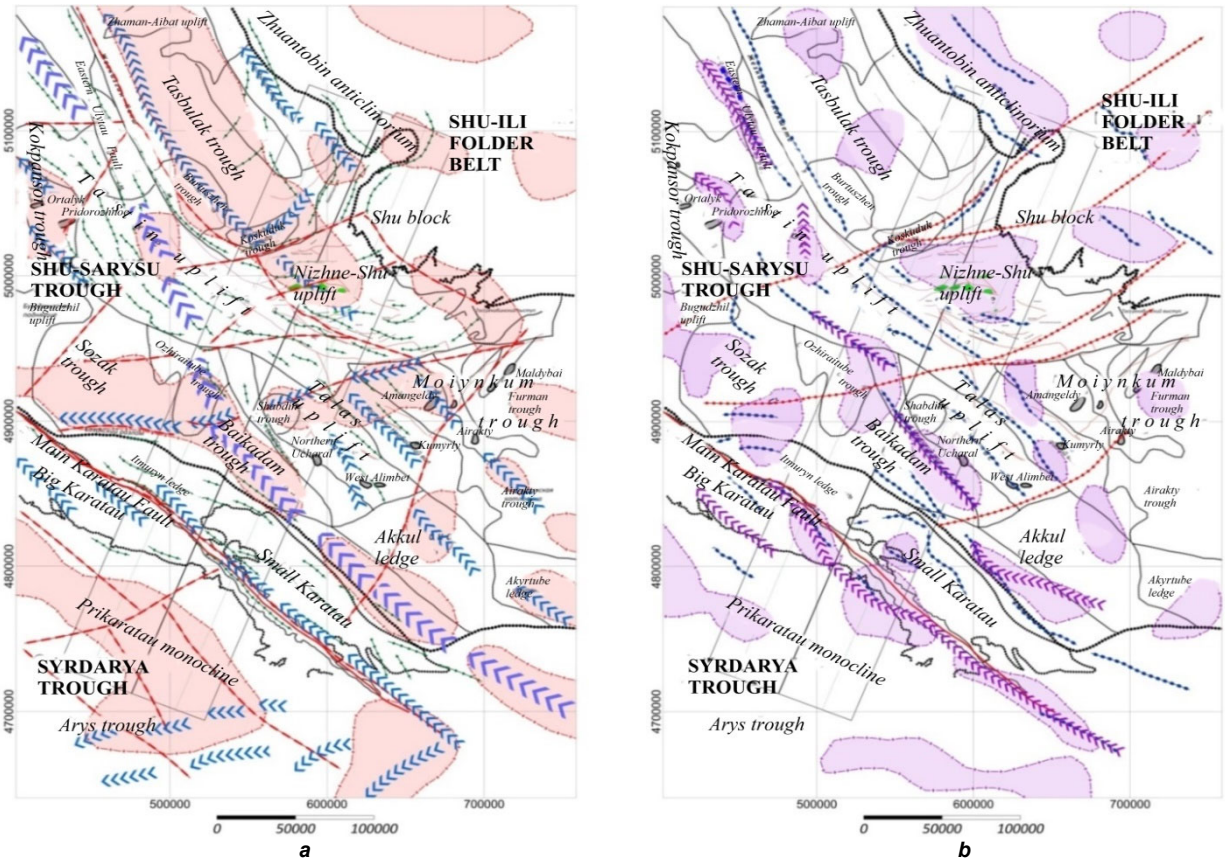


Fig. 3. Residual gravity anomalies (REIST model) against the background of a horizontal slice of a 3D model of excess density at the depth of 15 km (*a*) in comparison with the magnetic field normalized to the pole (*b*)



a *b*

Fig. 4. Schemes of lineaments against the background of a horizontal cut to the depth of 7 km geodensity (*a*) and geomagnetic (*b*) models



a *b*

Fig. 5. Elements of interpretation schemes for the density (*a*) and magnetic (*b*) models and their comparison (*c*)

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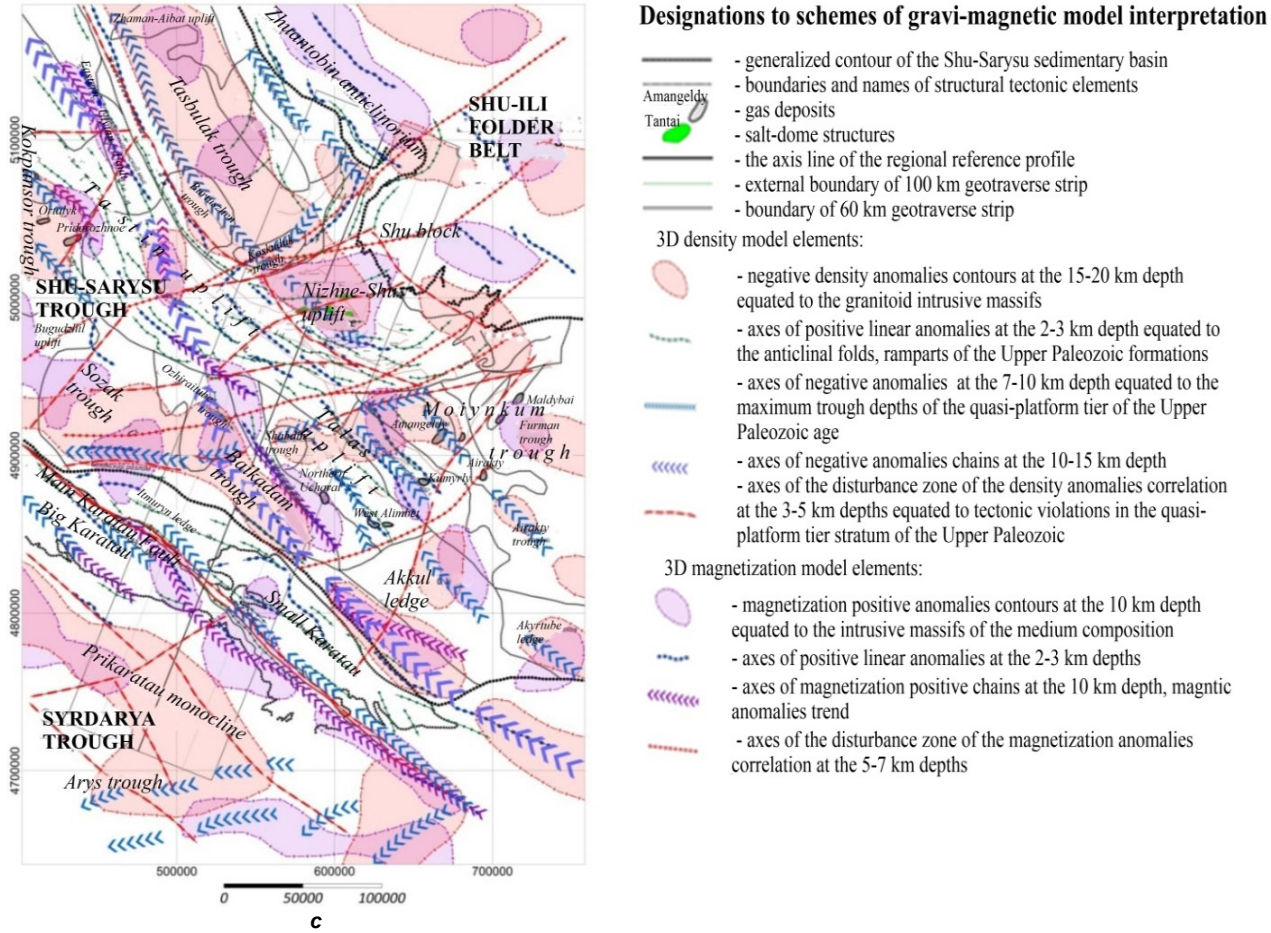

c

Fig. 5. (ending) Elements of interpretation schemes for the density (*a*) and magnetic (*b*) models and their comparison (*c*)

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КОМПЛЕКСНИЙ АНАЛІЗ ДАНИХ МАГНІТОРОЗВІДКІ ТА ГРАВІРОЗВІДКИ НА ОСНОВІ ОБ'ЄМНОГО ГРАВІМАГНІТНОГО МОДЕЛЮВАННЯ ВЗДОВЖ ГЕОТРАВЕРСА ШУ-САРИСУ

Метою представлених досліджень є отримання інформації про глибинну будову геологічних структур уздовж геотраверса Шу-Сарису; з'ясування закономірностей розташування родовищ корисних копалин і прогнозна оцінка перспективності території досліджень на пошуки вуглеводнів та інших корисних копалин. Для досягнення цієї мети застосовувався комплекс високоточних гравітаційних і магнітометричних вимірів. Показано високу ефективність комплексної інтерпретації гравімагнітного 3D-моделювання щодо геологічної будови кристалічного фундаменту (оцінка морфології його поверхні, речовинно-петрофізичне картування порід фундаменту) та осадового чохла (оцінка морфології опорних горизонтів, вивчення їх речовинного складу); при виявленні та уточненні положення розривних порушень, проведенні лінеаментного аналізу з метою розшифрування блокової будови площ, що вивчаються; під час побудови об'ємних 3D-моделей геофізичних параметрів; обґрунтуванні прогнозно-пошукових геофізичних критеріїв виявлення нафтогазових геологічних структур як у товщі осадових утворень, так і в породах кристалічного фундаменту. Прогрес зазначених методів зумовлений широким впровадженням у практику сучасних комп'ютерних технологій обробки та інтерпретації даних.

Ключові слова: ***геотраверс, гравірозвідка, аеромагніторозвідка, щільнісні властивості гірських порід, геомагнітна модель, трансформації поля, газ, 3D-моделювання потенційних полів.***

Автори заявляють про відсутність конфлікту інтересів. Спонсори не брали участі в розробленні дослідження; у зборі, аналізі чи інтерпретації даних; у написанні рукопису; в рішенні про публікацію результатів.

The authors declare no conflicts of interest. The funders had no role in the design of the study; in the collection, analyses or interpretation of data; in the writing of the manuscript; in the decision to publish the results.