ISSN 2518-170X (Online),
ISSN 2224-5278 (Print)

ҚАЗАҚСТАН РЕСПУБЛИКАСЫ
ҰЛТТЫҚ ҒЫЛЫМ АКАДЕМИЯСЫ

Satbayev University

ХАБАРЛАРЫ

ИЗВЕСТИЯ

НАЦИОНАЛЬНОЙ АКАДЕМИИ
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N E W S

OF THE ACADEMY OF SCIENCES
OF THE REPUBLIC OF
KAZAKHSTAN
Satbayev University

SERIES

OF GEOLOGY AND TECHNICAL SCIENCES

3 (453)

MAY – JUNE 2022

THE JOURNAL WAS FOUNDED IN 1940

PUBLISHED 6 TIMES A YEAR

ALMATY, NAS RK

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«ҚР ҰҒА Хабарлары. Геология және техникалық ғылымдар сериясы».
ISSN 2518-170X (Online),
ISSN 2224-5278 (Print)

Меншіктеуші: «Қазақстан Республикасының Ұлттық ғылым академиясы» РҚБ (Алматы қ.).

Қазақстан Республикасының Ақпарат және қоғамдық даму министрлігінің Ақпарат комитетінде 29.07.2020 ж. берілген **№ KZ39VPY00025420** мерзімдік басылым тіркеуіне қойылу туралы куәлік.

Тақырыптық бағыты: *геология, мұнай және газды өңдеудің химиялық технологиялары, мұнай химиясы, металдарды алу және олардың қосындыларының технологиясы.*

Мерзімділігі: жылына 6 рет.

Тиражы: 300 дана.

Редакцияның мекен-жайы: 050010, Алматы қ., Шевченко көш., 28, 219 бөл., тел.: 272-13-19
http://www.geolog-technical.kz/index.php/en/

Типографияның мекен-жайы: «Аруна» ЖК, Алматы қ., Мұратбаев көш., 75.

«Известия НАН РК. Серия геологии и технических наук».
ISSN 2518-170X (Online),
ISSN 2224-5278 (Print)

Собственник: Республиканское общественное объединение «Национальная академия наук Республики Казахстан» (г. Алматы).

Свидетельство о постановке на учет периодического печатного издания в Комитете информации Министерства информации и общественного развития Республики Казахстан **№ KZ39VPY00025420,** выданное 29.07.2020 г.

Тематическая направленность: *геология, химические технологии переработки нефти и газа, нефтехимия, технологии извлечения металлов и их соеденений.*

Периодичность: 6 раз в год.

Тираж: 300 экземпляров.

Адрес редакции: 050010, г. Алматы, ул. Шевченко, 28, оф. 219, тел.: 272-13-19

http://www.geolog-technical.kz/index.php/en/

Адрес типографии: ИП «Аруна», г. Алматы, ул. Муратбаева, 75.

News of the National Academy of Sciences of the Republic of Kazakhstan. Series of geology and technology sciences.
ISSN 2518-170X (Online),
ISSN 2224-5278 (Print)
Owner: RPA «National Academy of Sciences of the Republic of Kazakhstan» (Almaty).
The certificate of registration of a periodical printed publication in the Committee of information of the Ministry of Information and Social Development of the Republic of Kazakhstan **No. KZ39VPY00025420,** issued 29.07.2020.
Thematic scope: *geology, chemical technologies for oil and gas processing, petrochemistry, technologies for extracting metals and their connections.*
Periodicity: 6 times a year.
Circulation: 300 copies.
Editorial address: 28, Shevchenko str., of. 219, Almaty, 050010, tel. 272-13-19
http://www.geolog-technical.kz/index.php/en/

Address of printing house: ST «Aruna», 75, Muratbayev str, Almaty.

NEWS of the National Academy of Sciences of the Republic of Kazakhstan
SERIES OF GEOLOGY AND TECHNICAL SCIENCES
ISSN 2224-5278
Volume 3, Number 453 (2022), 17-31
https://doi.org/10.32014/2022.2518-170X.177

UDC 550.3: 550.812:550.831.015

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GRAVITY FIELD TRANSFORMS AT THE EXPLORATION FOR HYDROCARBON FIELD IN THE SOUTHERN PART OF THE USTYURT REGION

Abstract. The article discusses the results of the interpretation of gravity survey data in the southern part of the Ustyurt region in order to identify zones and areas heterogeneous in terms of the density properties of rocks. An attempt was made to relate the nature of the distribution anomalous gravity field with areas potentially productive for the discovery of hydrocarbon (HC) accumulations.

To this end, the following transforms were calculated: modules of vertical and horizontal potentially productive of Bouguer anomaly, local gravity anomaly (recalculated in the upper half-space at a height of 2.5 km), anisotropy transform, the accent of maximum gravity anomaly and Euler points.

The distribution of Euler points clearly demonstrates different depths of bedding of gravitational-disturbing boundaries in the crust of the Central Ustyurt dislocation system, the Shakhtakhty step and the Assakeaudan depression.

The depths of the latter are observed to coincide with the reflecting boundaries according to common depth point (CDP)-2D seismic data (surfaces of pre-Jurassic rock complexes, basement, and boundaries in the sedimentary cover). A high total thickness of the sedimentary cover and pre-Jurassic rock complexes of the Shakhpakhty step has been established. This statement is confirmed by the airborne gamma-ray spectrometer (radiometric) data, processed and interpreted by the thorium normalization method, as well as the results of interpretation and modeling of the aeromagnetic survey data.

The results of the integrated interpretation of gravity and magnetic field transforms, airborne gamma spectrometry and seismic CDP-2D data unambiguously indicate the prospects of oil-and-gas bearing of the local structures at the Shakhpakhty step with due regard for favorable historical-geological, structural and lithofacies factors.

Key words: gravity survey, Bouguer anomaly, transforms, density model.

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ҮСТІРТ ӨҢІРІНІҢ ОҢТҮСТІК БӨЛІГІНДЕГІ КӨМІРСУТЕГІ КЕН ОРЫНДАРЫН ІЗДЕУ КЕЗІНДЕГІ ГРАВИТАЦИЯЛЫҚ ӨРІСТІҢ ТРАНСФОРМАНТТАРЫ

Аннотация: Мақалада тау жыныстарының тығыздық қасиеттері бойынша біртекті емес аймақтар мен алаңдарды анықтау мақсатында Үстірт өңірінің оңтүстік бөлігі бойынша гравибарлау зерттеу жұмыстарының нәтижелері қарастырылған. Гравитациялық өріс аномалияларының таралу сипаты мен табиғатын көмірсутектердің (КС) жинақталуын анықтауға перспективалы аудандармен байланыстыруға әрекет жасалды.

Осы мақсатта Буге гравитациялық аномалияларының келесі трансформанттары есептелді: тік және көлденең градиенттер модульдері, жергілікті гравитациялық аномалиялар (жоғарғы жартылай кеңістікке 2,5 км биіктікке қайта есептелген), анизотропты трансформант, ауырлық күші аномалияларының максимумдары және Эйлердің нүктелері.

Эйлер нүктелерінің таралуы әр түрлі тереңдігі бойынша үш тектоникалық элемент – Орталық Үстірт дислокациялық жүйесі, Шахпахты сатысы және Ассакеаудан ойпаты оқшауланды. Сейсмикалық барлау деректері бойынша соңғылардың жату тереңдігінің жалпы тереңдік нүкте (МОГТ) -2Д әдісі (жыныстардың юраға дейінгі кешендерінің беті, шөгінді тыстағы іргетас пен шекара) бойынша сәйкес келуі байқалады.

Шахпахта сатысындағы шөгінді жамылғылар мен Юра дәуіріне дейінгі тау жыныстарының үлкен жиынтық қуаты белгіленді, бұл осы аумақты перспективалы санатқа шығарады. Жасалған қорытынды торийді қалыпқа келтіру әдісі бойынша өңделген және түсіндірілген аэрогаммаспектрометрия деректерімен, сондай-ақ магнит өрісінің деректерін түсіндіру және талдау нәтижелерімен расталады.

Гравитациялық және магниттік өрістердің трансформанттарын, радиометрия және МОГТ-2Д сейсмикалық барлау деректерін кешенді түсіндіру нәтижелері қолайлы тарихи-геологиялық, құрылымдық және литофациалдық факторларды ескере отырып, Шахпахта сатысының мұнай-газ оқшауланuына перспективалы екенін айқын белгілейді.

Түйін сөздер: гравибарлау, Буге аномалиясы, трансформанттар, тығыздық моделі.

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ТРАНСФОРМАНТЫ ГРАВИТАЦИОННОГО ПОЛЯ ПРИ ПОИСКЕ МЕСТОРОЖДЕНИЙ УГЛЕВОДОРОДОВ В ЮЖНОЙ ЧАСТИ УСТЮРТСКОГО РЕГИОНА

Аннотация: В статье рассмотрены результаты интерпретации данных гравиразведки по южной части Устюртского региона с целью выявлении зон и площадей, неоднородных по плотностным свойствам горных пород. Реализована попытка увязать характер распространения аномалий гравитационного поля с площадями, перспективными на обнаружение скоплений углеводородов (УВ).

В этих целях были рассчитаны следующие трансформанты гравитационных аномалий Буге: модули вертикального и горизонтального градиентов, локальные гравитационные аномалии (пересчитанные в верхнее полупространство на высоту 2,5 км), анизотропная трансформанта, акцент максимумов аномалий силы тяжести и точки Эйлера.

Распределение точек Эйлера со всей очевидностью демонстрирует различную глубину залегания гравивозмущающих границ в земной коре Центрально-Устюртской зоны поднятий, Шахпахтинской тектонической ступени, Ассакеауданского прогиба.

Наблюдаются совпадение глубин залегания последних с отражающими границами по данным сейсморазведки метод общей глубинной точки (МОГТ) -2Д (поверхности доюрских комплексов пород, фундамента и границ в осадочном чехле). Установлена большая суммарная мощность отложений осадочного чехла и доюрских комплексов пород на Шахпахтинской ступени, что однозначно выдвигает её в разряд перспективных на обнаружении скоплений УВ.

Сделанное утверждение подтверждается данными аэрогаммаспектрометрии, обработанными и проинтерпретированными по методу нормализации тория, а также результаты интерпретации и моделирования данных аэромагниторазведки. Результаты комплексной интерпретации трансформант гравитационного и магнитного полей, данных аэрогаммаспектрометрии и сейсморазведки МОГТ-2Д однозначно свидетельствуют о перспективах нефтегазоности локальных структур Шахпахтинской ступени с учетом благоприятных историко-геологического, структурного и литофациального факторов.

Ключевые слова: гравиразведка, аномалии силы тяжести в редукции Буге, трансформанты, плотностная модель.

Introduction. Gravimetric study and density characterization. In the southeastern part of the Mangyshlak - South Ustyurt trough system, gravity survey works have been carried out since 1954. Their main purpose was the general study of the regional and local components of gravity anomalies.

Density characteristics of rocks within the South Ustyurt (Daukeev, 2002) were studied by core drilling. Rock density (δ) of the Assakeudan depression sedimentary complex differs from that of the same-age formations of the Central Ustyurt uplift, which, apparently, is associated with their different hypsometric position.

According to the results of the studies, the density distribution with depth shows that the gravity minima and maxima, as well as the areas of distribution of rocks with reduced density characteristics are a reflection of the deep-lying structures confined to the Paleozoic basement.

The average density (δcf) of the Cenozoic sediments in the Assakeudan depression is 2.05 g/cm^3. For Mesozoic rocks δcr = 2.44 g/cm^3, with the lowest values (2.37 g/cm^3) characterized by the Upper Cretaceous sediments, the highest (up to 2.74 g/cm^3) - Middle and Upper Jurassic.

In the Central Ustyurt dislocation system, the density of Mesozoic rocks is much lower and varies from 2.23 g/cm^3 (Upper Cretaceous sediments) to 2.46 g/cm^3 (Middle Jurassic).

In general, the rock density of the sedimentary cover of tectonic elements increases with depth and levels off at 2.60 g/cm^3 for consolidated formations due to compaction (closure of the pore space) at greater depths.

At depths greater than 5-6 km, the surface of the basement loses the properties of the gravitationally active boundary.

Hardware support. Methods of processing and interpretation of gravity survey data. In 2019, GEOKEN LLP carried out comprehensive geophysical surveys to identify oil and gas prospective areas and areas in the

Central Ustyurt dislocation system and in the southeastern part of the South Mangyshlak-Ustyurt trough system.

Automated CG-5 AutoGrav Scintrex gravimeters (Canada) were used to make gravimetric observations. In order to bring the gravimetric survey to the level of the State Gravimetric Network (GSN), a reference gravimetric network was created on the study area.

Linear gravity surveys were performed in the direction of the profiles from south to north with a length of 100 km, the distance between the profiles in the Central Ustyurt dislocation system of 2 km, in the Assakeaudan depression and in the Shakhpakhty step from 500 meters to 1 km.

Each observation at an ordinary point consisted of at least 2 cycles of 20 seconds each. At discrepancies of more than 0.02 mGal additional measurements were carried out until a group of at least 3 readings with discrepancies between them not more than 0.05 mGal was obtained. The duration of flights is determined by linearity of zero-point gravimeters and, as a rule, did not exceed 10 hours.

For geodetic referencing we used dual frequency satellite positioning systems Differential Global Positioning System (DGPS) Trimble R7 (GPS+GLONASS, L1/L2), equipped to work in Static, Post Processing Kinematic and Real Time Kinematic (RTK) modes. The gravimetric survey points were aligned in contemporaneous with the gravity survey using the DGPS satellite positioning system. The system consisted of dual-frequency receivers operating in RTK.

The series gravimetric survey was performed by independent complex (gravity survey, topography) control measurements. The control measurements were evenly distributed over the area. A total of 4% of the total volume was monitored. The methodology of observations in special control trips was the same as in ordinary trips. At the final stage of the survey, profile anomalies and high anomalies with weak correlation were monitored.

The mean square error of a single gravimetric observation and determination of anomalies in the Bouguer reduction was ± 0.04 mGal, the error in determining the position of gravimetric points in the plan ± 1.2 m and in height ± 0.08 m.

Processing of the ground gravity survey data (Ming-hua Zhang, 2018; Leonidovich, 2006) included the following: compilation of schemes and catalogs of the reference network, compilation of a catalog of ordinary gravity points, evaluation of the level and quality of previously performed surveys, bringing gravity anomalies from previously performed surveys to a unified level, construction of the gravity anomaly map in Bouguer Reduction with intermediate layer density: real equal to 2.30 g/cm^3 of scale 1:100000 with 0.5 mGal section. Processing and interpretation was performed using the Gravity and Terrain Correction module of the Geosoft Oasis Montaj software package.

For the most informative and objective characterization of the gravity field of the site, we calculated its various transforms: tracing of axes of the Bouguer anomaly and horizontal gradient, anisotropic transforms - the accent of maximum gravity anomalies and gradient of gravity anomalies, etc.

Results of the calculation of the gravity field transforms. The initial gravity field reflects the total gravitational influence of both geological structures of the upper tiers and deep structures of the Earth's crust and upper mantle.

The gravity field of the research region (Blakely, 1996) is alternating and is characterized by successive changes in Δga values from +24 mGal in the Central Ustyurt dislocation system (Akmechet structure) to -32 mGal in the Assakeaudan depression (Birinzhik structure).

Gravity anomalies in the Central Ustyurt dislocation system are characterized by a linear character and northwestern orientation.

In the Shakhpakhty step, especially in its southern part, anomalies Δga are characterized by a complex pattern, combining the presence of linear-drawn, polygonal and festoon-cut forms, also north-west trending.

In the northern part of the Assakeudan depression, no clearly pronounced zoning in the distribution of gravity field anomalies is observed.

Modulus of horizontal derivative of Bouguer gravity anomaly.

The bands of increased horizontal gradient (Castro, 2018) of the field (Fig. 1) are caused by faults with a gradient of 0.001 mGal/m, limiting the system of rises from the north to the south.

In general, the study region is characterized by heterogeneous distribution of this parameter. For example, in the central and southern regions of the Shakhpakhty step (Samtyr and Kozhantai structures), lower values of the horizontal gradient of the D ga anomalies (less than 0.0005 mGal/m) are noted.

In other areas, including on the oil-and-gas prospective structures (according to airborne gamma-ray spectrometer (radiometric) data) Utezhan, Otynshi, North Kozhantai values of horizontal gradient increase up to 0.001 mGl/m.

Maximum values of this parameter are recorded in the Central Ustyurt dislocation system (Akmechet structure), where they acquire values up to 0.003 mGl/m and more (Fig.1).

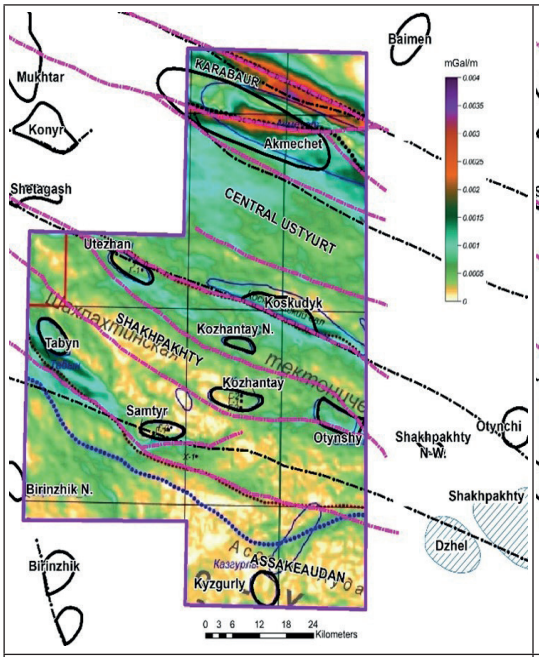

Fig. 1. Module of horizontal derivate of Bouguer anomaly

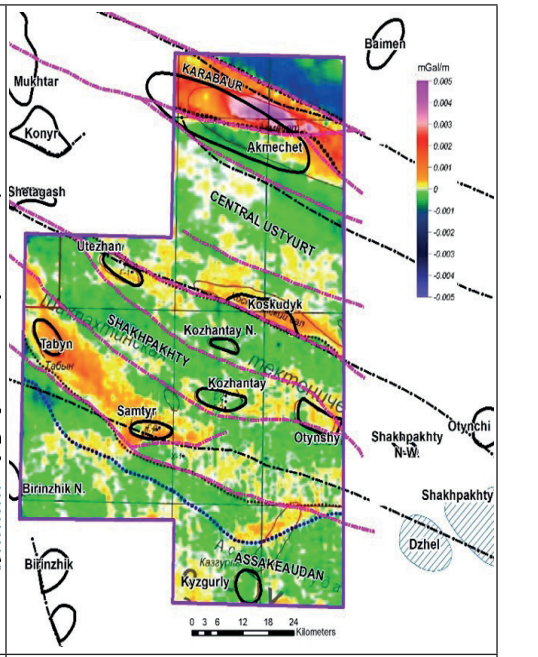

Fig. 2. Module of the vertical derivate of Bouguer anomaly

The dashed black lines indicate major faults along V reflecting horizon. Dashed pink lines indicate major tectonic breaks highlighted on a set of completed research (gravity exploration, magnetic prospecting, thermal fields and terrain). Dashed blue line of the regional negative gravity system of the anomaly, corresponding to the Assakeaudan depression.

Modulus of the vertical derivative of Bouguer gravity anomaly.

According to the values of the vertical gradient modulus (Bychkov, 2010; Lyandres, 2009) of the gravity anomaly, several regions are distinguished. First of all, the northern part of the Central Ustyurt dislocation system (Akmechet structure) characterized by the maximum vertical gradient (up to 0.005 mGl/m) of Bouguer anomalies attracts attention.

In the southern part of this dislocation system (the Khoskuduk structure) and in the south of the Shakhpakhty step (the Samtyr and Tabyn structures), intermediate values (0.002 - 0.0025 mGl/m) of this gradient of D

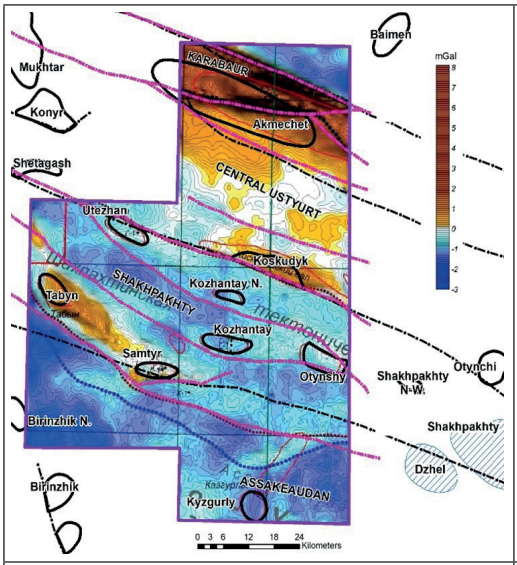

Fig. 3. Local gravity anomaly (recalculated in the upper half-space at a height of 2.5 km)

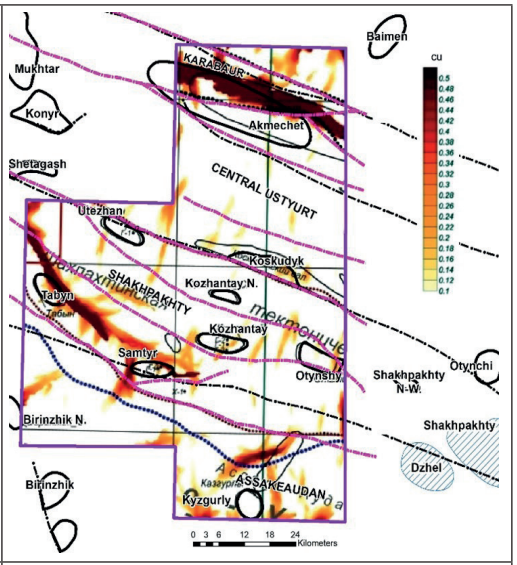

Fig. 4. Anisotropy transform, the accent of maximum gravity anomaly. Sliding window size 5 km x 2km

The dashed black lines indicate major faults along V reflecting horizon. Dashed pink lines indicate major tectonic breaks highlighted on a set of completed research (gravity exploration, magnetic prospecting, thermal fields and terrain). Dashed blue line of the regional negative gravity system of the anomaly, corresponding to the Assakeaudan depression.

In the remaining areas of the Shakhpakhty step and on the northern side of the Assakeaudan depression, there is a mosaic placement of weakly intense (0-1 mGal) and moderately intense (-1 to -3 mGal) local negative Bouguer anomaly (Fig.3).

The transform tracing of axes (Petrov, 2003) of the Bouguer anomaly did not show significant differentiation of the study region and for this reason we consider as uninformative.

On the basis of the anisotropic tranformation result (Matusevich, 2006), we interpreted the higher values along the Tabyn, Samtyr and Akmechet structures (Fig.4) as zones with significantly variation of rock density.

Euler points.

The distribution of Euler points in the vertical section it well illustrates the placement of gravitationally disturbing bodies by depth.

Calculated in the Geosoft Oasis Montaj software using the algorithm of three-dimensional deconvolution (Inoubli, 2015), the major special Euler

points, are concentrated near the edges of the anomalies, correspond to the position and depth of anomaly-forming or gravitationally disturbing bodies (Abetov, 2017).

By this transform, as well as by integration with other transforms as module of the vertical and horizontal derivate, local gravity anomaly and anisotropy transforms of the gravity field anomalies, large (regional) structural elements are reliably distinguished. Calculations on theoretical examples show that even if the Euler points do not form dense clusters near the anomaly-forming sources, at least along the lateral edges of the anomalies the density of solutions can be relevant.

The schemes of location of special Euler points (Fig. 5), the table of location of special Euler points in the depth range of 0.6 to 8.0 km and the graph of distribution of these points in the gravity field (Fig. 6) convincingly testify to the density heterogeneity of rocks in the study region and their different depth of occurrence, which is emphasized by previously considered transformans of the gravity field.

The strike of gravity-disturbing objects in the study region is sharply differentiated by area. For example, in the 2-8 km depth interval in the northern part of the Shakhpakhty step, Euler points are grouped into bands of northeastern strike.

In the southern part of the Shakhpakhty tectonic step and in the Assakeaudan depression, these points form a cloud that trends northwestern to northern.

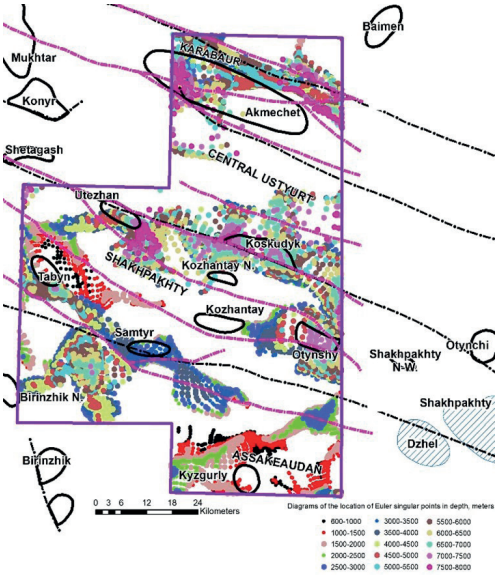

Fig. 5. Scheme of position of Euler's points at depths up to 8.0 km (interval 0.5 km)

The dashed black lines indicate major faults along V reflecting horizon. Dashed pink lines indicate major tectonic break highlighted on a set of completed research (gravity exploration, magnetic prospecting, thermal fields and terrain). Dashed blue line of the regional negative gravity system of the anomaly, corresponding to the Assakeaudan depression.

In the Central Ustyurt dislocation system, special Euler points are concentrated in bands of predominantly northwestern strike.

The maximum number of Euler points on the surface of gravity-disturbing bodies is concentrated in the Assakeudan depression at depths of 1000-2000 m, in the Central Ustyurt dislocation system of 4000-5000 m and in the Shakhpakhty step of 6000-7000 m (Table 1).

Table 1. Locations of Euler points in the depth interval of 600-8000 meters

Areas	600-1000	1000-2000	2000-3000	3000-4000	4000-5000	5000-6000	6000-7000	7000-8000
Central Ustyurt dislocation system	0	41	156	415	1759	804	249	231
Shakhpakhty step	0	41	252	455	507	584	611	278
Assakeaudan depression	196	1940	1391	1006	687	676	290	5

Figure 6 demonstrates a similar picture, in general, showing that up to 7000-8000 m depths large differences in the depths of occurrence of gravity-disturbing bodies persist, while deeper these differences are considerably leveled. It can be assumed that this is due to the general transition from the formations of the sedimentary cover and intermediate structural step to the basement rocks.

In relation to the correlation between the depths of occurrence of gravitational and magnetically disturbing masses, it is possible to note that the accumulations of magnetically disturbing bodies in the Central Ustyurt dislocation system are observed in the depth intervals of 4000-6000 m. It is important to note that the depths of the occurrence of gravitationally and magnetically disturbing bodies coincide.

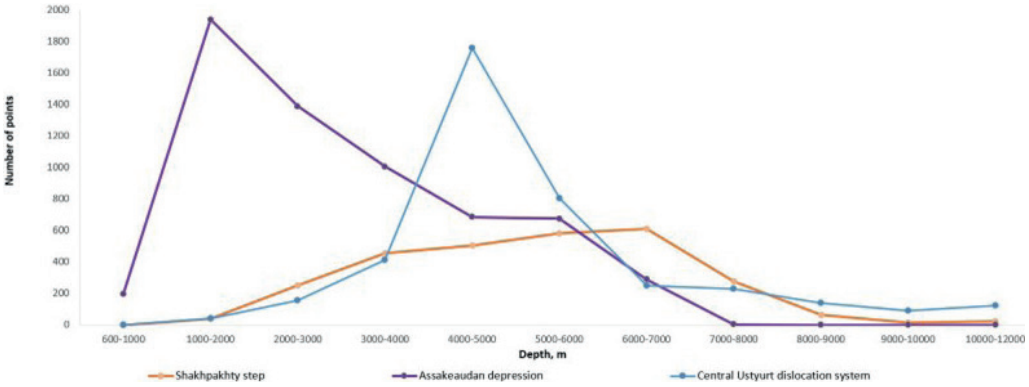

Fig. 6. Graph of the distribution of Euler points in the gravity field at depths from 600 meters to 12000 meters

At the same time, in the Central Ustyurt dislocation system, the presence of deeper Euler solution (10-12 km) with a maximum number of special Euler points was recorded, which indirectly indicates the northward dipping of the Karabaur swell under the North Ustyurt massive, i.e. the "twin" crustal effect.

However, this assumption needs further serious verification with the construction of 3D geological and geophysical models.

According to CDP-2D seismic data (Ibragimov A.A., Almaty, 2020), the depth of the basement surface in the Central Ustyurt dislocation system varies widely, varying between 4-8 km. The structures distinguished on this surface have linear shapes, extend in the northwestern direction, and are characterized by a general dip in the southern direction. In the area of the Akmechet structure, the basement surface deepens to 9 km.

Consequently, we can indicate that the distribution of Euler points with depth fits into the variations in the depths of basement occurrence revealed by CDP-2D seismic data.

In the Assakeudan depression, a serious discrepancy in the depths of occurrence of gravity-disturbing masses and magnetically disturbed objects is revealed.

The upper edge of the gravitational masses lies at depths of 1000-2000 m and, apparently, reflects the transition of unconsolidated and weakly consolidated Lower Cretaceous rocks to Upper Jurassic sediments. A similar phenomenon has been detected in some areas of the North Ustyurt depression (Abetov, 2017).

The upper edge of the magnetically disturbing masses descends to depths of 8-10 km and reflects the level of maximum distribution of rocks of the basic and ultrabasic composition in the basement rocks.

According to the CDP-2D seismic survey (Ibragimov A.A., Almaty, 2020),

the surface of the basement of the northern side of the Assakeaudan depression is deepening in the southern direction from 7 km to 10 km (in the area of the Birinzhik structure). On the surface of Upper Jurassic deposits (III reflecting horizon), on the contrary, there is a trend of its uplift in the southwestern direction from 2.6-2.8 km near the Kazgurly structure to 1.7-2.0 km near the Birinzhik and Birinzhik North structures.

Thus, it becomes evident that the upper edge of the gravitationally disturbing masses, in general, correlates with the surface of the Upper Jurassic deposits, whereas the upper edge of the magnetically disturbing masses is isolated in the depth interval of the basement surface.

In the Shakhpakhty step, the upper edge of the magnetically disturbing masses sinks to a depth of 8-12 km, whereas the magnetic and density disturbing objects are buried to 6-7 km. Such a character of their distribution demonstrates the difference in the depths of occurrence of the basement and intermediate structural levels.

This is partly confirmed by CDP-2D seismic data (Ibragimov A.A., Almaty, 2020), according to which the depth of surface dip of Upper Paleozoic carbonate-terrigenous deposits changes in a wide range from 3.75 km on the Tabyn structure, 4.5 km on the Samtyr and Utezhan structures and to over 5.5 km on the Kojantai and Otynsha structures.

The structures along this surface do not lend themselves to any geographical zoning classification; they have polygonal forms and mosaic character, as well as a general character of dipping in a southeasterly direction. The exception is the Tabyn structure with a northwestern orientation and brachyanticlinal forms.

It is difficult to discuss about the dipping depth of the basement surface at the Shakhpakhty step because it does not exhibit good acoustic stiffness.

Consequently, we can say that in the Shakhpakhty step, the upper edges of the gravity and causative magnetic body are distinguished by their maximum depths. In the Assakeudan depression, these characteristics enjoy a large scatter and in the Central Ustyurt dislocation system, they are isolated by small fluctuations.

Tabyn Kozhantai, Kozhantai S., Utezhan and Kyzgyrly structures, which are recommended for further detailed study by CDP seismic survey and deep drilling, can be considered as promising zones for hydrocarbons by interpretation of the anomalous magnetic field (Abetov, 2021 b) and by parameters of potassium and uranium contents (Abetov, 2021 a) and gravity data interpretation results.

Conclusion. The main conclusions on the analysis of the transformation of the gravitational field of the region of research are as follows:

The Shakhpakhty tectonic step of the Assakeudan depression and the Central Ustyurt dislocation system are sharply differentiated by the distribution of gravity field transformants.

Assakeaudan depression stands out by the minimum values of transform of horizontal and vertical derivative of Bouguer gravity anomalies, local negative gravity anomalies (recalculated in the upper half-space at a height of 2.5 km).

The Central Ustyurt dislocation system is everywhere characterized by increased values of local gravity anomalies (recalculated in the upper half-space at a height of 2.5 km). Intermediate values of the transformants of the moduli of horizontal and vertical gradients of the Bouguer gravity anomalies are observed here.

Shakhpakhty tectonic step is distinguished by reduced values of the transformant module of the horizontal gradient of the Bouguer anomalies, increased values of the vertical gradient, weakly and moderately intense local positive and negative Bouguer anomalies (recalculated at a height of 2.5 km). The Shakhpakhty step, the upper edges of the gravity and causative magnetic body distinguished by the maximum depth.

In turn, this circumstance is evidence in favor of the high total thickness of the sedimentary cover and the intermediate structural stage at the Shakhpakhty step, which unambiguously puts this element in the category of promising hydrocarbon accumulation discoveries.

This statement is confirmed by the airborne gamma-ray spectrometry data, processed and interpreted by the thorium normalization method.

Based on the fact that the content of potassium and uranium over the oil and gas deposits has characteristically low values (Julia B. Curto, 2012) in relation to the background values in the region of research, a total of 15 zones were identified (Abetov, 2021 a), with a relatively reduced background of total radioactivity; low isoconcentrations of potassium; reduced uranium content. Most of these 15 zones are isolated in the area of the Shakhpakhty step.

In addition, the results of interpretation and modeling of aeromagnetic survey data in the region of studies in the Oasis Montaj software (Julia B. Curto, 2015) performed in order to identify zones and areas of heterogeneous magnetic properties of rocks, testify to the increased prospects of oil-and-gas content of Shakhpakhty step

The obtained results of the complex interpretation of gravity and magnetic field transforms, airborne gamma-ray spectrometer (radiometric) data, processed and interpreted by the thorium normalization method unambiguously indicate the prospects of oil and gas bearing structures of local Utezhan, Kojantai, North Kojantai, Otynshy with regard to favorable historical-geological, structural and lithofacial factors.

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www:nauka-nanrk.kz
http://www.geolog-technical.kz/index.php/en/
ISSN 2518-170X (Online),
ISSN 2224-5278 (Print)

Редакторы: *М.С. Ахметова, А. Ботанқызы, Р.Жәлиқызы, Д.С. Аленов*
Верстка на компьютере *Г.Д.Жадыранова*

Подписано в печать 15.06.2022.
Формат 70x90$^{1}/_{16}$. Бумага офсетная. Печать – ризограф.
17,5 п.л. Тираж 300. Заказ 3.

Национальная академия наук РК
050010, Алматы, ул. Шевченко, 28, т. 272-13-19