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Satbayev University

ХАБАРЛАРЫ

ИЗВЕСТИЯ

НАЦИОНАЛЬНОЙ АКАДЕМИИ НАУК
РЕСПУБЛИКИ КАЗАХСТАН
Satbayev University

NEWS

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GEOMAGNETIC FIELD TRANSFORMS AND THEIR INTERPRETATION AT EXPLORATION FOR HYDROCARBON FIELD IN THE SOUTHERN PART OF THE USTYURT REGION

Abstract. The results of interpretation of aeromagnetic survey data in the southern part of the Ustyurt region in order to identify zones and areas of rocks heterogeneous in terms of magnetic properties are discussed in this article. An attempt has been made to tie up the depth and nature of the propagation of the magnetoactive layer with areas potentially productive for the detection of hydrocarbons accumulations (HC).

With these purposes there were calculated such reduced-to-the-pole transforms of the anomalous magnetic field: vertical and horizontal derivatives, analytic signal, tilt derivative (TDR) of this field, high- and low-frequency components, tracing of axes of magnetic anomalies ΔTa, and position of 3d modeling of Euler's points.

The occurrence of a network of faults indicates the abrupt changes in the sign and direction of ΔTa anomalies, the presence of linear zones of high values of the magnetic field gradient, displacements of anomalies in plan and rectilinear ledges in the relief.

Three tectonic elements, the Central Ustyurt dislocation system, the Shakhtakhtin step, and the Assakeaudan depression are distinguished by the character of the transforms of the geomagnetic field, and, consequently, by the depth of occurrence and the scale of propagation of magnetic rocks.

The Shakhpakhty step is first of all recommended for setting up exploration in order to study the geological structure and oil and gas potential in more detail by the method of geological analogies and taking into account the available geological and geophysical data.

Key words: magnetic field transforms, airborne magnetic survey, vertical and horizontal derivatives, Euler points.

Introduction. The relevance of the use of effective innovative methods in the search and exploration of hydrocarbon (HC) fields is currently growing due to the emerging trend of depletion of a large number of exploited oil and gas fields.

There is an urgent task of finding algorithms for solving geological problems to replenish the mineral resource base of Kazakhstan through prospecting and putting into development new hydrocarbon fields.

In order to solve these tasks, in 2019 LLP "SPC" Geoken" Company carried out comprehensive geophysical study to identify of oil and gas prospective areas within the Central Ustyurt system of dislocation and in the southeastern part of the South Mangyshlak-Ustyurt system of troughs.

Materials and methods. An independent role in these studies was given to aeromagnetic exploration with the solution of specific geological tasks. Aeromagnetic survey was carried out using the airborne geophysical complex GT-MAG-2, acquired along 1000 m spaced flight lines flown at a nominal 100 m above terrain.

The daily variations in the magnetic field were taken into account using the PBM Pico complex based on a CS-3 cesium magnetometer. The TrimbleR7 GNSS L1 / L2 dual-frequency GPS receiver was used as a ground reference station for geodetic referencing. The alignment accuracy of the survey route in plan was ± 1 m.

The field preprocessing of aeromagnetic survey data was performed in two stages:

At the first stage, field data processing included input of corrections on devices` deviations and daily variations of the magnetic field and tie-up of survey lines with the method of statistic levelling and filtering and correction of magnetometry data by subtracting the distorting effect of man-made noise.

The second processing stage consisted of the following procedures:

a. calculation and input of corrections for radar-altimeter`s readings and hypsometry of surface relief;
b. aeromagnetic survey data filtering and correction;
c. magnetic field mapping and profiles plotting;
d. compiling database on magnetic variations;
e. calculation of the normal (IGRF) and anomalous magnetic fields and their most informative transforms, including vertical and horizontal derivatives, analytic signal, tilt derivative (TDR) of this field, high- and low-frequency components, tracing of axes of magnetic anomalies ΔTa, and Euler's points.

Matrixes were produced using the algorithm "Bidirectional Line Gridding" in the Oasis Montaj software (Geosoft, 2014), using a 250 m cell size.

For calculation of the anomalous magnetic field, the IGRF international analytical model was assumed as the Earth`s normal magnetic field. Oasis Montaj software was used for the calculations.

With the purpose to obtain the maximally valuable geological information, there were computed the following transforms [9] of the observed geomagnetic field (IGRF): analytic signal, vertical derivative of the magnetic field, horizontal derivative modulus of the anomalous magnetic field and tilt derivative (TDR), high- and low-frequency components of the magnetic field, position of 3d modeling of Euler's points and tracing of axes of anomalies ΔTa (Table 1) [2].

Table 1 - Statistics on the transforms of the anomalous magnetic field for the analyzed region.

Transform	Regional areas		
	Assakeudan depression	Shakhpakhty tectonic step	Central Ustyurt system of dislocations
Anomalous magnetic field reduced-to-the-pole, nT	from 100 to 300	from -50 to 100	from 100 to 400
Analytic signal, nT/m	from 0 to 0.005	from 0.005 to 0.008	from 0.002 to 0.02
Tilt derivative (TDR) of the magnetic field anomalies, radian	from 0 to 1.560	from -1.567 to 0	from -1.200 to 1.560
Vertical derivative of the anomalous magnetic field, nT/m	from -0.002 to 0.006	from 0 to -0.006	from -0.01 to 0.01
Horizontal derivative of the modulus magnetic field, nT/m	from 0 to 0.006	from 0 to 0.002	from 0.002 to 0.010
Transformation of the magnetic field anisotropy, cu.	from 0 to 0.002	from 0 to 0.0005	from 0 to 0.002
Tracing of axes of magnetic field anomaly, cu	from -0.5 to 1	from -3 to 0.5	from -5 to 5

Results. Distribution of the geomagnetic field anomalies in the area surveyed. The magnetic field within the surveyed regions is represented by linearly elongated ΔTa anomalies characterized by NW striking directions. In order to distinguish contacts of anomalous zones and provide more accurate estimate of the rock magnetization value the anomalous magnetic field was reduced-to-the-pole (Fig. 1A).

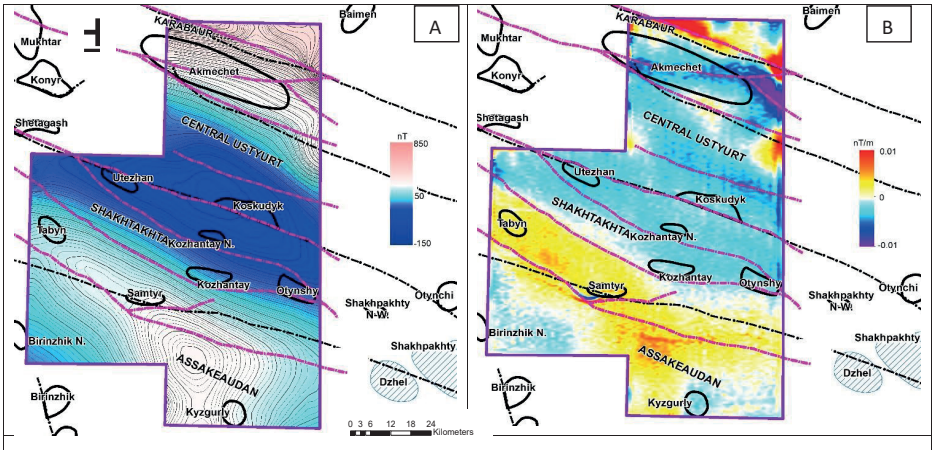

Fig. 1- (A): Anomalous magnetic field reduced-to-the-pole; (B): Vertical derivative of the anomalous magnetic field reduced-to-the-pole. The dashed black lines indicate major faults along V reflecting horizon. Dashed pink lines indicate major tectonic break highlighted on a set of completed research (gravity exploration, magnetic prospecting, thermal fields and terrain).

Karabaurskiy swell is characterized by high values of intensity of the anomalous magnetic field reduced-to-the-pole (+240+360 nT, occasionally to +520+800 nT). At that, the peak of values is related to the northern edge of Karabaurskiy swell, which implicitly indicates its depression in northern direction under Northern Ustyurt massif. The south part of zone of Central-Ustyurt system of dislocations is marked by a domain of lower magnetization of rocks, which was revealed in reduce of the geomagnetic field intensity to +50 nT.

The boundary between Shakhpakhty Tectonic Step and Central Ustyurt zone of uplifts (Kol`sai trough and Koskudyk swell) is characterized by minimal values varying from +46 nT to +14 nT.

The northern part of Shakhpakhty Tectonic Step is distinguished by an areas of negative values of the anomalous magnetic field reduced-to-the-pole (to -50-100 nT) in the area of the local structures Utezhan, Koskudyk, Kozhantai, Northern Kozhantai and Otynshy.

This fact indicates generation of anomalies of the geomagnetic field in the epochs different from those for the Central Ustyurt system of dislocations and Assakeudan Depression.

In the southern part of Shakhpakhty Tectonic Step there is observed another inversion of the geomagnetic field, and a high derivative zone of ΔTa anomalies with growth of numeric values of ΔTa anomalies to +100+120 nT revealed.

In Assakeudan Depression, there are revealed two big anomalies of the geomagnetic field of the north-western strike with intensity to +300 nT (Fig. 1A).

Vertical derivative of the magnetic field. On this transform (dZ) of the geomagnetic field, the tectonic boundaries between Central Ustyurt systems of uplifts, northern and southern parts of Shakhpakhty Tectonic Step and Assakeudan Depression (Fig. 1B) are distinguished in a pretty sharp and contrasting way.

The vertical derivative of the magnetic field emphasizes high frequencies anomalies, reveals block structure of magnetic and non-magnetic rocks within a surveyed region, and allows outlining the high-frequency component and seeing more clearly peculiarities of tectonically formed structure on chains of anomalies in mapping dislocations. Supposedly, through a part of those HCs migrated in conditions of favorable structural and tectonic conditions available.

When, on the way of migrating HC a trap is occurred then some changes in the oxidation-reduction environment over the reservoir resulting in newly generating such magnetic minerals as magnetite, hematite, pyrrhotine, etc. These processes are reflected in the magnetic field structure as dissected and brittle isodynams with a variegated picture observable on a high-frequency component of the field.

The picture like this is observed in the area of Utezhan, Kozhantai, and Northern Kozhantai local structures in areas marked by negative values of this transform. This geological phenomenon needs being additionally studied.

In general, minimal variations of this transform distinguish Assakeudan Depression (-0.002 +0.006 nT/m). Intermediate values of those - Shakhpakhty Tectonic Step (0 to -0.006 nT/m). Maximal values are observed in the Central Ustyurt system of dislocations (-0.01 +0.01 nT/m).

Horizontal derivative of the magnetic field. The complete horizontal derivative of the magnetic field reduced-to-the-pole was obtained through analysis of variability of the geomagnetic field (Fig. 2A). On this transform, Shakhpakhty Tectonic Step is characterized by derivative intermediate values (from 0 to 0.002 nT/m) which in the northern direction, towards the Central Ustyurt system of dislocations, grow to 0.010 nT/m, whereas, in the southern direction, towards Assakeudan Depression they go down to 0-0.006 nT/m.

Magnetic anisotropy transform [10]. The magnetic anisotropy transform reduced-to-the-pole indicates boundaries of anomaly-generating objects best of all (Fig. 2B). In calculation of this transform the size of sliding window of 5x2 km was used.

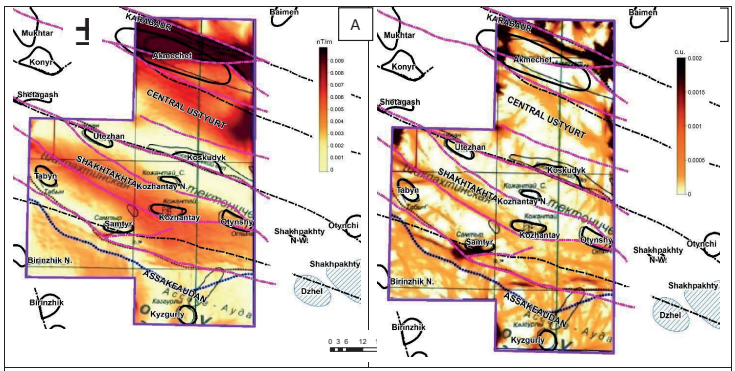

Fig. 2-(A): Horizontal derivative modulus of the magnetic field reduced-to-the-pole. (B): anisotropy transform, the accent of the maxima of the magnetic field reduced-to-the-pole. The dashed black lines indicate major faults along V reflecting horizon. Dashed pink lines indicate major tectonic violations highlighted on a set of completed research (gravity exploration, magnetic prospecting, thermal fields and terrain).

Higher values of the magnetic anisotropy transform (higher heterogeneity) characterize the southern and northern boundaries of Shakhpakhty Tectonic Step, and in the border the latter is adjacent to Assakeudan Depression and Central Ustyurt systems of dislocations (to 0.002 cu). Shakhpakhty Tectonic Step itself is distinguished by lower heterogeneity values (0-0.0005 cu), including local structures Utezhan, Kozhantai, Northern Kozhantai, and Otynshy, which is considered as a favorable historical and geological factor indirectly influenced on formation of the sedimentary subsurface.

Analytic signal. On character of distribution of the transforms [2] the territory surveyed is conditionally distinguished to several areas.

First of all, the most noticeable region is the area where the local structures Utezhan, Koskudyk, Kozhantai, North Kozhantai, and Otynshy are situated. The area is characterized by lower values of the analytical signal and distinguished in the northern part of the Shakhpakhty Tectonic Step and within the band where it joins to the Central Ustyurt systems of dislocations.

In the south-east of Shakhpakhty Tectonic Step, within the territory of the Republic of Uzbekistan, in earlier times, there were discovered big-size oil fields Shakhpakhty and Jel in Upper Jurassic sediments.

In the southerly located Assakeudan Depression, the analytical signals get minimal values (Kyzgurly, Birinzhik, and Northern Birinzhik structures).

Higher values of this transform are observed in the Central Ustyurt system of dislocations (Akmechet` structure).

The zone sequence distinguished in distribution of the analytical signal is confirmed by values of the magnetic induction derivative, with those varying within 0.005 - 0.008 nT/m for the Shakhpakhty Tectonic Step, 0 - 0.005 nT/m for the Assakeudan Depression, and 0.002 -0.02 nT/m for the Central Ustyurt system of dislocations (Table 1).

It would appear that such character of distribution of this transform is associated with block structure of the basement, where, on the one hand magnetically active rocks have got development variable in scales. On the other hand, there is a common plunge of upper edges of causative magnetic masses to the south.

Tilt derivative (TDR) of the magnetic field. This transform (measured in radians) reflects peaks of the initial geomagnetic field independently on their intensity and allows plain mapping of objects and their contours as well as tracing of structural elements [3, 4].

On intensity of TDR peaks the depth the objects are occurred may be evaluated. TDR transform peaks correspond to axial lines of magnetically active objects, and zero values – to their external boundaries.

The obtained results indicate that the northern part of Shakhpakhty Tectonic Step is distinguished by minimal values of negative angles of the derivative vector inclination angle of the magnetic field (from -1.567 to 0 radians) reduced-to-the-pole (structures Utezhan, Koskudyk, Kozhantai, Northern Kozhantai and Otynshy) (Table 1).

Within Assakeudan Depression and in the south part of Shakhpakhty Tectonic Step (structures Samtyr, Tabyn, Kyzgurly, Birinzhik and Northern Birinzhik) there are observed closely adjacent values of this transform (0-1.560 radians).

In the Central Ustyurt system of dislocations there were fixed maximal negative values (-1.200 -1.560 radians) of TDR transform slope angles (Akmechet structure).

Tracing of axes of magnetic field anomalies reduced-to-the-pole. This transform [8] is used with purpose to localize axes of Ta anomalies (Fig. 3). On typical elements of the magnetic field there were distinguished some tectonic dislocations availability of which was detected on a sharp variability of the magnetic field intensity along a line; on typical displacements of anomalous values relatively this line.

The axes of key anomalies help to distinguish the margin zone of Assakeudan Depression, where the contact of which with Shakhpakhty Tectonic Step is revealed by a narrow boundary.

In general, minimal variations of this transforms distinguish Assakeudan Depression (-0.5 +1 cu). Intermediate those - Shakhpakhty Tectonic Step (0.5 to -3 cu). Maximal values in auto-tracking of anomaly axes of the magnetic field reduced-to-the-pole are observed in the Central Ustyurt system of dislocations (-5 +5 cu), which seemingly may be explained by involvement of these tectonic structures into Later Paleozoic tectonic genesis.

Euler points. Distribution of magnetically active bodies in the depth is well illustrated by such transform of the magnetic field as Euler Deconvolution solution points, positions of which is calculated in the Oasis Montaj software. We use the structural index 1 with window size of 20 km.

Magnetic lineaments were primarily traced from contours of anomaly-generating objects or causative magnetic masses. We used the higher density clouds of Euler points as the basis to rank the order these lineaments according to their depth. [6].

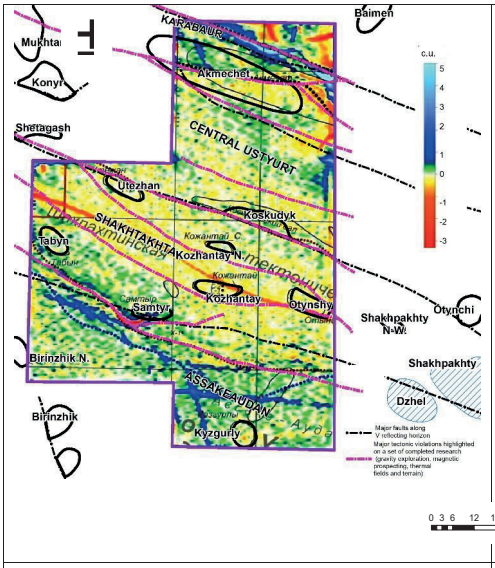

Fig. 3 - Tracing of axes of magnetic field anomaly, reduced-to-the-pole

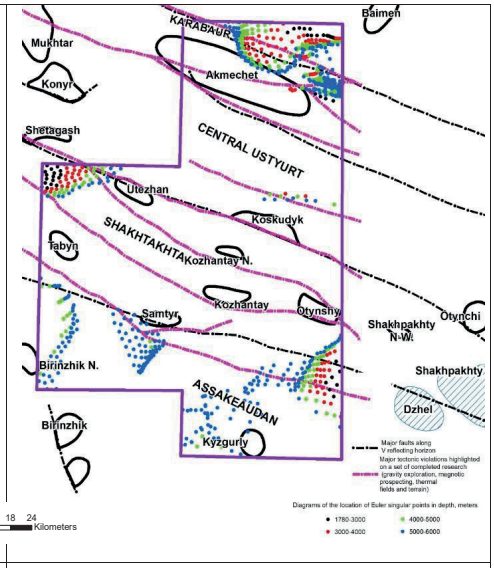

Fig. 4 - Scheme of position of Euler's points at depths to 6 km.

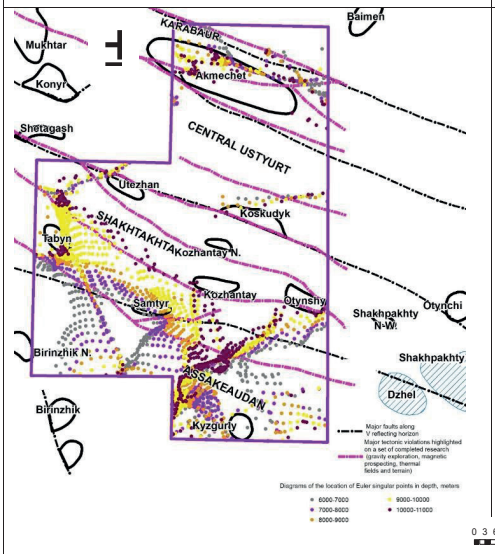

Fig. 5 - Scheme of position of Euler's points at depths from 6 to 11 km.

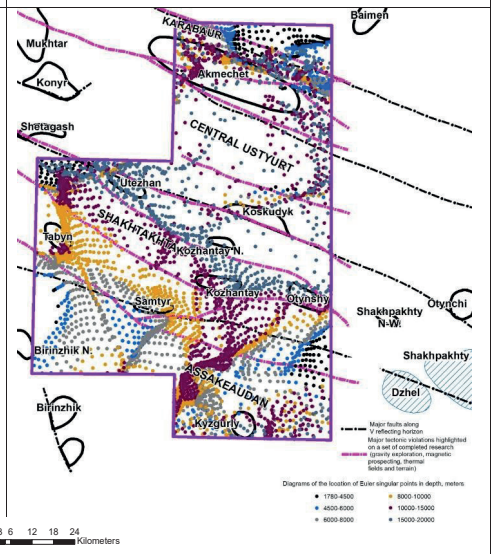

Fig. 6 - Scheme of position of Euler's points at depths to 20 km.

Layout sketches of Euler points (Fig. 4-6) and distribution diagram for those points in geomagnetic fields (Fig.7) strongly indicate the magnetic heterogeneity of rocks in the area surveyed and different depths of their occurrences which is outlined by the earlier considered transforms of the geomagnetic field.

Extension of causative magnetic masses within the region surveyed is sharply differentiated across the area. For instance, at the depth interval of 6-11 km in the northern part of Shakhpakhty Tectonic Step, the Euler points are grouped into bands of north-eastern extension (Fig. 5).

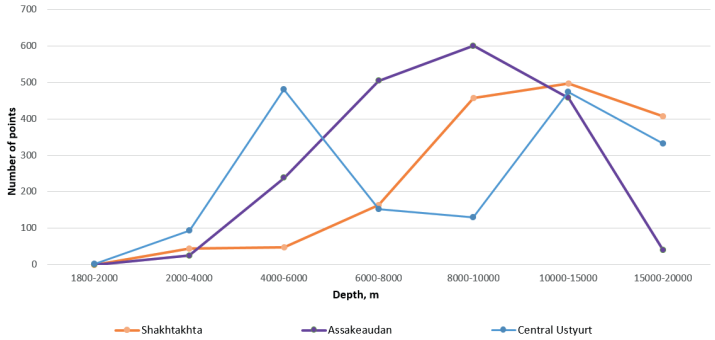

Fig. 7 - Graph of the distribution of Euler points by regions in geomagnetic models

In the southern part of Shakhpakhty Tectonic Step and in Assakeudan Depression those points generate a cloud of a variable from EW to NS trend. And, finally, in the Central Ustyurt system of dislocations the Euler points are grouped as a NW band at the depth interval of 6-11 km (Fig.7).

Taking into consideration the way the Euler points are distributed at depths in geomagnetic models, it turns to be possible to come up to the preliminary conclusion that the top edge of the causative magnetic masses within the Central Ustyurt system of dislocations occurs in the intervals of 4-6 km and 10-15km depths, in the Assakeudan Depression area – 8-10 km, and in the area of Shakhpakhty Tectonic Step – 10-15км.

Implicitly, the fact revealed indicates a large total thickness of sedimentary cover rocks and intermediate structural stage in Shakhpakhty Tectonic Step, which, in its turn, point out this tectonic element as a favorable one in respect of oil-and-gas potential perspective of the object.

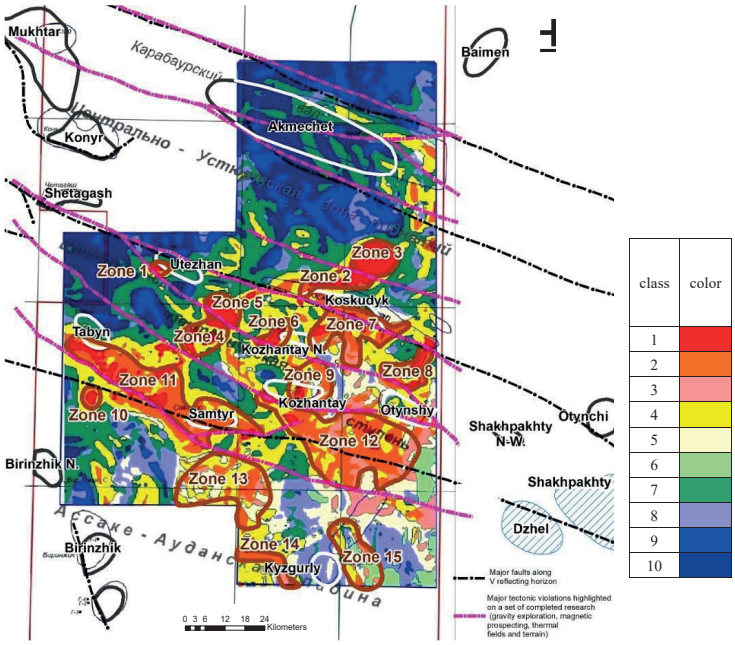

Fig.8 - Zoning of the site according to the RAE (radioactive) parameters (according to the algorithm of A.V. Petrov) [7].

Discussion. The results obtained from the interpretation of the magnetic data is confirmed by airborne gamma-ray spectrometer (radiometric) data processed and interpreted by the thorium normalized method [7].

According to the parameters of the contents of potassium, uranium and thorium, the survey area were zoned in the COSCAD software. 10 regions (classes) were identified according to the complex of RAE (radioactive elements) contents. The most promising in terms of prospecting for oil and gas are classes 1, 2 and 3, partially 4 (Fig.8).

Based on the fact that content of potassium and uranium above oil and gas reservoirs has typically low values versus background values (and potassium concentrations lower to a greater extent than uranium those), in the region surveyed there were distinguished 15 zones with relatively lower background of general radio activity, lower iso-concentrations of potassium, and lower content of uranium. The greatest part of these 15 zones is located in the area of Shakhpakhty Tectonic Step.

Based on the data of interpretation of the anomalous magnetic field and potassium and uranium content parameters, the structures including Tabyn Kozhantai, Northern Kozhantai, Utezhan, and Kyzgyrly may be considered as potentially promising for HC exploration. The structures are recommended to be further explored for detail with CDP seismic survey method and deep drilling.

Conclusion. The aforementioned allows formulating the following below conclusions:

a. Based on the distribution character of the transforms in the magnetic field within the surveyed region, there are differentiated Shakhpakhty Tectonic Step, Assakeudan Depression, and Central Ustyurt system of dislocations.

b. Shakhpakhty Tectonic Step is outlined by lower values of the transforms including analytical signal, magnetic anisotropy, auto-tracking of anomaly axes of the magnetic field, higher values of intensity of ΔTa negative anomalies. Here there are observed intermediate values of transforms of horizontal and vertical derivatives of the magnetic field, and minimal values TDR of transforms for this field;

c. Assakeudan Depression is distinguished by higher and maximal values in transforms of magnetic anisotropy and derivative vector inclination angle of the magnetic field. There were stated minimal values of transforms of the analytical signal, vertical derivative, auto-tracing of ΔTa anomaly axes of the magnetic field; lower values of TDR transforms; large anomalies of the geomagnetic field with positive sign and NW trend.

d. Central Ustyurt system of dislocations is commonly characterized by higher values of transforms of the analytical signal, magnetic anisotropy, horizontal derivative of the magnetic field, as well as by maximal values of transforms of the vertical derivative and TDR vector inclination angle of the magnetic field; auto-tracking of anomaly axes of ΔTa, and maximal values of intensity of positive anomalies.

e. There was taken an attempt to tie-up the depth and character of distribution of magnetically active layers with areas potentially prospective for HC accumulations to be detected. The integrated analysis of the magnetic field transforms and airborne gamma-spectrometry data indicate favorable oil-and-gas bearing perspectives for the area of Shakhpakhty Tectonic Step. The factor that implicitly confirms this expectation is a significant plunging depth of the magneto-active layer.

Thus, the transforms of the initial geomagnetic field presumably increase reliability in detecting of anomalous objects, and may be considered as an extra exploration criterion in prospecting and exploration of HC fields.

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ҮСТІРТ ӨҢІРІНІҢ ОҢТҮСТІК БӨЛІГІНДЕГІ КӨМІРСУТЕГІ КЕН ОРЫНДАРЫН ІЗДЕУ КЕЗІНДЕГІ ГЕОМАГНИТТІК ӨРІСТІҢ ТРАНСФОРМАНТТАРЫ ЖӘНЕ ОЛАРДЫҢ ИНТЕРПРЕТАЦИЯСЫ

Аннотация. Мақалада магниттік қасиеттері бойынша біртекті емес тау жыныстарының аймақтары мен аудандарын анықтау мақсатында Үстірт өңірінің оңтүстік бөлігіндегі аэромагниттік зерттеу жұмыстарының нәтижесі қарастырылған. Магниттік белсенді қабаттың таралу тереңдігі мен табиғатын көмірсутектердің жинақталуын анықтауға перспективалы аудандармен байланыстыруға әрекет жасалды.

Осы мақсатта аномалды магнит өрісінің полюске дейін азайтылған трансформаталары есептелді, айта өтсек, аналитикалық сигнал, осы өрістің көлденең градиент векторының көлбеу бұрышы, тік және көлденең градиенттер, жоғары жиілікті және төмен жиілікті компоненттер, ΔТа аномалия осьтерінің автотрассациясы және Эйлердің ерекше нүктелерінің орналасуы.

Δ Та аномалиясының белгісі мен бағытының күрт өзгеруі, магнит өрісінің жоғары градиенттерінің сызықтық аймақтарының болуы, жоспардағы ауытқулардың жылжуы және рельефтегі тік сызықты кертпелер жарылым желісінің бар екендігін көрсетеді.

Геомагниттік өрістің трансформаттарының табиғаты бойынша, яғни пайда болу тереңдігі және магниттелген тау жыныстарының даму ауқымы бойынша үш тектоникалық элемент – Орталық Үстірт дислокациялық жүйесі, Шахпахты сатысы және Ассакеаудан ойпаты оқшауланды.

Геологиялық ұқсастықтар әдісі бойынша және қолда бар геологиялық-геофизикалық деректерді назарға ала отырып, геологиялық барлау жұмыстарын мұнай-газ барлауға бірінші кезекте Шахпахты сатысы егжей-тегжейлі зерттеуге ұсынылады.

Түйінді сөздер: магнит өрісінің трансформанттары, аэромагниттік барлау, тік және көлденең градиенттер, Эйлер нүктелері.

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ТРАНСФОРМАНТЫ ГЕОМАГНИТНОГО ПОЛЯ И ИХ ИНТЕРПРЕТАЦИЯ ПРИ ПОИСКЕ МЕСТОРОЖДЕНИЙ УГЛЕВОДОРОДОВ В ЮЖНОЙ ЧАСТИ УСТЮРТСКОГО РЕГИОНА

Аннотация. В статье рассмотрены результаты интерпретации данных аэромагниторазведки в южной части Устюртского региона с целью выявления зон и площадей неоднородных по магнитным свойствам горных пород. Осуществлена попытка увязать глубину и характер распространения магнитоактивного слоя с площадями, перспективными на обнаружение скоплений углеводородов (УВ).

В этих целях были рассчитаны такие трансформанты аномального магнитного поля, приведенного к полюсу, как аналитический сигнал, угол наклона горизонтального вектора градиента этого поля, вертикальный и горизонтальный градиенты, высокочастотные и низкочастотные составляющие, автотрассирование осей аномалий ΔTa, положение особых точек Эйлера.

Резкие изменения знака и направленности аномалий Δ Ta, присутствие линейных зон повышенных градиентов магнитного поля, смещения аномалий в плане и прямолинейные уступы в рельефе индицируют присутствие сети разрывных нарушений.

По характеру трансформант геомагнитного поля, а, следовательно, по глубине залегания и масштабам развития намагниченных пород, обособляются три тектонических элемента – Центрально-Устюртская система дислокаций, Шахпахтинская ступень и Ассакеауданский прогиб.

По методу геологических аналогий и беря во внимание имеющиеся геолого-геофизические данные, в первую очередь рекомендуется Шахпахтинская ступень для постановки геологоразведочных работ с целью более детального изучения геологического строения и перспектив нефтегазоносности.

Ключевые слова: трансформанты магнитного поля, аэромагниторазведка, вертикальный и горизонтальный градиенты, точки Эйлера.

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