CIS-CASPIAN DEPRESSION AND ITS REFLECTION IN GEOPHYSICAL ANOMALIES

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Abstract

The article presents new methodological methods for interpreting geological and geophysical data with the aim of justifying the search for oil and gas in the inner regions of Cis-Caspian depression and confirming the hypothesis of uplifted foundation blocks and large drillable subsalt elevations. For the territory of Cis-Caspian depression, new schemes of composite magnetic field strength and gravity field anomalies maps were obtained at different transformation parameters, taking into account qualitative zoning of the territory according to sign ratios. The transformed parameters are obtained by analytic continuation into the upper half-space to a height of 5-50 km by calculating the residual values and difference in the geophysical values between the altitude levels, i.e. by obtaining interval transformants that narrowed the range of the possible interval of the geological section, in which the appearance of anomalous-forming masses in the subsalt paleozoic can be expected. The observed fields were represented in the form of numerical matrices covering the entire territory of Cis-Caspian depression with 120*100 dimensions of elements for maps of 1: 1 000 000 scales. A total of 40 schemes of geophysical parameters were generated.

In the central part, the transformations allowed identifying large, intense anomalies associated with the morphology of the subsalt bed surface. Gravity steps, which limit large anomalies, testify to the steep slopes of structural elements. This is the possible zones of transition from shallow-water conditions to deep-water ones.

The oil and gas prospects of the geological situation are determined by a combination of negative magnetic and positive gravitational fields observed in the increasingly thick areas of carbonate rocks caused by organogenic structures of basinal, flank and shelf type on the slopes of major elevations.

As a result of processing and interpretation, in Hobdin high area the author predicts the existence of an elevated relative to the depression part zone within which a possible socle for further growth of large carbonate structures such as Karachaganak
is located. The zone with the same signs is also registered in the western part of the Central Caspian depression in the region of Aralsor gravity high.

**Keywords:** Oil and gas prospects, geology, geophysics, Cis-Caspian depression, gravity prospecting, magnetic prospecting, interpretation, anomalies, transformations.

I. Introduction

Insufficient efficiency of oil and gas geological exploration in complex geological conditions at great depths posed new theoretical and practical problems, without solution of which it is impossible to develop the predictable potential resources of Cis-Caspian depression as a new oil and gas bearing region of Russia. Such problems include the development of highly effective methods of prospecting and exploration with the aim of increasing industrial hydrocarbon reserves. It seems to be difficult to use the existing experience in other regions for the solution of these problems, and most of them are impossible to solve due to the unique geological structure of Cis-Caspian depression as a whole and its individual deposits.

The selection of exploration strategy is determined by various concepts of the structure and development of Cis-Caspian depression. Thick sedimentary cover (> 20 km) and thick salt layers, subsalt deposits structure complexity, sharp changes in the lithological composition of the rocks, numerous interruptions in sedimentation and faultings do not allow unambiguously interpreting the structure and history of the territory geological development. The analysis of the actual material led to the emergence of various models that reflect different points of view on the geological structure and genesis of the depression, generating two approaches to the justification for the location of geological exploration [VI, IV, III, II, XXVIII, and XXII].

First of all, we need to analyze the ways to improve the productivity of methodological approaches to the interpretation of geological and geophysical data. It is also necessary to continue the optimization of the methods for multi-geological and geophysical information summarization to confirm or refute the proposed Cis-Caspian depression structure concept with a view to the choice of oil and gas exploration lines in accordance with the most appropriate geological conditions in order to identify the most promising sites and areas.

Purpose

The hypothesis of uncompensated sedimentation suggests a low oil and gas potential potential of the central regions. Other hypotheses suggest the presence of elevated foundation blocks and large subsalt elevations drillable not only in the peripheral but also in the central parts of the depression. The exploration of the inner regions of the Caspian depression seems to be perspective, however, it is the central part that is characterized by the insufficient volume of geological and geophysical material, due to the poor drilling exploration and the ambiguous interpretation of geophysical data. Thus, it is necessary to develop new methods of geological and geophysical data interpretation, integrate them with the purpose of confirming or refuting a particular concept on the structure of Cis-Caspian depression, especially of its inner regions,
and, ultimately, selecting well-founded focus area for oil and gas prospecting with the identification of the most promising objects and areas.

Highly productive cheap exploratory geophysical gravitational and magnetic prospecting methods were considerably developed practically on the whole territory of the depression, giving continuous objective information on the area in the form of integral maps of magnetic field strength and gravity field anomalies.

II. Methodology

It is known [XVI] that observations of gravitational and magnetic fields, as a rule, are represented by complex interference patterns and their visual examination does not allow establishing geological environment structure features. It is believed that the nature of anomalies attenuation, depending on the height (level) of the recalculation, makes it possible to draw a number of important conclusions about the tectonic structure of an investigated territory, to define the location of large geostructural elements such as humps, depressions, bars, deflections, etc. The maps of regional anomalies help to identify zones of large dislocations, main structures extent and draw conclusions about their estimated sizes [XIV, X].

Under these conditions, it is important to transform an observed field so that the information contained in the resultant field about its components associated with individual geological formations will be revealed in a visual form. Appropriate transformations methods are selected depending on the variant of the discrimination of a regional or local component from an observed field, [VIII, XXVI, XIII, XV]. In order to obtain the converted parameters, the following conversion methods were used:

a) analytic continuation to the upper half-space at the altitudes of 5, 10, 15, 20, 30, 40 and 50 kilometers, followed by the construction of regional anomalies circuits $\Delta g \ h = 5$, i.e. at the height of 5km, $\Delta g \ h = 10$, $\Delta g \ h = 15$, etc.;

b) calculation of an anomalous values difference on an observation outliers surface and at the altitudes of 5, 10, 15, 20 km, and the construction of local anomalies circuits $\Delta g \ lok = \Delta g \ n - \Delta g \ h = 5$, etc.;

c) Calculation of the difference $\Delta g$ anomalous values at the altitudes of 5-10, h = 5-15, and 10-20 km and interval values schemes construction $\Delta g \ int = \Delta g \ h = 5-\Delta g \ h = 10$; $\Delta g \ h = 10 - \Delta g \ h = 15$, etc.

In the procedures performed the selection of recalculation altitudes (parameters) is determined by the a priori geological model of the Caspian Sea, to be more exact by the occurrence depth of the main gravity surfaces: salt top and base, foundation, Mohorovicic boundary. The calculation of the difference between the different altitudes made it possible to narrow the range of the possible geological section interval, in which the manifestation of anomalous-forming masses in the subsalt paleozoic can be expected. For processing, the observed fields were represented in the form of numeric matrices of 12,000 elements for maps of 1:1 000 000 scale.

Geophysical data interpretation required for the usage of traditional complex geological interpretation [XIX, XXI, XXIII, XXIV, XXV, XX]. Despite the correspondence of $\Delta g$ and $\Delta T$ combinations to diverse geological structures and

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geological situations, there are studies that make more specific conclusions about the relationship of anomalies to the tectonic plan [V, XVIII, IX, XXIX]: in particular, $+\Delta g + \Delta T$ ratio is considered as the foundation elevated sections indicator, $-\Delta g$ and $-\Delta T$ reflect the maximum submerged zones of crystalline basement and sedimentary cover horizons, $-\Delta g + \Delta T$ corresponds to superimposed basins localized above the raised blocks of magnetoactive foundation. In most cases, positive structures correspond to lower $\Delta T$ values and $\Delta g$ alternating-sign field [XV]. The hump blocks, caused by faultings and representing the final result of all tectonic transformations, are reflected by $\Delta T$ lows, limited along the periphery by linear highs.

$-\Delta T$ and $+ \Delta g$ combination can be considered as the most interesting combination, reflecting a geological situation as potentially oil and gas promising. It is associated with carbonate rocks increased thickness areas, caused by organogenic structures of basinal, flank and shelf type. In a magnetic field, these sections correspond to highs slope zones, which correspond to local values increases in $\Delta g$ field.

III. Results and Discussion

The maps of the potential fields generated as a result of method-by-method transformation were analyzed for the identification of zones similar to those described above, taking into account the qualitative zoning of the territory according to sign ratios.

The isolines of the observed Cis-Caspian depression gravitational field and represented on the scale 1: 1,000,000 are characterized by the complex configuration of closed anomalies of various shapes, intensities and extent. The effect of salt-bearing section doesn’t explain the observed large, intense (up to 30-40 mHl) anomalies, even with a change in the density of the interdome deposits beyond the limits of the reasonable ones. The large, intense gravitational anomalies [XIV, IX, XXIX] observed in the central part of the depression are related to the salt-dome tectonics and morphology of the subsalt bed surface. Then, it can be assumed that there is a connection of these anomalies with large structures of the subsalt bed in the inner part of Cis-Caspian depression. Consequently, it is possible to predict favorable conditions for oil and gas promising reefogenic structures formation.

The magnetic field of Cis-Caspian depression is characterized by a calm character in the regional aspect. In the north-west and in the central part the anomalies are extensive and non-intensive. In the southern and eastern part of the territory, the magnetic fields acquire a mosaic form. It can be explained by the fact that the salt bed lies here at a relatively lower depth, and therefore the nonmagnetic salt domes and highly magnetized argillo-arenaceous deposits troughs which separate them are pronounced better than in the submerged areas – the western and central parts of the depression. The marginal ledge line is not reflected in the magnetic field.

The analysis of the transformed fields maps generated for different levels allows concluding that at the altitude of 15 km the gravitational field is largely free from the influence of salt-dome tectonics. The north-western and southern sides of the depression are clearly visible. In the region of Aralsor gravity high, the gravitational field is of a linear structure and extends from the south-west to the north-east with

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changing from +15 to -15 c. u. Hobdin triangular gravity high is limited by a gradient zone with a difference of values up to 50 c. u. Large relative highs and lows are observed throughout the Caspian depression basin with 30-50 c. u. amplitude and dimensions of 50-100 km, delineated by zones of high horizontal gradients of 2-4 c. u./km. The nature of these anomalies, obtained by altitudes recalculations, can be considered from different points of view [X].

The consideration of the transformed magnetic field scheme from the point of view of anomalies with tectonics elements allows for the statement that there is no strict regular connection between foundation structures and ΔT field anomalies. Most of the elements – the Astrakhan and Guryev dome folds, South Emben and Dzhanybek elevations, Pallasovsk and Upryamovsk bars are located in the zones of the transition from +2 to -2 c. u. [XIX]. Unlike the gravitational field, -ΔT closed negative anomalies configurationally coincide with the contours of Azgirian, Mintobinsky, Oktyabrsky elevations, whereas closed positive ones – with the Kzyljar, Tengiz, Ilek basement highs. Such complex reflection of the region tectonic features once again testifies to the ambiguous interpretation of potential fields when analyzing the results of each method separately.

The comparison of interval transformations maps with averaged and smooth Δg isolines drawing [XXVII] represents a complex pattern of a set of alternating-sign and different in shape and dimensions anomalies. However, the characteristic features of the field remain: flank zone contour, regional highs and lows zones. The zone along the Ural River is characterized by higher intensity. It consists of uniformly alternating highs and lows, which can be explained by the manifestation of salt-dome tectonics on the one side and extended zone of regional faults on the other. The outlines of large and intense anomalies are complicated by small closed and semi-closed field elements, and anomalies of small amplitudes are localized within the regions of constant field values. The contours of tectonic elements can be distinguished in the contours of interval anomalies. The above-mentioned northwestern region of Hobdin high is complicated by positive local anomalies against the background of a “monoclinic” slope along the magnetic field. Thus, from Δg 5-10 and Δg 15 gravity anomalies and ΔT 10 magnetic field maps it can be seen that Cis-Caspian depression in general and in its central part is differentiated. If to proceed from the generally accepted point of view on the structure and development of the depression, the central part of its structure should be much “calmer” (simpler) than its marginal regions, but its area is equally differentiated in regional transformants.

The transformed gravity and magnetic fields anomalies practically do not coincide with each other that can indicate different sources of Δg and ΔT anomalies. At the same time, there are areas where anomalies sources monogeneity is expected – Temir dome fold, South Emben elevation, the northern extremity of Hobdin high. In addition, areas that are known for their oil and gas prospects are distinguished (Astrakhan dome fold, Karaton-Tengiz elevation zone [I]). They are characterized by the orthogonality of potential fields. In such areas, in addition to indicating various sources of anomalies, the sign of Δg and ΔT fields inverse correlation can
characterize a certain relationship between sedimentary cover and deep structures of Cis-Caspian depression.

A joint analysis of the potential transformed fields shows that in the eastern part of the depression the shape and extent of large positive gulf-like $\Delta T$ anomaly isanomalies coincide in the same parameters with negative extensive $\Delta g$ anomaly that testifies to a single source of potential fields in Mugodzhar region. The region of Hobdin gravity high adjoining to this region from the west is limited by a high-amplitude gravitational step coinciding with the linear sublatitudinal gradient zone of the magnetic field in the north. The latter changes its direction to the south by analogy with gravity field. The southwestern region of this high is of particular interest – the isolines of its magnetic field intersect the isanomalies of the gravitational field. Potential fields regional topography mutual orthogonality is also observed in the area of Astrakhan dome fold, Karaton-Tengiz elevations and in the northwestern corner of flank zone. $-\Delta T + \Delta g$ combinations are confined to the known areas of Astrakhan dome fold, in part South Emben elevation, Biikzhal and Guryev Arch dome folds. The central depression zone includes two similar areas located within Aralsorsky and Hobdin gravity highs. The coastal North Caspian elevated zone, eastern extension of Astrakhan-Aktyubinsk elevations and an area of the Caspian Sea inner flank zone also fall into $-\Delta T + \Delta g$ combination zones. Of special interest is certain combinations zones configuration. Hobdin high zone, resembling a triangle, is connected to a configurationally similar zone. Based on this ratio, it can be assumed that the triangles articulation area is in the center of the destructive zone, which was a potential fields various combinations segmented regions root element.

The area of interest between Aralsorsky and Hobdin highs, where $\Delta g$ negative zone, adjacent to the southwestern side of Hobdin triangle, is complicated by isometric intense positive $\Delta T$ anomaly, which manifested itself in local gravity field forms and corresponds to an intense gradient zone in the magnetic field. It is in this region, according to seismic data, Kushumsky dome fold [XII] is distinguished at depths of 9-10 km. The literature analysis allows concluding that the historical aspect was formed by the views on $\Delta g$ and $\Delta T$ anomalies nature. In 1940, Yu. A. Kosygin made an assumption about the existence of Hobdin cape, a wide barrier stretching up to the Ural folded zone which stipulated for the differences in sedimentation conditions to the north and south therefrom in Permian times. The basis for this assumption was the difference in the mineralogical associations of the Lower Permian potassium salts and the Upper Permian red beds that accumulate to the north (in Sol-Iletsk region) and to the south (in Temir region) of this hypothetical barrier. Yu. A. Kosygin regarded reef-like massifs in Kungurian strata, Kungur capacity decrease and apparent absence of salt beds therein as the signs of the transverse elevation of the folded zone lying on the eastern extension of Hobdin cape. V. V. Znamensky [XXIX] also believed that Paleozoic and crystalline basement dense rocks elevation correspond to Hobdin and Aralsor regional gravity highs. This elevation, in his opinion, probably was accompanied by dislocations of fault nature, as evidenced by the presence of gravitational stages. V. V. Znamensky wrote that a single central elevation is apparently complicated by a transverse cavity reflected in negative
However, he admitted that, this elevation obviously does not manifest itself in Mesozoic-Cenozoic and Upper Permian sediments. Another scientist, E. E. Fotiadi [XI], believed that Hobdin and Aralsor regional gravity highs reflect deeply embedded basement high similar to Tatar dome fold. His calculations of magnetic anomalies showed that in the central part of Hobdin high, the crystalline basement lies at a depth of 7.5 km, directly to the north of the Hobdin high the depth of its occurrence increases to 9 km. Taking this into account, E. E. Fotiadi assumed that Cis-Caspian depression crystalline basement surface thickness fluctuations are significant with the deepest basement depressions corresponding to the thickest deposits of the salt-bearing complex and the most intense gravity lows. N. V. Nevelin [XVII] came to the conclusion that Hobdin gravitational high can be fully explained if to assume the existence of Pre-Cambrian hump with a reduced thickness of Paleozoic deposits. He pointed out that “... the Paleozoic (pre-Kungur) units within the intended Hobdin Precambrian hump in the present structural plan, apparently, are a plateau with a slope to the west or deeply buried (5.5-7 km) thyroid elevation of relatively small amplitude”. Throughout the research N. Ya. Kunin took refracting boundary as Mokho surface at the elastic vibrations spreading rate equal to 8.0 km/s, and thus he constructed the relief scheme of Mokho surface located in Caspian depression [XV]. From the scheme it is evident that there are several humps, of which Hobdin, Aralsorsky and Lower Volga are the most expressive ones. Crust bottom occurrence minimum depths amount to 30-34 km. Only Hobdin high region is characterized by the relatively regular correlation between Mokho surface elevations and gravitational anomalies. Aralsorsky and Astrakhanskiy gravitational highs correlate with the upper mantle humps only approximately. The author suggests that the humps of the upper mantle in Caspian depression once belonged to a single linear rift-related structure and their position is a consequence of modern large blocks horizontal displacements. In 1960 V. S. Zhuravlev [XXIX] discovered Hobdin and Aralsorsky meganticlines, in 70s E. K. Aznabaev et al. [VI] detected Novonadezhdinsky dome fold, in 1970 Yu. P. Kontsevich was first to discover a number of salt beds and foundation elevations in the central part, including in Aralsorsky and Hobdin highs areas.

Hobdin and Aralsorsky regional highs are associated with either Paleozoic deposits elevations or they were regarded as the zones approaching the depression areas of Cis-Caspian depression, or even as the areas of its maximum deflection. Finally, some researchers interpreted them as Paleozoic and crystalline basement solid rocks elevations. In general, Hobdin regional high can be hump-block but -Δ T negative magnetic anomaly in the central part of Hobdin high may serve a foundation for one of the two conclusions. On the one hand +Δg - Δ T ratio shows a possible carbonate buildup on a socle elevation slope, and on the other, sharp changes in Δ T negative – Δ T anomaly circumferentially in Δg positive field indicates salt bed elevations. The comparison of tectonic scheme with the data obtained reveals that the eastern part of Central Cis-Caspian depression is characterized by the area which corresponds to a positive gravity anomaly on transformant map, this same area coincides with the
hump on Mokho surface and subsalt sediments bottom, and also falls to the negative gradient zone in a magnetic field. All this confirms the main conclusion about the possible reflectors elevation in the area. An area with the same characteristics (Δg high, ΔT gradient, mantle elevation) is also registered in the western part of Central Cis-Caspian depression. Perhaps, this elevation is also similar to the above. Given the nature of gravitational and magnetic anomalies, it can be assumed that Hobdin triangle area is elevated relatively to the depression part and can serve as a socle for further flank and shelf oil and gas perspective carbonate buildups increase and may be a normal platform massif.

III. Conclusion

New regional gravitational and magnetic fields maps were generated at various parameters of transformations, the structure differentiation of which is caused by the heterogeneous structure and petrophysical properties of Cis-Caspian depression geological environment. A variety of oil and gas promising geostuctural elements can be allocated as possible traps in structural differentiation areas of the central part of the depression. In particular, a zone elevated with respect to the depression part may be located in Hobdin high area. This zone contains a socle which can ensure the further carbonate growth of large buildups of “Karachaganak” type. The zone with the same features is recorded in the western parts of Central Caspian depression in the region of Aralsorsky gravity high. The results of the research can be used to select priority detailed oil and gas exploration areas and to reduce drilling facilities preparation costs.

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