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Use of Gravity and Magnetic Methods in Oil and Gas Exploration: Case Studies from Azerbaijan

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ABSTRACT

Numerous studies have proved the connection between low-amplitude local anomalies of gravity and magnetic field with oil and gas deposits in both platform and geosynclinal areas. In theoretical and experimental studies, gravity and magnetic prospecting methods for forecasting oil and gas accumulations in various geological structures have been used. They show out that oil and gas deposits located in different oil and gas regions of the world are noted discoveries with geophysical methods, including gravitational and magnetic fields. As a result, new exploration signs have identified the appearance of local gravitational and magnetic minima of various intensities above the productive parts of the structures. It has been established that the first physical and geological prerequisites for using gravimetry and magnetometry to explore hydrocarbon deposits in Azerbaijan are decreases in the density and magnetic susceptibility of rocks in the area of the deposit. Gravity-magnetic studies carried out in the Kura depression show that over the known deposits (Muradkhanly, Jafarly, Tarsdallar, Gazanbulag, Babazanan, Bandovan, etc.), gravitational and magnetic minima of 0.2-0.8 mGal and 20 -30 nT. the Physical and geological properties of the Muradkhanli field have been modeled by studying some of the physical parameters in the Middle Kura depression of Azerbaijan (the changes in the magnetic susceptibility, temperature, and density of rocks in the subvertical zone above and below the reservoir). In this study, the results of gravimetric and magnetometric studies performed for oil and gas deposits on the areas of Arabkubaly, Naftalan, Northern Naftalan, Gedakboz of Azerbaijan are presented. Consequently, the outcomes of experimental and systematic work carried out in the areas of Middle Kura Depression and Lower Kura Depression show the effectiveness of gravity-magnetic methods.

1. Introduction

To explore oil and gas deposits, various geophysical and geochemical methods are used. At the same time, special attention is paid to geophysical methods because the practical results of various geophysical surveys can prove a fairly straightforward display of hydrocarbon (HC) deposits. Since the 1950s, numerous seismic-gravity and magnetic studies have been performed in many regions of the world, purposing to identify characteristic anomalies of geophysics associated with oil and gas deposits. Those ones have shown that absorption (attenuation) of wave energy is found in seismic fields several times, and local minima appear in the gravitational field over oil and gas deposits (Medovskiy and Mustafaev, 1959; Medovskiy and Komarova, 1959; Tsimelzon, 1959). Subsequent numerous studies have also proved the connection between low-amplitude local anomalies of gravity and magnetic field with oil and gas deposits in both platform and geosynclinal areas (Berezkin et al., 1978, 1982; Agulnik et al., 1982; Karshenbaum et al., 1982; Mikhailov, 1982; Gadirov, 1991, 1994; 1997; 2009). The presence of relative temperature maxima, signs of hydrocarbon deposits, has been shown in the literature

(Gadirov, 1991; 2009; 2014; Gadirov and Eppelbaum, 2015). Seismic, gravimetric, magnetic, and thermometric measurements have been conducted on the Southern Lugovsky gasfield in the south of Sakhalin Island since 2003, and some anomalies have been identified. It was found that the planned location of the deposit is clearly observed in the gravitational and thermal anomalies. It was also revealed that these anomalous zones are noted on seismic time sections as well (Roslov et al., 2009; Parovyshny et al., 2018).

The study regarding the magnetic field and magnetic susceptibility of the soil cover within the hydrocarbon deposits in the Outer Zone of the Ciscarpathian trough has revealed negative magnetic anomalies with an amplitude (4-7 nT). A genetic relationship has been established between local magnetic anomalies and oil and gas content in Venezuela, in the Wessex basin of England, in Russia, in Azerbaijan, etc. (Saunders et al., 1991; 1999; Aldana et al., 2003; Emmerton et al., 2012; Gadirov, 2013; Kuderavets et al., 2013; Machel and Burton, 1991; Menshov et al., 2014).

The in situ gravity and magnetic methods as well as aerogeophysical studies for predicting oil and gas accumulations in various geological settings are also presented in the literature (Nettleton, 1976; Donovan et al., 1984; Geist et al., 1987; Lyatsky et al., 1992; Fooote, 1992; 1996; Gadirov, 1994; Piskarev and Tchernyshev, 1997; Matolin et al., 2008; Eppelbaum and Mishne, 2011; Perez-Perez et al., 2011; Gadirov and Eppelbaum, 2012; Kuderavets et al., 2013; Satyana, 2015; Eke and Okeke, 2016; Stephen and Iduma, 2018; Gadirov et al., 2018; Ozdemir et al., 2020a; 2020b; 2020c; 2021a; 2021b). From the studies mentioned above, it turns out that deposits located in various oil and gas regions of the world are determined with confidence by conducting geophysical surveys (including gravitational and magnetic methods). As a result, the anomalies of gravity and magnetic prospecting have been determined. These anomalies indicate the emergence of local gravitational and magnetic minima of various intensities over the productive parts of the structure.

Since 1975, gravity-magnetic studies have been carried out in Middle Kura Depression (MKD) of Azerbaijan for exploration of oil and gas deposits. This research aims to examine the useability of gravimetric and magnetometric surveys for the exploration of oil and gas deposits in the Middle Kura Depression of Azerbaijan. The deposits here are confined to the effusive rocks of the Upper Cretaceous, the Eocene marl member, and partly Chokrak sandstones. The work was performed along rectilinear profiles, placed parallel on the study area to obtain correlated connections between the corresponding areas. At the same time, for the observation step, 100 m was mainly used, and the distance between the profiles is 500-700 m. The gravitational field in the Bouguer reduction was calculated with an accuracy of 0.07-0.08 mGal, and the magnetic field (ΔZ and T) was 1-2 nT and 0.1 nT. The gravimetric studies have shown that over the known oil and gas fields, minima are observed in the gravitational and magnetic fields of 0.1-0.4 mGal and 15-30 nT. The reason for the appearance of gravity-magnetic minima over the deposits, as already mentioned, is explained by a decrease in density and magnetic susceptibility in the areas of the deposit and sub-vertical zone above the deposit, even reaching the day surface (Gadirov, 2012; Gadirov and Eppelbaum, 2012).

2. Purpose and Physical-Geological Prerequisites for Using Gravity-Magnetic Methods in Exploration of Hydrocarbon Deposits

Numerous publications on petrophysical and geophysical studies associated with individual structures or regions show that physical parameters of oil and gas deposits differ from their host rocks. A decrease in density of 0.1-0.25 g/cm3, an increase in the electrical resistance of rocks up to 1.5-5 times, an increase in the polarizability of rocks of 15%, a decrease in the velocity of longitudinal seismic waves up to 25-30%, an increase in the absorption of seismic waves up to 10 times, a decrease in magnetic susceptibility up to 2-8 times, an increase in temperature up to 10-18% can be observed within the reservoir (Berezkin et al., 1978; Gadirov, 1994; 2009; Gadirov and Eppelbaum, 2012).

The physical and geological prerequisites for using gravimetric and magnetometric methods to explore hydrocarbon deposits in Azerbaijan are, first of all, connected to a decrease in the density and magnetic susceptibility of rocks in the field of the deposit. An analysis of the density characteristics of rocks in the Middle Kura depression shows a decrease in the density of rocks within the reservoir up to 0.15-0.17 g/cm3. In this case, the calculated gravitational anomaly could be 0.2-0.3 mGal, depending on the thickness of the deposits.

The magnetic susceptibility of rocks decreases even several times within and below the reservoir and overlying deposits above the reservoir. Gravity-magnetic studies carried out in the Kura Depression show that over the known deposits (Muradkhanli, Jafarly, Tarsdallar, Gazanbulag, Babazanan, Bandovan, etc.), gravitational and magnetic minima of 0,2-0,8 mGal and 20-30 nT (Gadirov, 1991; 2009; Gadirov and Eppelbaum, 2012; Gadirov et al., 2018). Therefore, the combination of these methods increases the efficiency of forecasting oil and gas deposits. It is assumed that oil and gas lead to a change in the physical properties of the overlying and surrounding rocks. The migration of light hydrocarbon fractions into the overlying layers affects the physical properties of rocks above the reservoir. Many researchers have paid attention to such a change. It has been established that pyritization, color, and magnetization changes occur in the rocks above the oil deposits (Donovan et al., 1984 and many more studies).

Generally, sedimentary rocks and sediments are characterized by low magnetic susceptibility. The sedimentary cover over the deposit accumulates magnetic minerals such as magnetite, maghemite, hematite, greigite, which are the physical and geological prerequisites for using magnetic prospecting methods in exploration for oil and gas deposits. Therefore, under the influence of hydrocarbons in the sub-vertical zone above the deposit, secondary mineralization occurs along with the transfer of heavy metals by microbubbles from the area of the deposit, which leads to a change in the magnetic field above the deposit (Foote, 1996; Putikov et al., 2000; Ustinova, 2002).

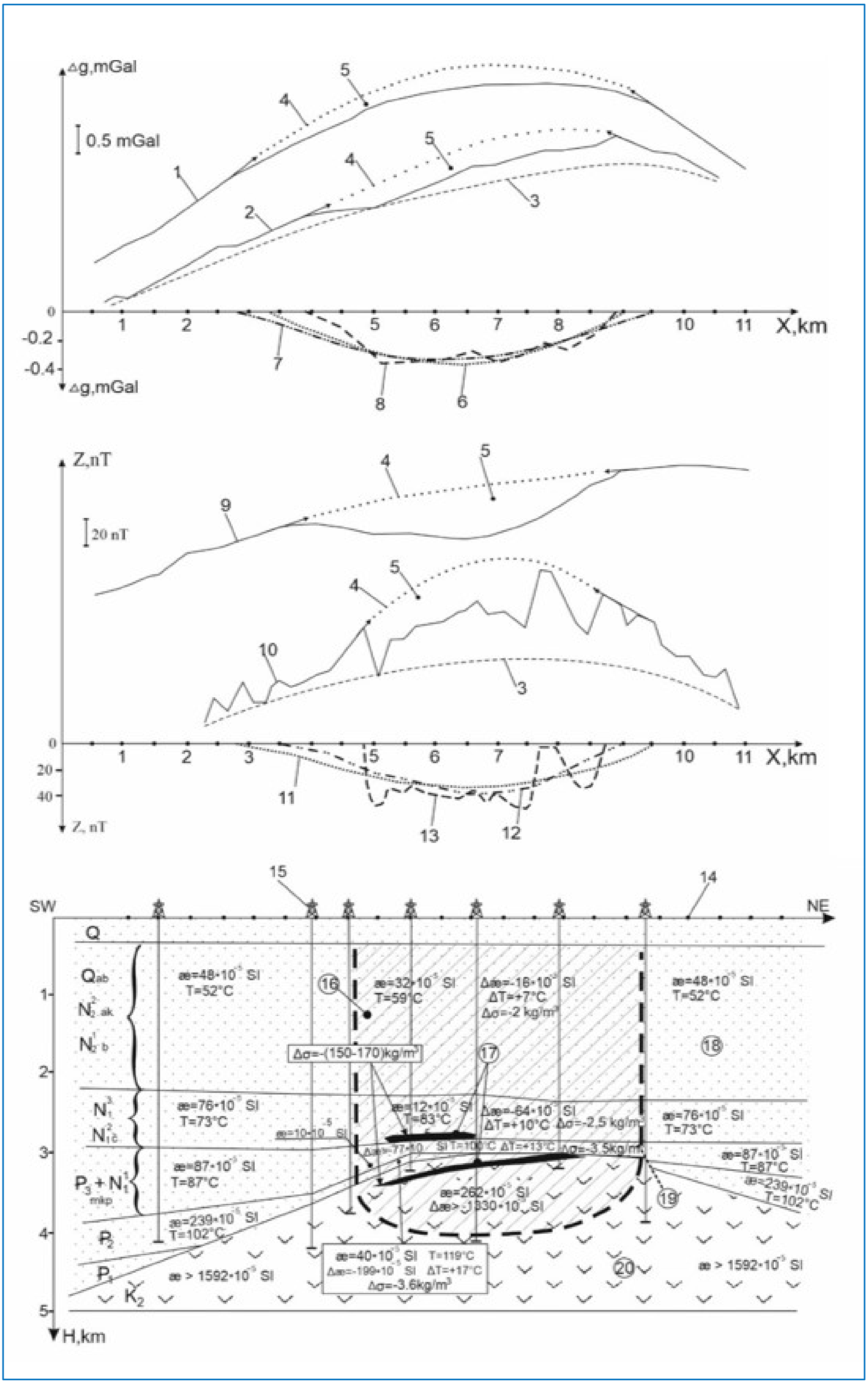

Fig. 1. Physical and geological model of the Muradkhanly. 1 and 9- calculated gravitational and magnetic fields of the model; 2 and 10- observed gravitational and magnetic fields; 3- regional background; 4- restored maximum; 5- local minima associated with oil and gas content; 6- calculated gravitational anomalies of deposit zone and oil reservoir; 7 and 8-local gravity anomalies, selected from curves 1 and 2; 11- calculated magnetic anomalies of deposit zone; 12 and 13- local magnetic anomalies, selected from curves 9 and 10; 14- points at which theoretical effects are calculated; 15- exploration wells; 16- sub-vertical deposit zone; 17- oil reservoir; 18- sedimentary deposits; 19- fault; 20- effusive formation

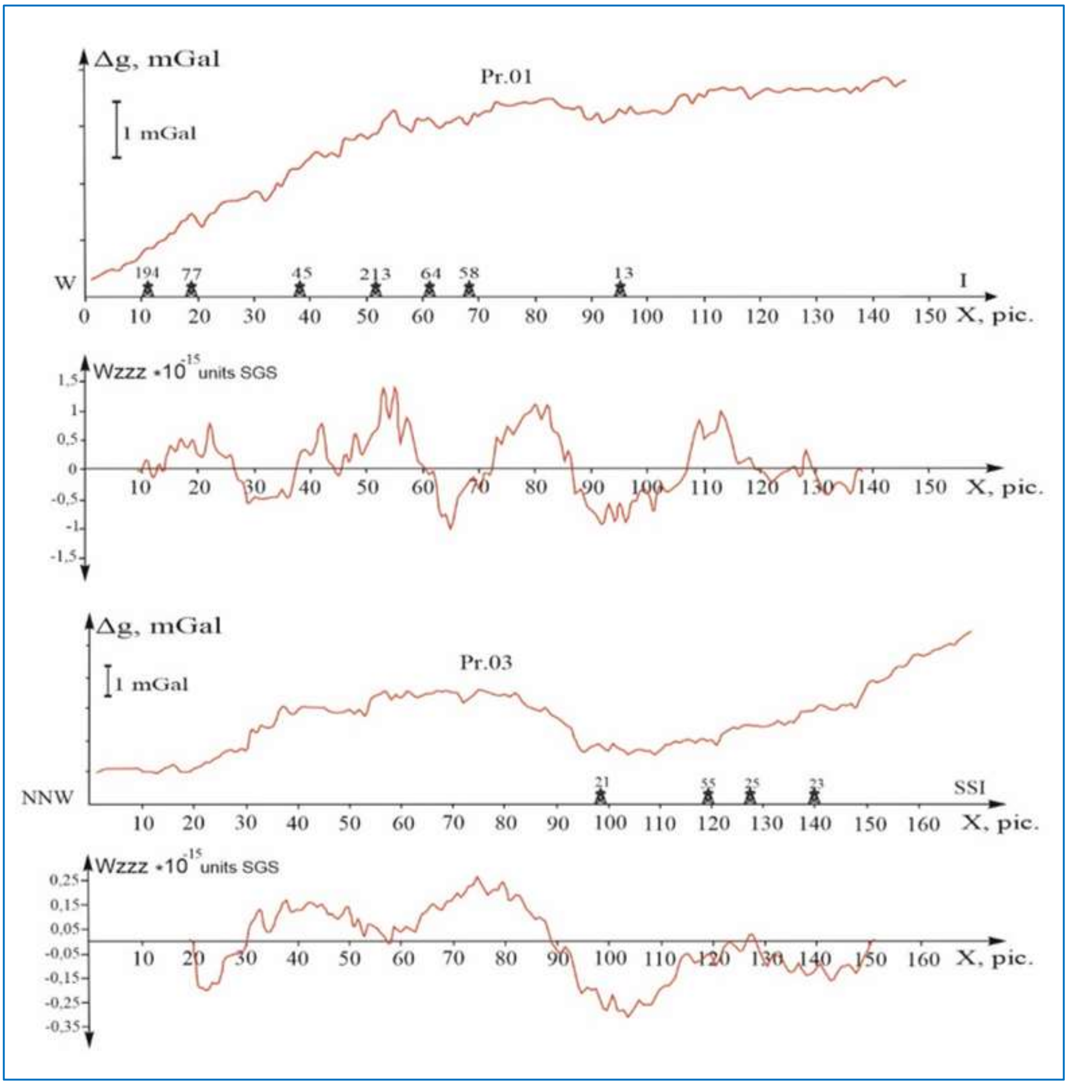

Fig. 2. Separation of local anomalies using the third derivatives of the gravity potential Wzzz (Muradkhanli areas, pr. 01 and 03)

The magnetic anomalies observed over oil and gas fields were also explained by the flow of natural electric currents over the fields, leading to the appearance of thermal and magnetic anomalies (Pirson, 1971; Seifulin, 1980). Megerya et al. (2003) indicated the presence of negative gravitational and positive magnetic anomalies in the form of a subvertical channel in the areas of Western Siberia, where oil-producing wells are located. This subvertical element of geophysical fields is characterized by a low density and increased magnetization

The Geosoliton concept of the occurrence of hydrocarbon deposits indicates that, regardless of the types of deposits, they accumulate by a common occurrence mechanism. The general principle for all types of deposits is the presence of specific “roots” (sub-vertical channels) extending from each of them (deposits) deep into the depths. Similar sub-vertical geological objects are mapped in most oil and gas regions of Western Siberia (Russia) and the world as a whole, in the form of small-sized geophysical anomalies with almost all geophysical methods (including seismic, gravity, magnetic, electrical), and radiometric, thermal and geochemical surveys (Bembel et al., 2006). In the magnetic and gravitational fields, the mosaic structure of such geodynamic foci of energy and matter radiation manifests itself quite unambiguously on the continents and in the oceans.

2.1. Physical Characteristics of a Sub-Vertical Zone above a Reservoir

The Geosoliton concept of deposit formation accepts the presence of a peculiar zone above the deposit and also proves that all deposits, regardless of their types, have their "roots" going deep into the earth (Bembel et al., 2006). Such peculiar subvertical zones, according to the authors, are associated with deep faults and degassing processes of the earth.

Many researchers expressed the presence of a peculiar zone above the deposit. The physical parameters of this zone are to differ from its environment. Hydrocarbon invasion areoles over the oil and gas reservoir have been established, also by drilling. Moreover, geochemical studies have shown that such zones can be traced even to the surface of the earth (Saunders et al., 1991; Machel and Burton, 1991; Gadirov, 1991; 1994; Schumacher and Abrams, 1996; Foote, 1996; Aldana et al., 2003; Liu et al., 2004; Emmerton et al., 2012; Gadirov and Eppelbaum, 2012).

However, there were no quantitative estimates of changes in the physical parameters of the subvertical zone above the reservoir. It was sometimes impossible to establish such changes from core materials, for example, by density, since it was determined with an accuracy of 0.01 g/cm3. By inspecting some physical parameters in the Middle Kura Depression of Azerbaijan, it has been possible to quantitatively estimate the change in magnetic susceptibility, temperature, and density of rocks above and below the reservoir, which was used in compiling a physical and geological model of the Muradkhanly field (Gadirov, 1991; 1994; 2012) (Fig. 1).

Data on density, porosity, magnetic susceptibility for the southeastern part of the Middle Kura depression were obtained in laboratory conditions from cores. The density defect within the sub-vertical zone above the reservoir was calculated using the formula (Gadirov, 2014; Gadirov and Eppelbaum, 2015).

As can be seen from Fig. 1, the physical parameters of the reservoir zone differ sharply from the surroundings. For example, in the sediments of the Absheron, Akchakyl and the Balakhani (Pliocene) outside the deposit, the magnetic susceptibility and temperature are 48×10-5 SI and 52 °C, respectively whereas, within the deposit, these values are 32×10-5 SI and 59 °C. It can be seen that upon entering the deposit zone, the magnetic susceptibility decreases by 16×10-5 SI, i.e. up to 1.5 times, and the temperature increases up to 7 °C, i.e. up to 13%. As the depth increases, the difference in magnetic susceptibility (up to 199×10-5 SI), temperature (up to 17 °C), as well as a density reduction (up to 3.6 kg/m3) in sedimentary rocks in the deposit zone increases. Based on core materials, a strong decrease in magnetic susceptibility has also been established in effusive formations at the top of the structure, at the same time in the vicinity of the deposit. If the magnetic susceptibility of these formations is on average 1592×10-5 SI, then at the top of the structure, where there are oil deposits, it takes the value of 262×10-5 SI.

It can be assumed that oil and gas lead to a change in the physical properties of the rocks surrounding the deposit. The migration of the light hydrocarbon fraction to the overlying layers affects the physical properties of the rocks above the reservoir. It should be noted that the secondary factors, in contrast to the primary ones (thickness, depth of the deposit, oil and gas density, porosity, and oil and gas saturation coefficient), have not been sufficiently studied.

The combination of the above factors (changes in physical parameters of the geological cross-section) ultimately leads to anomalous changes in the gravitational and magnetic fields over oil and gas deposits. On the observed geopotential fields, characteristic local anomalies appear due to the presence of oil and gas deposits in the geological cross-section.

The calculated gravitational and magnetic fields of the constructed model (curves 1 and 9) have been compared with the observed gravity and magnetic fields (curves 2 and 10). As can be seen, a comparison of local minima (5, as well as curves 7 and 12 and curves 8 and 13) extracted from the theoretical curves (curves 1 and 9) and the observed field (curves 2 and 10) by the reconstructed maximum (curve 4) shows that these anomalies match well enough. In this case, the contour of the minima corresponds to the contour of the subvertical deposit zone (curve 16). The calculated gravity and magnetic anomalies of the deposit zone (curves 6 and 11) are turned out to be more prominent in linear size.

Calculations show that the calculated gravitational effect of the deposit zone (together with the oil reservoir) is 0.35 mGal. The calculated magnetic impact of the subvertical deposit zone reaches up to 40 nT. Such anomalies can be detected with modern gravimeters and magnetometers.

3. Diagnostic Signs and Identification of Gravity and Magnetic Anomaly Types of Reservoirs

Experimental studies carried out in Russia, Uzbekistan, Belarus, Ukraine, Azerbaijanestablished some rules in the display of oil and gas deposits in gravitational and magnetic fields (Agulnik et al., 1982; Karshenbaum et al., 1982; Mikhailov, 1982; Nikitsky and Glebovsky, 1990; Gadirov, 1991; 1994). At the same time, a study in terms of the contours of characteristic local gravitational minima and hydrocarbon deposits was revealed. The presence of a sharp change in gravity gradients at the boundaries of anomalous objects was also shown (Mikhailov, 1982). Special attention has to this study.

Various transformations of these potential fields are used to distinguish weak local gravitational and magnetic anomalies associated with oil and gas deposits. The calculation of the third derivatives of the gravity potential, the "grad" method, the fully normalized gradient, the continuation of the gravity in the lower half-space, etc. are applied (Berezkin et al., 1978; Mudretsova and Veselov, 1990). Despite this, different sources indicate the inapplicability and ambiguity of various traditional transformation methods for separating potential fields and identifying local anomalies associated with hydrocarbon deposits (Agulnik et al., 1982; Karshenbaum et al., 1982). The studies in recent years show that any transformation inevitably introduces fundamental distortions in the separated components, leading to the appearance of many "false" local anomalies that have nothing to do with geological reasons.

Using several examples in this study considers the results of the third derivatives of the gravity potentials in the Muradkhanli area of the Middle Kura Depression in Azerbaijan. From profiles 01 and 03 passing through deep wells, from the observed fields Δg, Wzzz was calculated (Fig. 2). In this case, the formula for M = 9 points was used in the differentiation section 2L = 4 km (Berezkin et al., 1978). The Wzzz curve calculated from profile 01 shows the alternation of maxima and minima. The Well 58 with a high oil ratio falls into the Wzzz minima. In the area of borehole 13, there is also an intense minimum in the Wzzz field, but this borehole, firstly, is not productive. Secondly, a fault along the Mesozoic was established according to seismic and borehole data. The Well 64, located in the zone of Wzzz minimums, turned out to be not productive, but the Wells 45 and 213, which produced oil with mass flow rates of 2-10 tons/day, are in the zone of maximum Wzzz. On profile 03, between pickets 90-95, according to seismic and gravimetric data, a fault is noted along the Mesozoic surface, with an amplitude of 300-400 m. In this section of the profile, a deep Wzzz minimum appears, which cannot be associated with oil and gas deposits. The Well 21, located in the minimum zone, did not produce, but The Wells 55 and 98 located in the zone of relative maximum Wzzz gave an inflow of oil having industrial importance.

These data indicate the ambiguity of the Wzzz results. It has also been pointed to some ambiguities in the analytical continuation methods of Δg to the lower half-space and the full normalized gradient when solving the issue of exploration for oil and gas deposits (Berezkin et al., 1978; Karshenbaum et al., 1982). As can be seen, the identification of anomalies associated with the reservoir is challenging.

The results of gravity and magnetic exploration carried out in different oil and gas regions of Azerbaijan show that a special approach can be used to distinguish the gravitational and magnetic anomaly over the oil and gas reservoir (Gadirov, 1991; 1994; 1997; 2009). In this case, a sharp change in the gradients of indicated potential fields is used (Mikhailov, 1982; Gadirov, 1991; 2009). Local minima are distinguished against the background of maxima, which is a diagnostic sign of anomalies of the type of reservoir.

For this reason, stated above, a regional background is constructed to adjoin the curves from the side of the lowest value of potential fields, making it possible to identify anomalies caused by the structural properties of the geological cross-section. Then, along the zones of gradient changes, local maxima are restored, and characteristic local minima are distinguished against their background due to the presence of oil and gas deposits in the structure (Gadirov, 1991; 2009).

Fig. 3 shows the construction of the curves of the regional background (4) and the restored maximum (6) on the curves (1 and 2) reflecting the gravitational and magnetic fields, as well as the regression equations corresponding to these curves, based on the profile passing through the Muradkhanly field. To show local variations in the observed fields ΔgB and Z, nodal points (3) were selected on these curves, a regional background curve (4) passing through these points was constructed, and local maxima (5) existing in the potential field were highlighted. On the wings of the identified local maxima, the maxima (6) were reconstructed at the selected nodal points (3), and the difference between the reconstructed curve and the local maximum curve was noted as an anomaly of the local minimum associated with oil and gas (7).

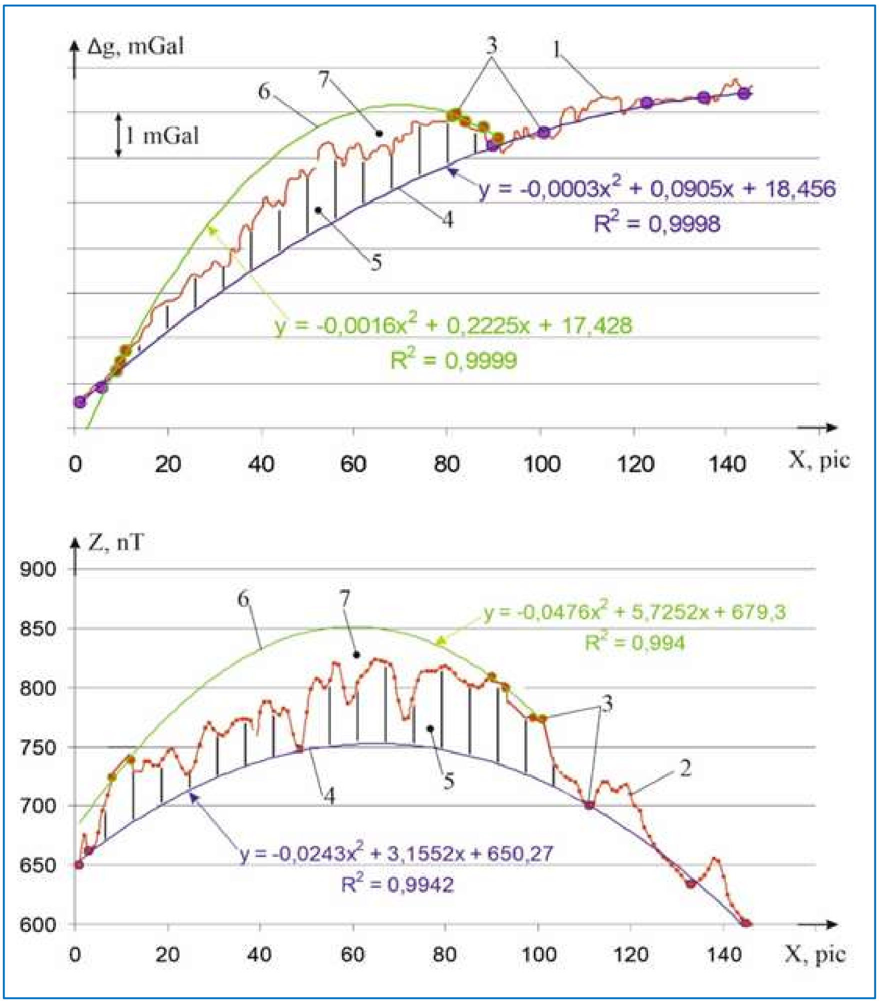

Fig. 3. Separation of local anomalies associated with oil and gas deposits from gravitational and magnetic fields. 1 and 2- curves of gravitational and magnetic fields, 3- nodal points of interpolation, 4- regional background, 5- local maxima, 6- restored maximum, 7- local minima associated with oil and gas content

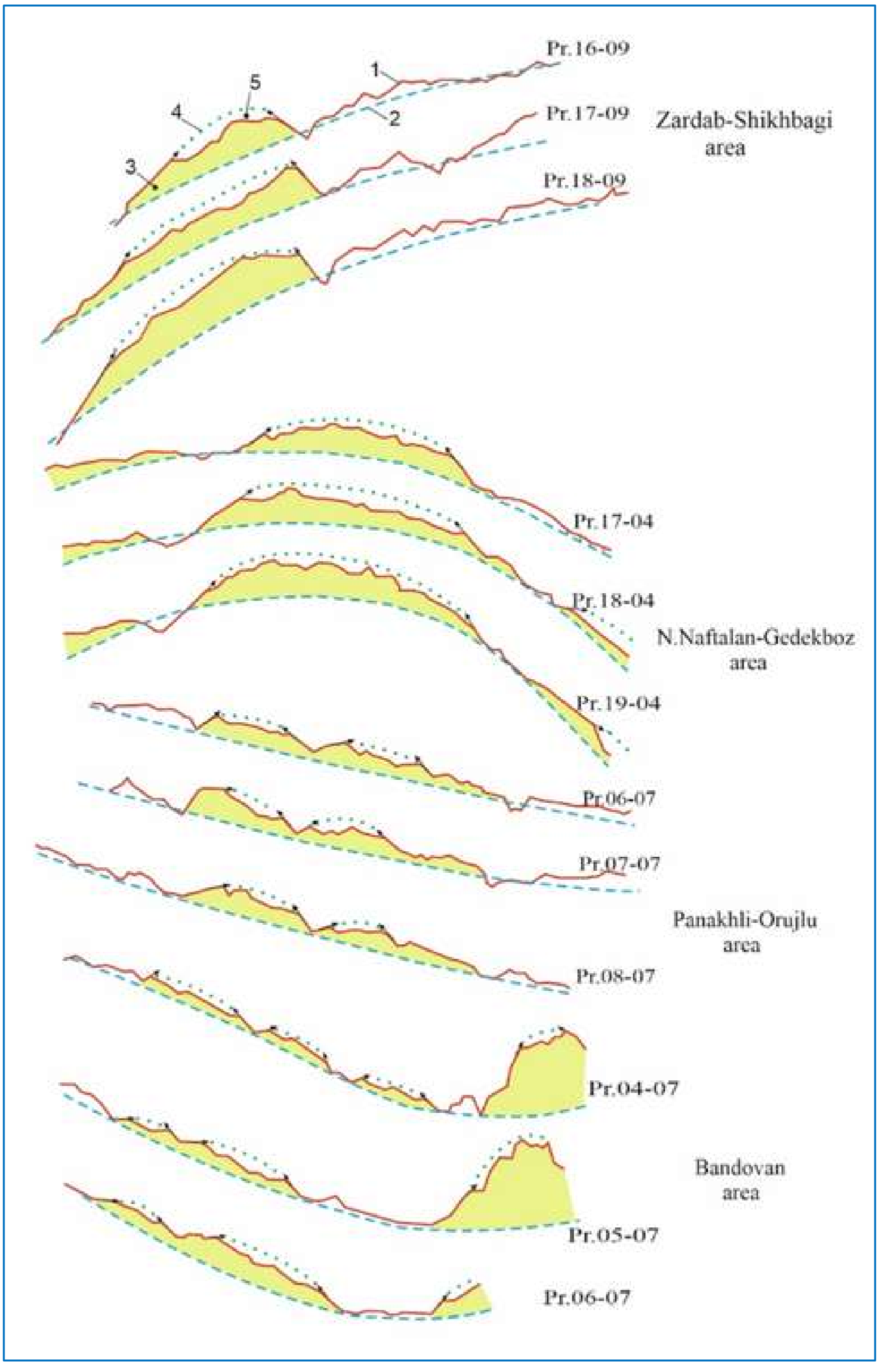

Fig. 4. Separation of local anomalies associated with oil and gas from the field of gravity (Δg) (Zardab-Shikhbagi, North Naftalan-Gedakboz, Panakhli-Orujlu and Bandovan fields). 1- observed Δg curve; 2- regional background; 3- local maxima; 4- restored maximum; 5- local minima

Similarly, in recent years, in the areas Naftalan, North Naftalan, Gedakboz, Duzdag, Gazanbulag, Borsunlu, Dalimamedli, Zardab-Shikhbagi, Jafarli, Orujlu, Bandovan, Gektepe Middle- and Lower Kura Depressions based on data obtained on straight and parallel profiles was determined gravity, also in the areas where magnetometric studies have been carried out (Tarsdallar, Jeyranchel), magnetic minima associated with oil and gas (Figs. 4 and 5).

In areas of Zardab-Shikhbagi and Panahli-Orujlu, the gravity values are positive, and in areas of Naftalan-Gedakboz and Bandovan, they are negative. In the Zardab-Shikhbagi and Naftalan-Gedakboz regions, the regional background is expressed by a convex curve (maximum), in the Byandovan region - by a concave curve (minimum), and in the Panahli-Orujlu region - by a straight line (Fig. 4).

In the Tarsdallar and Jeyranchel areas, the regional background of the geomagnetic field is expressed by a straight line, which highlights the local magnetic maximum (Fig. 5). Despite the difference in the shape (convex, concave, straight) of the regional curve, against the background of the identified local maxima in these areas, it was possible to distinguish characteristic gravity and magnetic minima associated with oil and gas using the proposed method (Gadirov, 1991; 2009).

Predicting locations of oil and gas deposits by the gravity and magnetic methods has proved themselves in the Jafarly and Bozgobu areas of the Middle Kura Depression, where drilled deep wells confirmed the presence of deposits in the zone of local gravity and magnetic minima. In addition, in different areas of the Middle and Lower Kura Depressions (North Naftalan-Gedakboz, Arabkubaly, Bandovan, Geytepe), the Absheron (Gala, Hovsan), locations of oil and gas deposits have been predicted, and deep wells have been planned.

4. Results and Discussion

Arabkubaly areas: Gravimetric and magnetometric studies carried out in the Arabkubaly area (in the central part of the Kurdamir-Sabirabad zone of uplifts, overlooking the southwestern slope of the Lower Kura depression) showed the presence of a local uplift along the surface of Mesozoic sediments (Gadirov, 1991; Gadirov and Eppelbaum, 2012).

In the meantime, characteristic local gravitational and magnetic minima associated with oil and gas were detected on 5 profiles (profiles 12-16), and on their basis, a diagram of the distribution of local gravity-magnetic minima over the study area was constructed (Fig. 6). The intensities of local minima are 0.4.-0.5 mGal and 30-40 nT, respectively, which corresponds to the anomalies observed at the Muradkhanly and Jafarli oil fields. The zone of local minima, about 2 km wide, extends more than 8 km north and southeast of the arch of the asymmetric structure of Arabkubaly.

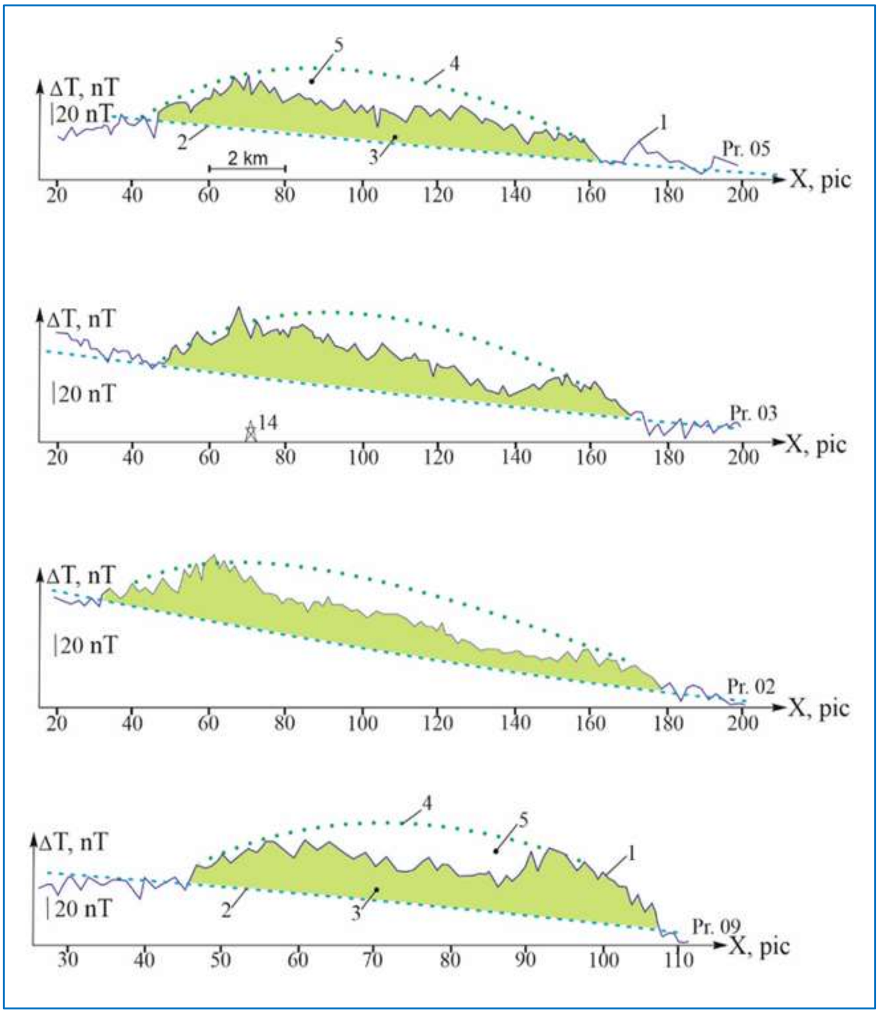

Fig. 5. Separation of local magnetic anomalies associated with oil and gas deposits (Tarsdallar-Jeyranchel fields). 1- observed ΔT curve; 2- regional background; 3- local maxima; 4- restored maximum; 5- local minima

On the other hand, it was found that local minima are manifested not at the crest of the Arabkubaly structure, but in the eastern wing, which underwent a sharp dip (Gadirov, 1991). Considering that the surface of the Mesozoic sedimentary complex drops sharply to the east and that the overlying deposits pinch out to the Mesozoic surface, it can be assumed that the probable deposit is associated with pinch-out zones, as in the areas of the Mugan monocline in the Lower Kura depression.

Seismic data show that on the southwestern slope of the Lower Kura depression in the Paleogene-Neogene complex, individual stratigraphic units pinching out to the Mesozoic surface formed stratigraphic traps. In the Mugan monoclinic, it was established that the traps of Khashimkhanly, Muganly, Sarkhanbeyli, Agchala, and Khirmandali were formed as a result of pinching out of the lower parts of the Balakhanian stage onto eroded Mesozoic sediments (Hajizade, 2003). In the Arabkubaly area, seismic prospecting also established pinch-out zones for the lower horizons of the Balakhanian stage.

On the geological cross-section built on the gravity-magnetometric profile No. 14 passing through the crest of the Arabkubaly structure, it can be seen that the proposed deposit on the arch of the structure lies at a depth of 3000 m, and sinks to 4000 m in the east (Fig. 7). According to the data of well No. 2 Western Garasu, located in the direction of this profile, the deposits of the Balakhanian stage were exposed in the depth interval of 3322-4473 m and have a thickness of 1151 m.

Seismic studies carried out in these areas in 1980-1990 also showed that the sediments of the Balakhanian stage, starting from the Western Garasu area to the Arabkubaly area, rise, their thickness decreases to 600-700 m, and the lower part of these sediments is gradually pinched out. It can be assumed that hydrocarbons may migrate from the Lower Kura depression and accumulate in a trap formed by the pinching out of the lower parts of the Balakhanian Stage on the surface of the Upper Cretaceous.

In general, the presence of an uplift in the Upper Cretaceous in the Arabkubaly area, manifestations of gravitational and magnetic minima associated with oil and gas deposits, requires the involvement of new geophysical studies in this area. And, if it is necessary to conduct exploratory drilling, it is important to place wells in the zone of local anomalies such as deposits, as shown in Figs. 6 and 7.

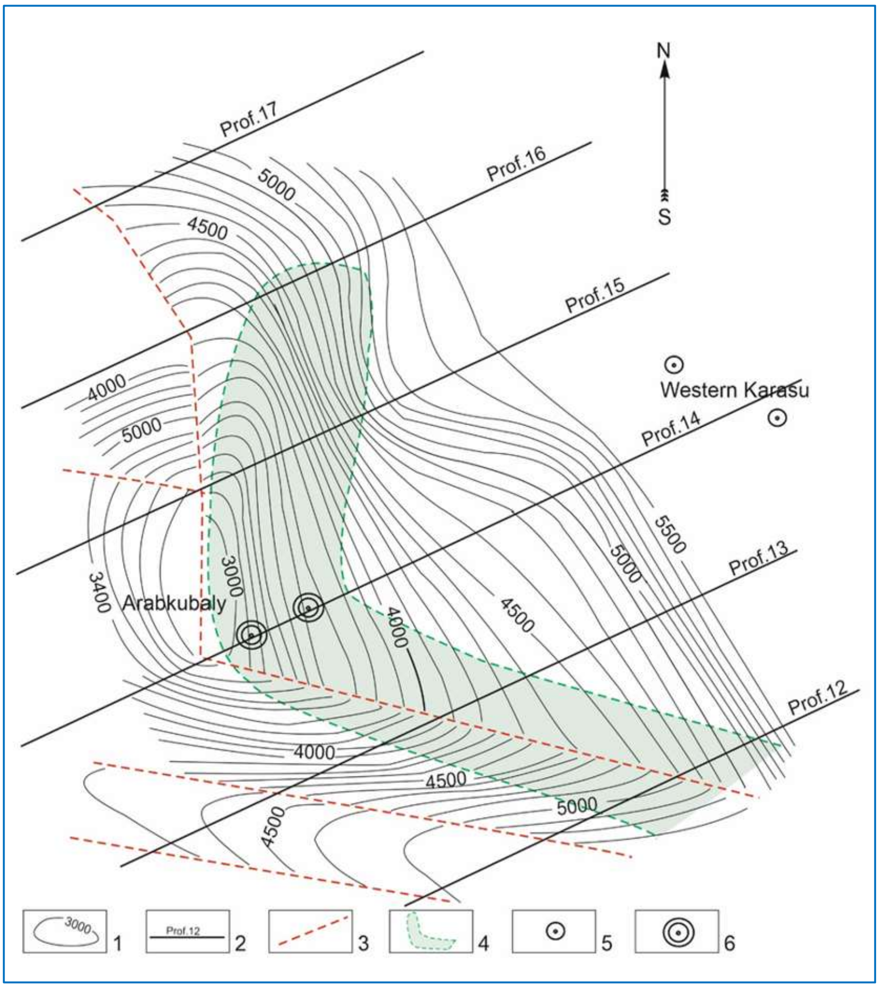

Fig. 6. Distribution scheme of local gravity-magnetic minima associated with oil and gas content in the Arabkubaly area 1 - isohypsum of the Upper Cretaceous according to gravimetric data; 2-gravity-magnetic profiles; 3- fault lines based on gravity-magnetic data; 4- zone of local gravity minima; 5- prospecting wells; 6- recommended wells

In 2004, 2005, and 2010 these gravimetric studies were carried out in Naftalan, North Naftalan, and Gedakboz areas. The gravity field observed on the profiles was analyzed, and characteristic local gravity minima (reservoir-type anomalies) associated with oil and gas deposits were identified. Hence, a map of local minima was constructed (Fig. 8). The map (Fig. 8) shows that local gravitational minima of varying intensity and size were identified in the study area. The intensity minima of 0.2-0.3 mGal are generally small in size and cover a limited area.

For the first time in the Naftalan region, several zones of local minima of a very complex configuration were revealed. The intensity of the local minimum in the area of wells 37 and 44 is 0.3-0.4 mGal (Fig. 8). It should be noted that well No. 37, drilled in 1935, produced oil from the Maykop suite with a flow rate of 20-30 tons/day. The Well No. 44 was drilled up to 500 m and penetrated the Akchakyl stage and the upper clay part of the Maykop suite.

In the area of the wells 56, 58, 43, 47, 33, 90, etc., the intensity of the local gravity minima is 0.1 mGal, and in a small area - 0.2 mGal. The Well No. 43 produced oil from horizon VI of the Maykop suite with an initial flow rate of 40-60 tons/day. The Well 33 had a gas gusher from horizon IV of the Maykop suite. In the well No. 58, drilled to a depth of 2500 m, oil was obtained at a rate of 0.2-0.3 tons/day, presumably from the Upper Cretaceous deposits. No exploration drilling was performed in the zone of local gravity minima with an intensity of 03.-0.4 mGal, found in the northwest of Well 56.

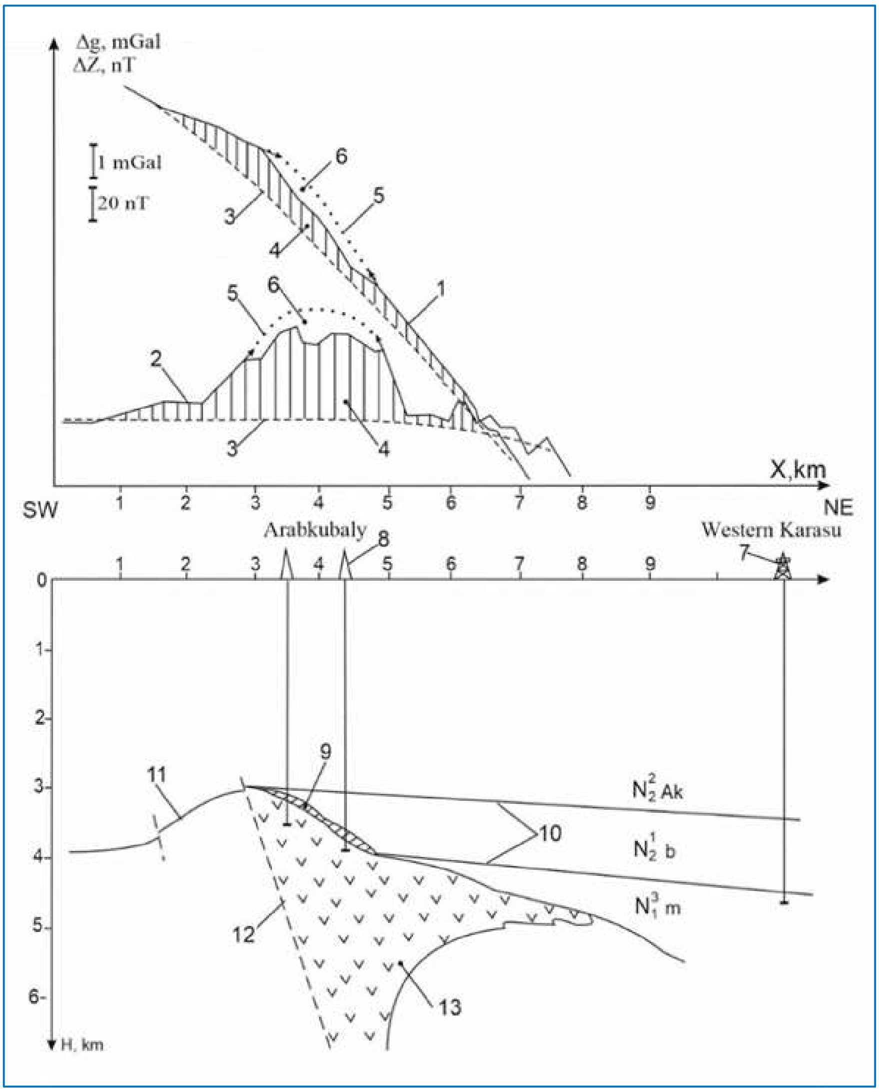

Fig. 7. The geological section on gravimagnetic profile (Arabkubaly area, prof. 14). 1 and 2- observed gravitational and magnetic fields; 3- regional background; 4- local gravitational and magnetic maximum; 5- restored maximum; 6- local gravitational and magnetic minima associated with oil and gas content; 7- exploration wells; 8- recommended wells; 9- estimated accumulation of oil and gas; 10- tops and bottoms of the Balakhani Formation according to seismic exploration; 11- Upper Cretaceous surface; 12- fault lines based on gravity-magnetic data; 13- effusive formations.

The other two zones of local minima in the Naftalan area are identified according to profiles 06, 07, 10, and 11. One of them is more intense and reaches 0.3-0.5 mGal. Another zone of minimum is observed in the Far East wing of the structure, at the end of profiles 06, 07, and 10. No prospecting drilling was carried out in this area either. It should be noted that the Well No. 63, located between the minimum zone found here, was drilled to a depth of 2125 m, penetrated the clay horizon of the Maykop suite, and was not productive.

In the Northern Naftalan area, the most intense areas of the gravity minimum associated with oil and gas (0.4 mGal) are located approximately 1 km northwest of well No. 2 (Northern Naftalan). The zone of local minima extends from north to south and has a size of approximately (2 × 4) km, within the isoanomaly of 0.2 mGal. It should be noted that borehole No. 2 (Northern Naftalan), located in the zone of local minima, gave an inflow of oil with water with a flow rate of 3.6 tons/day from the Middle Eocene sediments.

The Well No. 2 (Gedakboz) was not productive, and went beyond the zone of gravity minima. No characteristic local gravity minimum was recorded in the zone of the 3M well, where the Mesozoic deposits were penetrated.

Local gravity minima associated with oil and gas content is more complex in the Gedakboz Area. The zone of local minima, established based on a network of parallel profiles worked in 2005 and 2010, is located in the north-north-east-south-south-west direction.

In the area of well No. 10, the size of the zone of an intense local minimum 0.2-0.3 mGal is (1 × 2) km, the minimum zone located to the west of wells No. 6 and 8, within 0.2 mGal of the isoanomaly has a width of (1-1.5) km and more than 2 km in length.

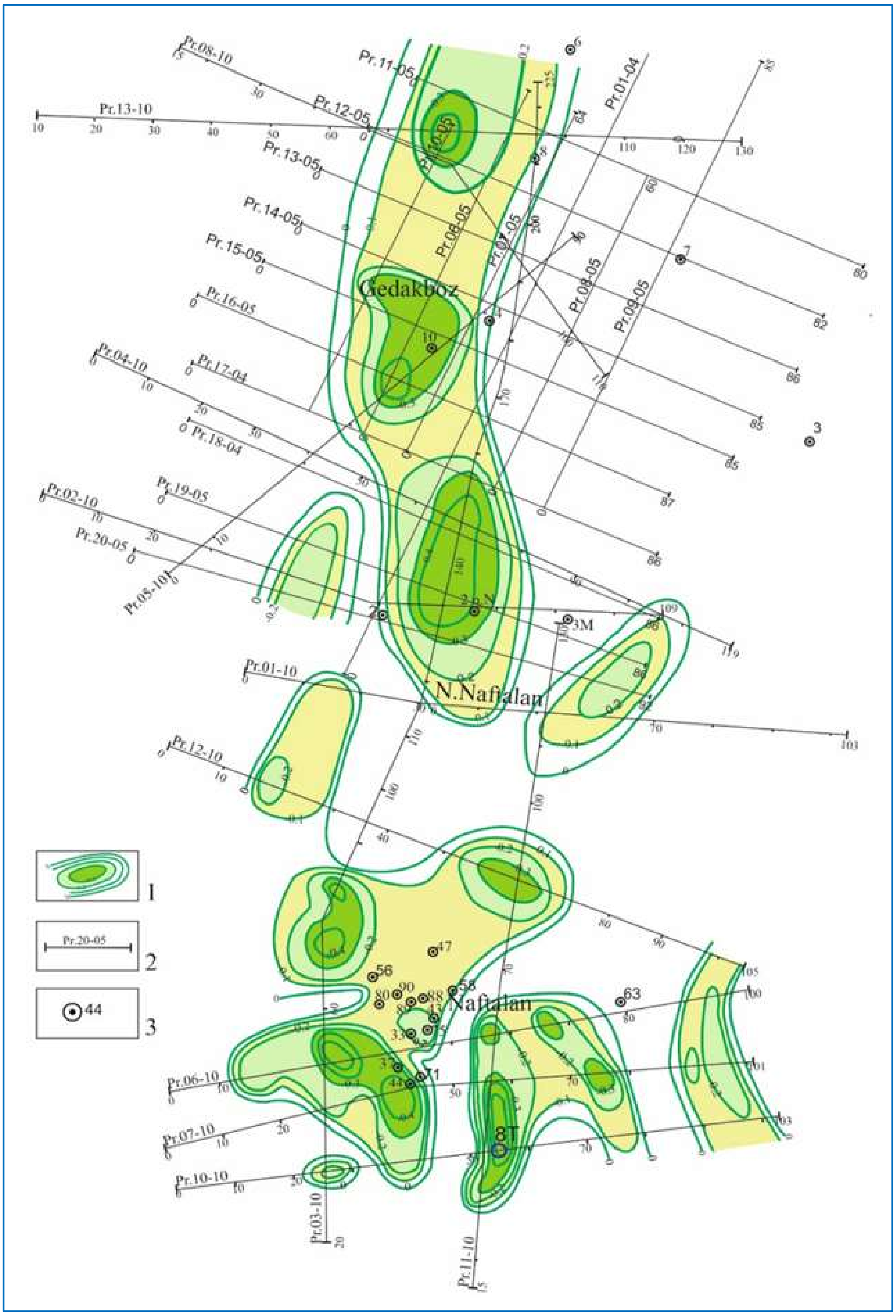

Fig. 8. Map of local gravity minima (Naftalan, Northern Naftalan, Gedakboz areas). 1- isoline of local gravitational minimums; 2- gravimetric profiles; 3-exploration wells

The most intense part of the gravimetric anomaly is located in the area of well No. 10 and practically covers the crest of the Gedakboz structure. Anomalies in the area of Well No. 6 are marked on the northern pericline of the structure.

Considering that the small volumes (0.5-1.5 tons/day) of oil from wells No. 6, 7, and 8 in this area are associated with deposits of the Middle Eocene, one can assume the presence of hydrocarbon deposits in the zone of local gravity minima

(Fig. 8). The Well No. 10, drilled to a depth of 2718 m, penetrated only 88 m of Middle Eocene sediments, and tests were not carried out in this interval.

In general, the identified zone of local gravity minima in the regions of Naftalan, Northern Naftalan, Gedakboz extends from south to north. This zone is bordered in the west by a deep fault, established by seismic prospecting. To the east of this fault and the southeast towards the Yevlakh-Aghjabedy trough, the surface of the Mesozoic deposits deepens, making it possible to substantiate the migration of hydrocarbons from the center of the trough to the wings. In this case, the marked deep fault can play an important role of a shield on the path of hydrocarbon migration.

5. Conclusions

To investigate the features of gravitational and magnetic fields, substantiate local gravity magnetic minima over oil and gas deposits, and compare the obtained theoretical results with the observed data, model work was conducted at the known Muradkhanly fields of the Middle Kura Depression, where there are a large number of wells, and numerous data on density, porosity, magnetic susceptibility have been obtained. Based on experimental and methodical work carried out in the areas of Tarsdallar, Naftalan, Naftalan, Gedakboz, Zardab, Jafarly (Middle Kura Depression), Kursanga, Babazanan, Bandovan, and others (Lower Kura Depression), where numerous wells discovered oil and gas deposits confined to different types of traps and deposits, different stratigraphy showed the effectiveness of gravity-magnetic methods. Depending on the coincidence of the obtained gravimetric and magnetometric local minima with the contours of oil and gas deposits (in Azerbaijan, Russia, Uzbekistan, Kazakhstan, Belarus, Ukraine, etc.), these methods give grounds using for direct exploration of oil and gas deposits.

According to this study, some conclusions on gravimetry and magnetometry have been drawn:

- ✓ Oil deposits, regardless of the shape of the structure on the gravitational and geomagnetic fields, are marked by local minima,
- ✓ The intensity of local gravity-magnetic minima depends to a greater extent on the thickness of the oil and gas reservoir, rather than on its depth,
- ✓ Deep-seated oil and gas deposits in gravity-magnetic fields are demonstrated due to the additional anomalous effect created by the sub-vertical zone above the deposit,
- ✓ The relatively large values of local magnetic minima (30-40 nT) in the Middle Kura depression are explained by the presence of volcanogenic rocks in the geological section and a relatively strong decrease in magnetic susceptibility in these rocks in the deposit zone,
- ✓ According to the real data, a decrease in the magnetic susceptibility of rocks not only in the deposit but also above and below it has been established,
- ✓ Gravitational and magnetic minima over deposits are created not just by the deposit itself, but by the entire sub-vertical deposit zone,
- ✓ Diagnostic signs of the detection of oil and gas deposits by gravimetric and magnetometric exploration can serve as characteristic local minima, identified by gradient zones against the background of local maxima.

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