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SPATIAL POSITION OF VOLCANOGENIC FORMATIONS IN THE NORTHWESTERN PART OF THE YEVLAKH-AGHJABADI DEPRESSION AND THEIR ROLE IN OIL AND GAS POTENTIAL

M. A. Bakirov[1], H. I. Shakarov[1,2]

[1]*"OilGasScientificResearchProject" Institute SOCAR, Baku, Azerbaijan*

[2]*Azerbaijan State University of Oil and Industry, Baku, Azerbaijan*

A B S T R A C T

The article investigates the spatial position of Upper Cretaceous volcanogenic formations and their oil and gas potential in the north-western part of the Yevlakh-Aghjabadi Depression (YAD), located in the central part of Azerbaijan, based on complex geological and geophysical data. The main objective of the study was to determine the distribution areas of volcanogenic masses, the depth of their surfaces, their thickness, and their relationship with deep faults through modeling of magnetic field data.The conducted analyses showed that volcanogenic formations developed in limited but tectonically active zones in the north-western part of the YAD, and their distribution is mainly associated with deep faults. The surface of the volcanogenic formations is located at an approximate depth interval of 2.5-6.5 km from the ground surface, and their thickness varies between 800-3000 m across different areas. In some profiles, the thickness of volcanogenic masses exceeds 2-3 km, and it was determined that magma-feeding channels were formed in narrow zones (approximately 1 km). The maximum thicknesses of volcanogenic masses are observed in areas close to deep faults and gradually decrease toward the flanks. The high density and low permeability characteristics of volcanogenic rocks indicate that they can create favorable geological conditions for hydrocarbon accumulation by acting as a screening barrier. The obtained results confirm that volcanogenic formations in the north-western part of the YAD are closely related to the paleogeodynamic development of the region and play an important role in the formation of oil and gas systems.

Keywords: Yevlakh-Aghjabadi Depression; volcanogenic rocks; magnetic anomaly; ΔZ component; magma-feeding channel; volcanotectonic traps; reservoir-type anomaly; complex geophysical interpretation.

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Introduction

The study of volcanogenic rocks is of particular importance in oil and gas exploration. For the purpose of studying such rocks, in addition to seismic exploration, the application of methods based on the investigation of potential fields (gravimetric and magnetometric) leads to obtaining more reliable results during the geological evaluation of the acquired data. Volcanogenic rocks play an important role not only in the geological structure but also in the formation of potential volcanotectonic traps. Studies conducted in several regions of the world – in the Caucasus, Central Asia, the Middle East, and other oil- and gas-bearing areas - have shown that a close relationship exists between the distribution zones of volcanogenic rocks and hydrocarbon accumulations [1-4]. The Yevlakh-Aghjabadi Depression (YAD), located in the central part of Azerbaijan, is also of particular interest in this context. As a result of seismic, gravimetric, and magnetometric studies carried out here, it has been determined that Upper Cretaceous volcanogenic rocks are widely distributed in the subsurface section [1, 5-11]. The presence of volcanogenic rocks has been confirmed through wells drilled in areas such as Muradkhanli, Zardab, Saatli, Garajaly, Amirarkh, Borsunlu, Godekboz, and Duzdag. However, it should be noted that only the wells have penetrated only the upper part of the volcanogenic sequence. In this regard, forecasting the full thickness of volcanogenic rocks in the area and determining their distribution range is possible on the basis of geophysical data.

One of the effective approaches for studying volcanogenic formations is the integrated interpretation of geophysical exploration methods (gravimetric, magnetometric, and seismic) data. In areas characterized by variability of density and magnetic properties, by using specialized techniques and selective modeling, it is possible to determine the geometric forms of volcanogenic formations at depth [6, 7]. This approach was widely applied in studies conducted in the south-eastern part of the YAD, yielding positive results [5-7, 10]. At the same time, international practice in recent years shows that the presence of volcanogenic and subvolcanic masses is often accompanied by the formation of structural traps, and these zones can be evaluated as prospective areas for oil and gas exploration [3, 4, 12].

***E-mail:** mustafabakirov@gmail.com

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The main objective of this study is to model the spatial position of volcanogenic formations in the north-western part of the YAD based on magnetometric and gravimetric data, to determine their relationship with deep-seated faults, and to assess the influence of these formations on the oil and gas prospectivity of the region.

Geological and tectonic setting

The YAD is located in the central part of the Kura-Araz lowland and tectonically covers the eastern part of the Middle Kura Depression. Along its flanks, it is bounded to the southwest by the Lesser Caucasus foreland, to the northeast by the Mingachevir-Lankaran zone, and to the northwest (in the part where it joins the Kura-Gabirri interfluve oil- and gas-bearing region) by the Ganjachay-Alazan deep-seated fault system. To the southeast, the YAD terminates in the northern part of the Talysh foreland maximum. The depression is well distinguished as an independent structural unit and extends in the general Caucasian direction. As a result of the conducted geological and geophysical exploration works, a number of structures have been identified and studied within the territory of the depression [6, 13]. This structural unit developed during multiple stages of the Alpine orogeny, and both deep faults and the activity of buried volcanic centers played an important role in the geological evolution. Deep wells drilled in different areas of the depression have confirmed the presence of volcanogenic sequences. For example, volcanogenic rocks were encountered at a depth of 3500 m in well No. 3M in the Godekboz area, at 4176 m in well No. 1M in the Duzdag area, at 4550 m in well No. 1M in the Borsunlu area, and at 1010 m in well No. 4 in the Delimammadli area. The penetrated thickness of these volcanogenic sequences varies from 146 m to 644 m across the areas. Specifically, the thicknesses recorded in wells Godekboz 3M, Duzdag 1M, Borsunlu 1M, and Delimammadli No. 4 were 511 m, 644 m, 146 m, and 447 m, respectively.

The YAD is complicated by a number of fault zones [14-17]. Along these faults, favorable conditions were created for the upward movement of magma to the upper layers and for the formation of effusive rocks. The conducted studies show that volcanogenic formations in the depression are mainly concentrated in areas characterized by deep faults (for example, the Hazirahmadli, Borsunlu, and Godekboz areas).

Methodology

In the study of volcanogenic formations, the interpretation of geophysical data is of significant importance alongside conventional well data. In our research, gravimetric and magnetometric data were primarily used.

The studies were carried out in the following sequence:

Analysis of gravity and magnetic fields. Considering the high density and magnetic susceptibility of volcanogenic rocks, local anomalies observed in gravity and magnetic fields were taken as the main objects of interpretation. Analysis of maps of the vertical component of the magnetic field (ΔZ) allowed the preliminary determination of the plan-view distribution areas of the volcanogenic masses. Recent studies show that analysis of the ΔZ component is particularly effective for identifying subvolcanic conduits.

Application of D.S. Mikov's palette. Based on the analysis of the amplitude and morphology of gravity and magnetic anomalies along selected synthetic profiles, the interpretation palette proposed by D.S. Mikov was applied [18]. Using this approach, and following the methodology previously proposed by V. Gadirov, the depth, thickness, and geometric shapes of buried volcanogenic bodies in the geological section of the Kura Depression were estimated [6, 7]. The application of a similar method made it possible to determine the depth to the top and geometric shapes of volcanogenic bodies, including magma-feeding channels, in the northwestern part of the YAD.

Synthetic profiles and modeling. Based on the vertical component of the magnetic field (ΔZ), depth sections were constructed along parallel synthetic profiles oriented southwest-northeast, with an approximate spacing of 4 km between them. These profiles were used to model the vertical thickness, lateral extent, and morphological characteristics of the volcanogenic formations. The obtained results were presented in the form of schematic maps and depth sections.

Integrated approach. The modeling results were compared with data from deep drilling wells and seismic exploration, and the degree of consistency was assessed. The integrated approach allowed for a more reliable determination of the distribution areas, surface depths, and thickness parameters of the volcanogenic formations.

Discussion of exploration results

In 2015, as a result of studies conducted along two arbitrary geophysical profiles in the north-western part of the YAD, the spatial position of the presumed volcanogenic formations in the geological section was modeled through the analysis of gravimetric and magnetic anomalies. One of these profiles extended from the Delimammadli area, passing through the Borsunlu and Godekboz areas, in a northwest-southeast direction. The second profile covered the well zones drilled in the Northern Naftalan-Godekboz area. Based on the local magnetic anomalies identified along these profiles, the approximate spatial position and geometric configuration of the volcanogenic formations in the geological section were determined using a selective method [2, 6, 9, 11]. In particular, along the Northern Naftalan-Godekboz profile line, in the area of well No. 3M and in zones located approximately 2-2.5 km east of this well, thick masses of volcanogenic rocks were identified. In this area, the thickness of volcanogenic rocks reaches approximately 2000 m, while in the zone of well No. 3M, this thickness is about 1200 m. In the western direction along the profile, within the submeridional fault zone [15, 16, 19] identified by seismic surveys, the thickness of the volcanogenic rocks gradually decreases until they completely pinch out within the cross-section. This indicates that regional tectonic changes and paleogeodynamic processes in the area have had a direct impact on the spatial distribution of the volcanogenic material.

On the other hand, geological and geophysical modeling conducted along the regional profile passing through the Delimammadli-Borsunlu-Godekboz areas confirmed the presence of volcanogenic rocks in two separate zones - in the Borsunlu and Northern Naftalan-Godekboz areas [6]. In the Borsunlu area, these rocks are estimated to be located at a depth of 400-800 m from the surface of the Upper Cretaceous deposits, with a total thickness of approximately 1500 m. These data are consistent with the results obtained in the Godekboz area, showing significant similarities between the geological sections.

In our study area, the spatial position of volcanogenic formations was determined along southwest-northeast oriented parallel synthetic profiles, spaced approximately 4 km apart (fig. 1). Based on these profiles, important information was obtained about the local character and amplitude variations of the magnetic anomaly fields, the magnetization degree of the rock types, and their morphology.

According to the section constructed along profile No. 02 in the Delimammadli-Bozyeri zone, based on a local magnetic maximum with an amplitude of 90 nT, volcanogenic rocks occur at a depth of approximately 500 m from the top of the Upper Cretaceous deposits (2500-3000 m below the ground surface), with a thickness of about 1800 m (fig. 2a). A similar situation is observed along profile No. 03, which runs parallel at a distance of approximately 4 km to the east. In the zone of these profiles, the vertical thickness of the volcanogenic body reaches approximately 2500 m, while its lateral extent is 11-12 km (fig. 2b). In the sections corresponding to points 20-21 of the profile, the root of the volcanogenic formation, i.e., the magma-feeding channel, was identified. This channel coincides with the northern continuation of a fault zone extending northeast of the Hazirahmadli area.

Slightly to the south, along synthetic profiles No. 04 and 05 passing through the Hazirahmadli area, depth sections indicate that the spatial position of the volcanogenic formation occurs at a depth of 500-800 m below the top of the Upper Cretaceous deposits (3000-4500 m from the ground surface), with a thickness ranging from 1000 to 3000 m and a lateral extent of approximately 15-17 km (fig. 3a, b). At point 20 of profile No. 04, the root of the volcanogenic body was identified. In this area, the volcanogenic block is interpreted to rise from deeper levels along the eastern flank of the fault zone extending northeast of the Hazirahmadli area, propagating toward the upper structural levels at a certain inclination.

Analyses along profile No. 06, constructed in the direction of the Qazanbulaq-Bozdag protrusion (fig. 3c), show that the volcanogenic mass in the deep fault zone identified by seismic exploration (between stakes 24-29) is localized within a 6000-6500 m interval from the ground surface, with a relative increase in thickness also observed. Moving slightly to the southwest, both the thickness and depth of the volcanogenic rocks gradually decrease, completely thinning out approximately 3.5-4 km west of well No. 1M in the Borsunlu area (at a depth of 3500 m), and are no longer observed in the section. It should be noted that in well No. 1M in Borsunlu, located only 1.5 km from this profile line, volcanogenic rocks were encountered at a depth of 4550 m (fig. 3c).

Thus, the deep fault and the distribution zones of volcanogenic formations revealed along profile No. 06 can be interpreted as indicators of the interaction between magmatic and structural processes in maintaining the geodynamic

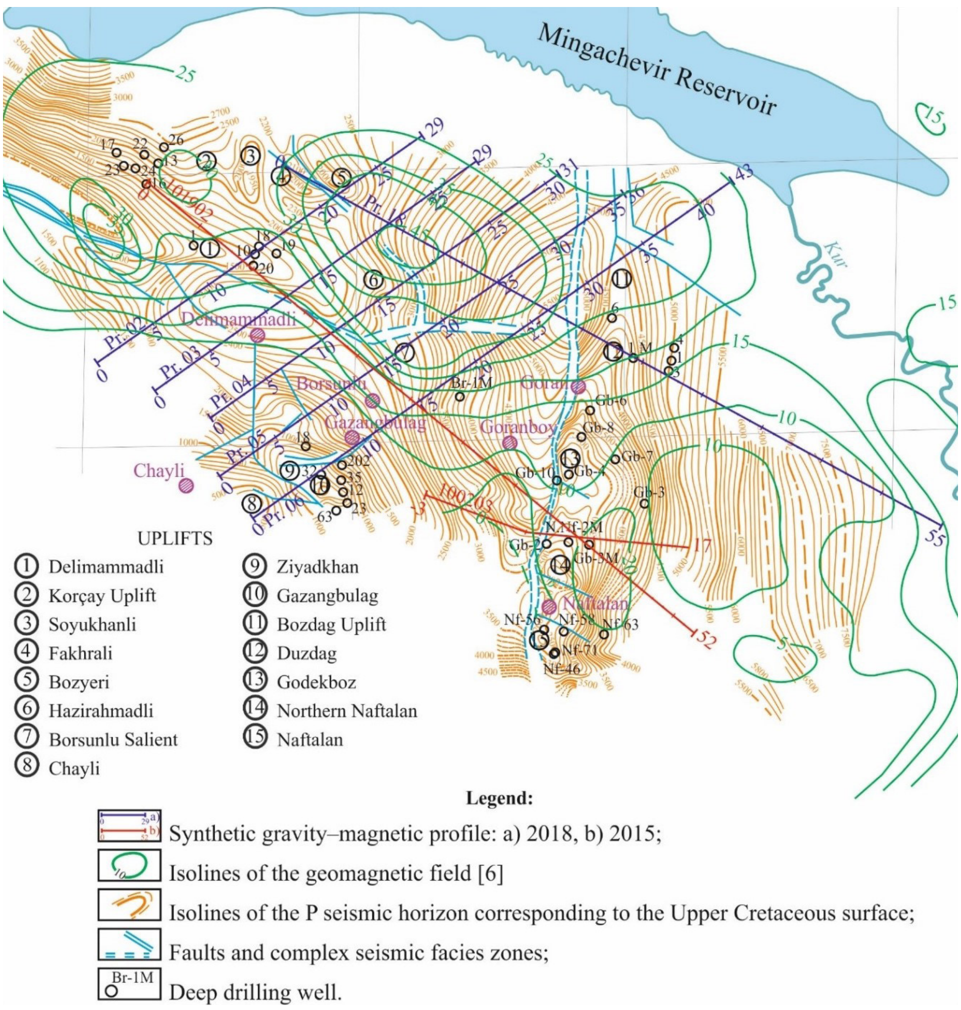

Fig. 1. Layout scheme of synthetic gravimagnetometric profiles and map of the geomagnetic field (ΔZ) in the north-western part of the YAD

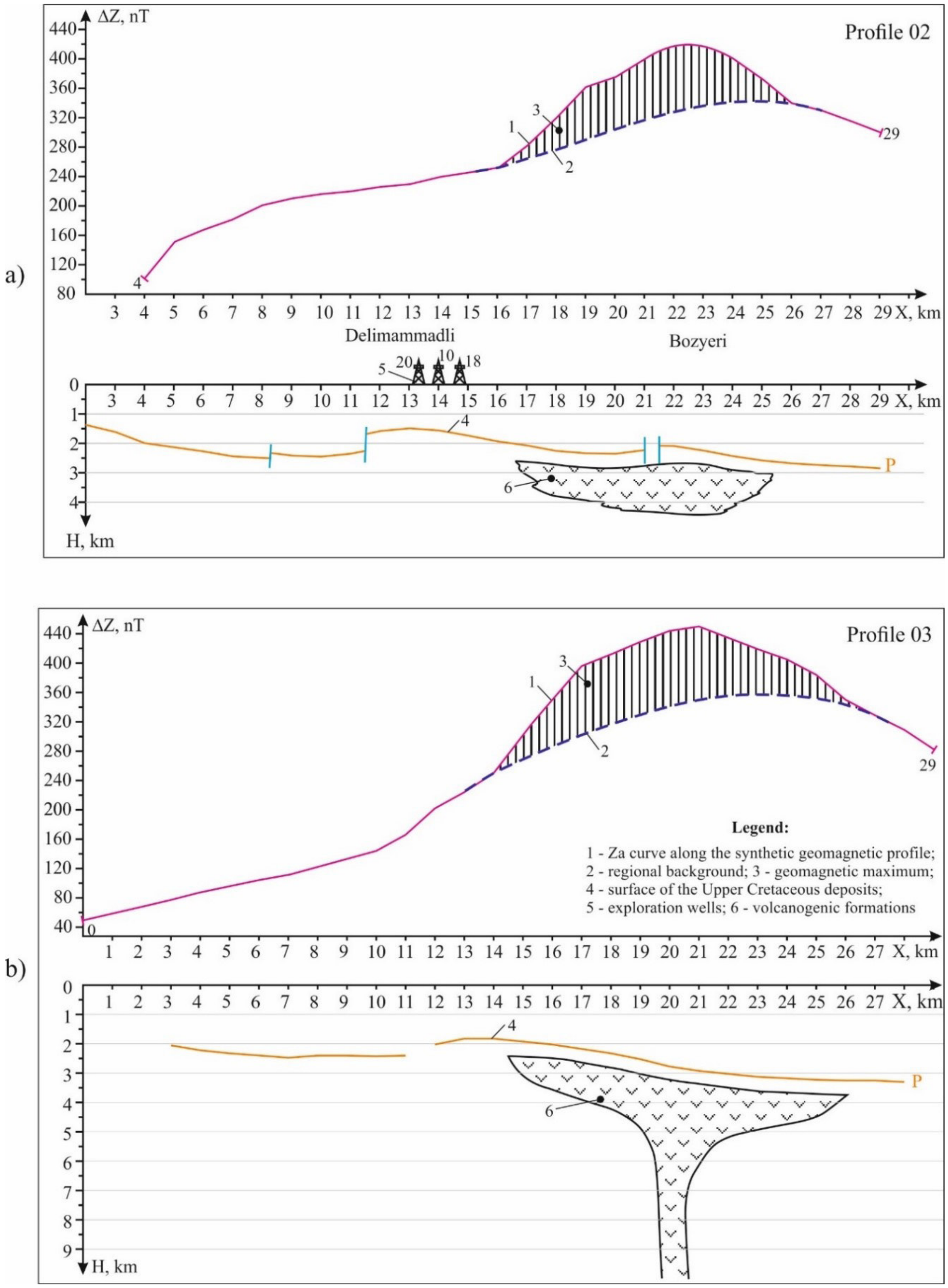

Fig. 2. Depth section reflecting volcanogenic formations based on magnetometric data:
a – synthetic profile No. 02; b – synthetic profile No. 03

balance of the region.

Analyses conducted in the north-western part of the YAD indicate that volcanogenic formations are distributed within limited areas. Based on these results, schemes were developed to determine the distribution areas, depths, and thicknesses of the volcanogenic formations in the study zone, using both geophysical and deep well data (fig. 4, 5). For the construction of these schemes, the first step was to analyze the magnetic field along the north-western segment. Then, based on the obtained magnetometric anomalies, an appropriate methodology was applied to model the surface and spatial position of the volcanogenic formations. In this way, depth sections of the volcanogenic blocks were constructed, allowing the determination of both the depth of their surfaces and their vertical thickness. The collected data and newly obtained results were compiled to produce schemes reflecting the depth and thickness parameters of volcanogenic formations in the north-western part of the YAD, followed by detailed geological and geophysical analysis of these schemes.

In the schemes constructed for the north-western segment of the YAD, the distribution areas of volcanogenic formations, as well as the minimum depth and maximum thickness values within these areas, are indicated. Specifically, the depth scheme of the north-western segment identifies two main volcanogenic areas. The first area extends from the Borsunlu-Bozyeri-Hazirahmadli fields to the deep fault passing west of the Duzdag field, while the second area is located east of this fault, covering the Northern Naftalan-Godekboz segment. In the western part of the fault zone, the surface of the first volcanogenic body occurs at a depth of approximately 6-6.5 km, corresponding to points 25-29 of profile No. 06. Moving relatively westward, the surface depth gradually decreases to a range of 2.5-3 km. In the Northern Naftalan-Godekboz area, in the well zones N.Nf-2M and Gb-3M, the surface of the volcanogenic formation is at the shallowest depth (3.5-4 km), whereas toward the Gb-7 and Gb-3 wells, the depth increases to 5-5.5 km.

The roots of the volcano (magma-feeding channels) are distributed within a relatively narrow range of approximately 1 km. In plan view, these channels are identified as practically linear structures along the northern side of the tectonic fault passing north of the Borsunlu protrusion, extending in a northwest–southeast (NW-SE) direction (fig. 5). At the same time, thickness schemes prepared based on gravimagnetometric data show the presumed deep faults, the roots of the volcanoes associated with them, and the distribution of the volcanogenic masses. The scheme clearly indicates that around the magma-feeding roots of the volcano, the thickness of the volcanogenic formations exceeds 2-3 km, gradually decreasing toward the edges to 400-500 m.

Thus, the analyses indicate that along the north-western segment of the YAD, volcanogenic formations are developed in localized zones-primarily intensified along deep faults and lithospheric discontinuities—while their stratigraphic distribution in the remaining areas is very limited. To refine the geological structure of the identified volcanogenic formations and to predict their hydrocarbon potential, data from seismic, gravimetric, and magnetometric surveys conducted in the area were analyzed in an integrated comparative manner. Based on data obtained using the common depth point (CDP) seismic method, schematic structural diagrams were compiled not only for the upper horizons but also for horizons within the Cretaceous deposits [19]. These diagrams indicate that the study area has a complex structural architecture and are consistent with the schemes reflecting the distribution areas of the volcanogenic formations. The depth of this horizon is located 500-1000 m below the top of the Cretaceous deposits. This feature suggests the presence of a reflective interface associated with the upper surface of volcanogenic formations within the Cretaceous deposits. Considering that the density of volcanogenic formations differs from the overlying sediments, reflections observed at this boundary are consistent with classical theory [16, 17, 20, 21].

Studies were also carried out in the area with the integrated application of the seismic refraction methods and gravimetric surveys for the purpose of forecasting oil and gas accumulations. The results of the investigation aimed at identifying hydrocarbon-prospective zones within the study area were summarized; the distribution of reservoir-type anomalies [6] was shown on the structural map compiled for the surface of the Mesozoic deposits of the investigated area [14, 19], and these were compared with schemes characterizing the distribution zone of volcanogenic formations. The conducted analyses showed that gravimetric and seismic reservoir-type anomalies generally confirm each other, and their spatial position (in the crest, eastern flank, and periclinal parts of the structures) increases the probability of correspondence to geological traps. Based on the integrated geophysical studies, reservoir-type anomalies associated with hydrocarbon potential were identified in different areas of the Delimammadli structure, at various orientations, scales, and depths. After comprehensive analysis with other data, reservoir-type anomalies corresponding to the surface of the Mesozoic deposits were found to align along NW-SE tectonic faults, while in the southern wing of the structure, they correspond to the arch segment. Gravimetric reservoir-type anomalies associated with hydrocarbon potential are reflected in the local gravitation minima map (Figure 6), showing that gravitation minima extend as zones along the Delimammadli structure. The anomalies detected by seismic data correspond to these areas [22, 23]. Calculations of the depths of reservoir-type anomalies based on seismic and gravimetric data showed that the anomalous objects are located 500-600 m below the Mesozoic surface. This indicates that the presumed reservoir is formed within the Mesozoic deposits and corresponds to volcanogenic sediments.

A comprehensive analysis of seismic, gravimetric, and magnetometric survey data shows that in the northwestern part of the YAD, volcanogenic formations are distributed in localized areas, and their development is directly related to deep-seated faults. These results fully correspond to the geodynamic evolution of the region. Analyses along local profiles provided important information about the structure and distribution patterns of volcanogenic masses. In particular, the magma-feeding channels observed along synthetic profiles No. 03 and 04 indicate a close association of effusive rocks with fault tectonics. This observation is consistent with international experience. For example, similar magnetometric studies conducted in the Kakheti zone of Georgia also showed that effusive rocks are mainly located along fault zones, with their greatest thicknesses observed near deep fault areas [24].

Analysis of the general schemes indicates that the

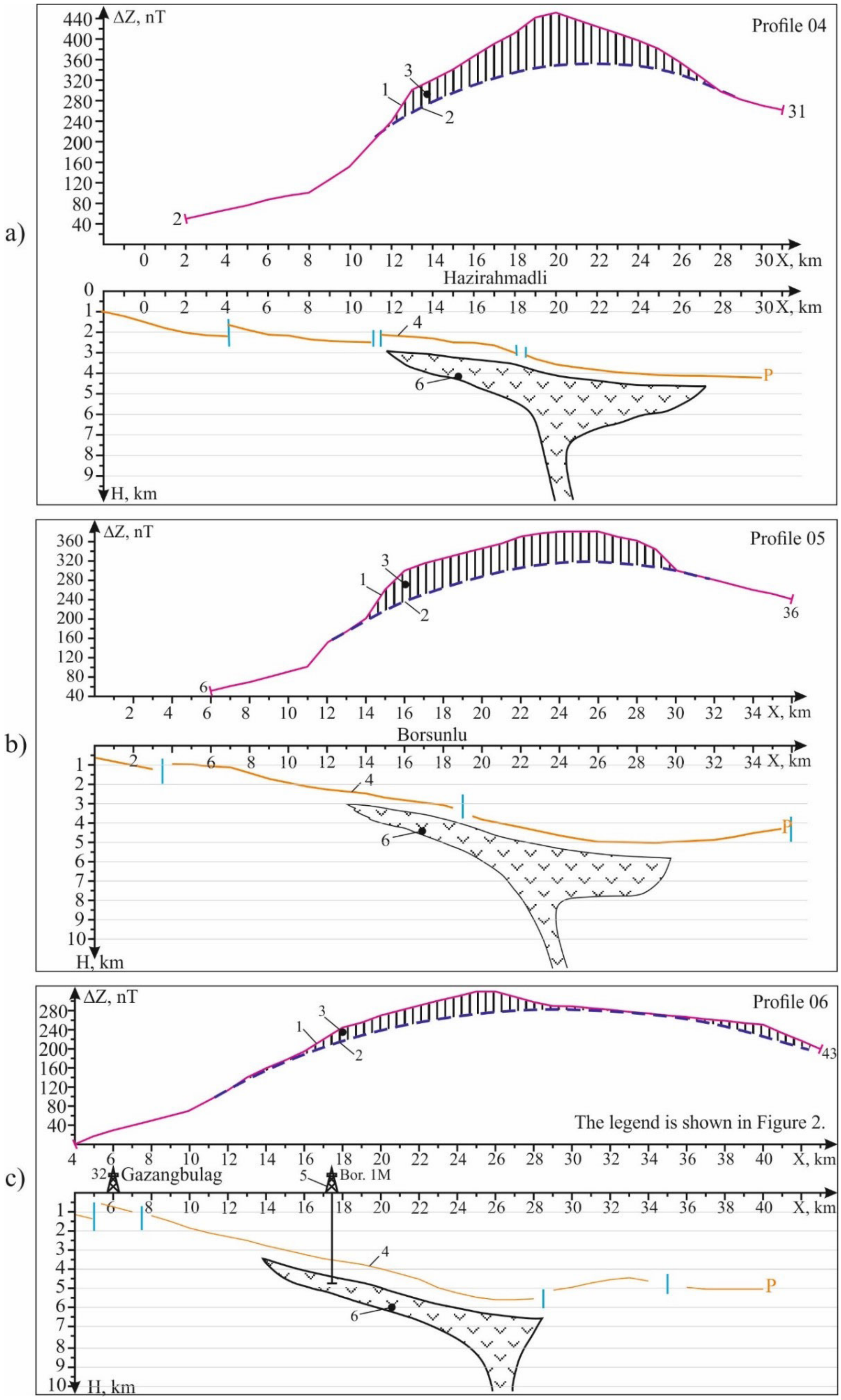

Fig. 3. Depth sections reflecting volcanogenic formations based on magnetometric data: a – synthetic profile No. 04; b – synthetic profile No. 05; c – synthetic profile No. 06)

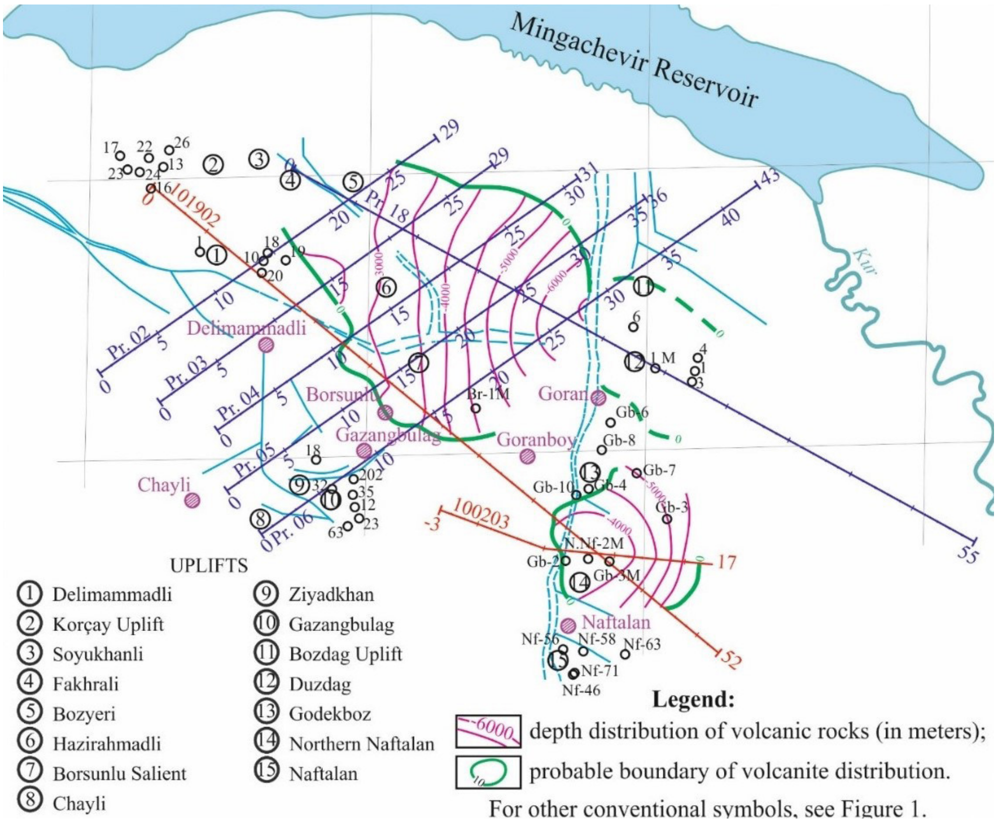

Fig. 4. Schematic map of the depth to the surface of volcanic formations (northeastern part of the Yevlakh-Aghjabadi Depression)

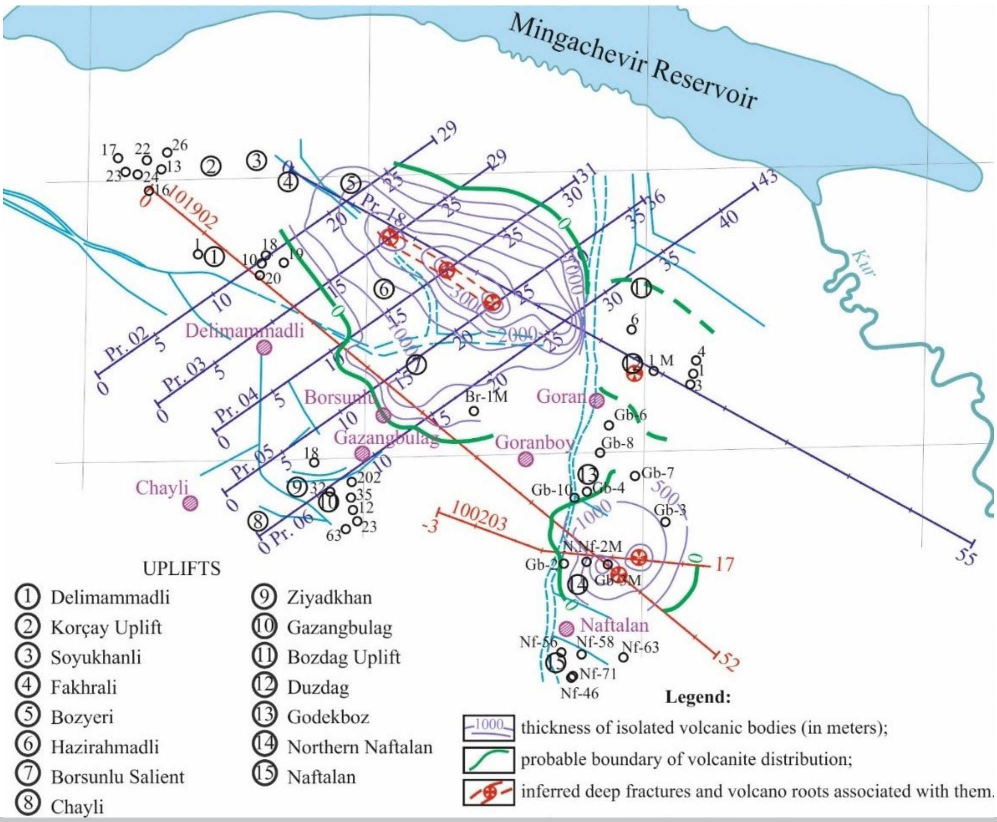

Fig. 5. Schematic map of the thickness of volcanic formations(northeastern part of the YAD)

distribution and morphology of volcanogenic masses are promising for hydrocarbon exploration. The likelihood of forming volcanotectonic traps is higher in areas surrounding magma-feeding channels and in zones where the thickness of effusive rocks reaches 2-3 km. Such traps create favorable conditions for hydrocarbon accumulation because volcanogenic rocks can both act as seals and contribute to the formation of structural traps. The consistency of these results with other geophysical (seismic and gravimetric) data further confirms these conclusions.

The results demonstrate that the presence of volcanogenic formations in the YAD is of critical importance for assessing the hydrocarbon potential of the region. In zones where the volcanogenic masses are thick, effusive rocks can deform sedimentary complexes and promote the formation of structural traps. In the distribution areas of effusive rocks, anticlinal-type uplifts are often observed, providing favorable structural conditions for the formation of potential reservoirs.

The high density and low permeability characteristics of volcanogenic rocks enable them to act as seals for hydrocarbon accumulation. These seals limit the upward migration of hydrocarbons, ensuring their accumulation. The movement of magma along fault zones can also serve as a channel for hydrocarbon migration. The distribution areas of volcanogenic rocks often coincide with deep faults, increasing the likelihood of hydrocarbon migration in these zones.

In many oil and gas basins worldwide (e.g., Central Asia, Iran, and other Caucasus depressions), industrially significant hydrocarbon deposits have been identified within the distribution zones of volcanogenic and subvolcanic rocks. The formation of these deposits is associated with deep-seated faults and magmatic processes [3, 4, 10]. International studies indicate that structural and lithological traps developed under volcanotectonic conditions create favorable environments for hydrocarbon accumulation. In this context, the results of the integrated geological and geophysical analyses indicate that similar geodynamic and structural-lithological conditions may exist in the north-western part of the YAD, supporting the conclusion that these zones are prospective for hydrocarbon exploration.

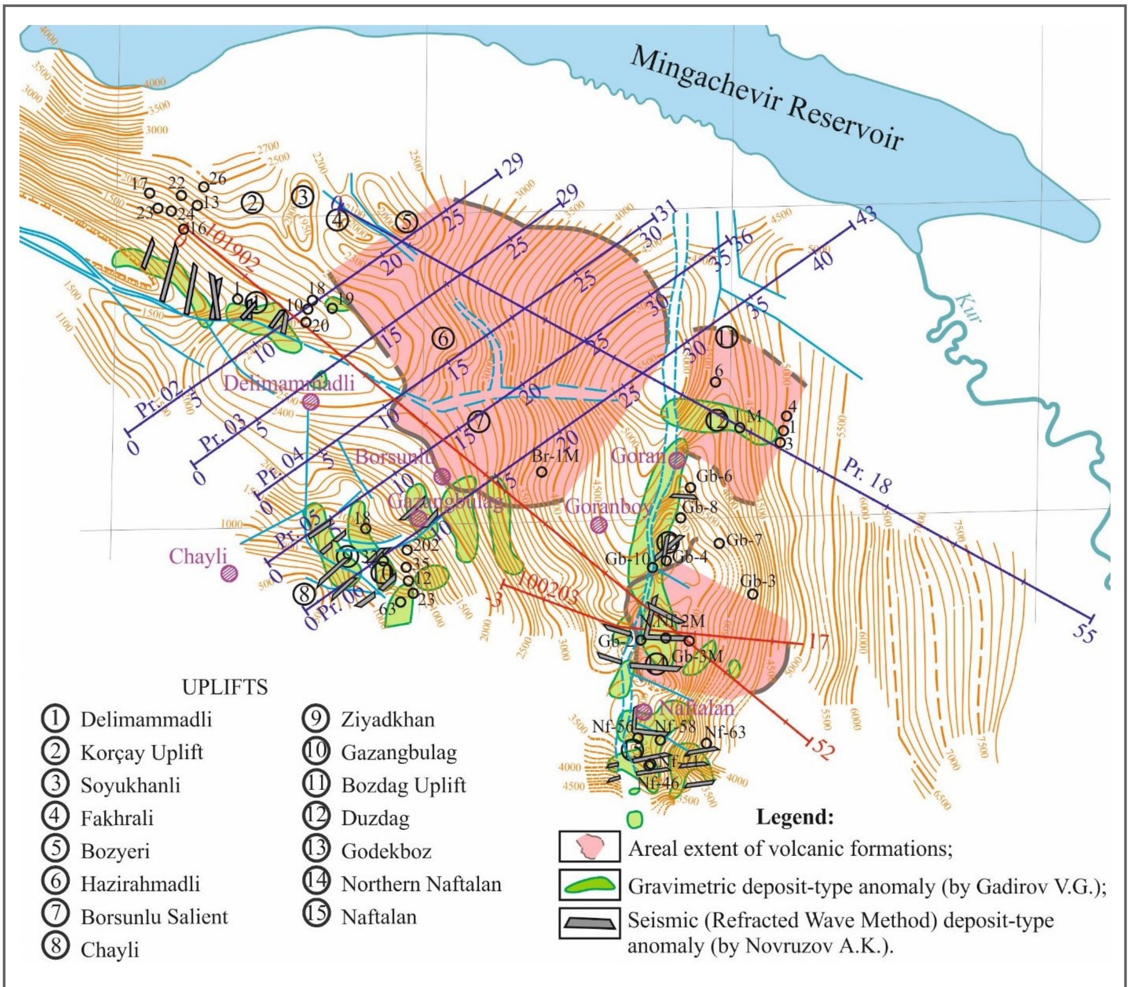

Fig. 6. Distribution area of volcanogenic formations and map of reservoir-type anomalies based on geophysical data in the north-western part of the YAD

Conclusions

The results of integrated geological and geophysical (seismic, gravimetric, and magnetometric) studies conducted in the north-western part of the YAD indicate that Upper Cretaceous volcanogenic formations in this area are limited in extent but developed in structurally significant zones. While data from deep drilling wells confirm the presence of volcanogenic rocks, determining their depth, total thickness, and lower boundaries was possible only through the integrated interpretation of geophysical data.

Modeling based on synthetic magnetometric profiles has shown that the surfaces of volcanogenic formations are mainly located at depths of 2.5-6.5 km below the surface, with thicknesses ranging from 800 m to 3.000 m depending on the area. The Godekboz, Borsunlu, and Hazırehmedli fields are particularly distinctive in this regard. In several profiles, the identification of magma-feeding channels demonstrates that the formation of volcanogenic rocks is directly related to deep fault zones.

The analyses indicate that the distribution of volcanogenic formations aligns with the paleogeodynamic development of the region. During the tectonic activation phase in the Cretaceous, the upward movement of magmatic material along fault zones contributed to the formation of volcanogenic masses. These findings are consistent with results from international studies.

Comprehensive geophysical interpretation has shown that volcanogenic rocks play an important role in the region not only in the formation of the geological structure but also in the development of oil and gas systems. Due to their high density and low permeability, volcanogenic bodies can act as a seal, facilitating the accumulation of hydrocarbons in structural and volcanotectonic traps. At the same time, magma-feeding channels and the associated fault zones can form favorable pathways for hydrocarbon migration.

Thus, the characteristics of the volcanogenic structures in the Yevlakh-Aghjabadi Depression, as determined using seismic, gravimetric, and magnetometric methods, are of critical importance both for hydrocarbon geology and for the study of volcanotectonic development.

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