SOCAR Proceedings

Geology, Geophysics & Formation Evaluation

journal home page: http://proceedings.socar.az

ANALYSIS OF THE PIRALLAHI DEPOSIT FOR LITHOFACIES OF THE LOWER PRODUCTIVE SERIES

A. M. Salmanov, S. O. Heydarli*, Y. R. Mustafayev

[1]*«OilGasScientificResearchProject» Institute, SOCAR, Baku, Azerbaijan*

[2]*Exploration and Field Appraisal Department, Head Office, SOCAR, Baku, Azerbaijan*

[3]*Balakhani Operating Company, Baku, Azerbaijan*

A B S T R A C T

This paper investigates the genesis of the Productive Series sediments within the uplift zone of Pirallahi Island, focusing on the distribution conditions and lithofacies characteristics of different origins. For this purpose, the lithofacies characteristics and conditions of the Lower Pliocene Productive Series sediments in the Pirallahi Island structure have been analyzed, particularly based on geophysical well logging (GWL) data. Using a significant number of well logging diagrams, the distribution of sand and shale lithologies for the productive horizons were determined, systematically classified, and correlation schemes were established. The research includes a detailed analysis of the sedimentary environments to interpret depositional patterns, integrating GWL data with lithological core analyses where available. The facies analysis on Pirallahi Island has included nearly all the boreholes drilled in the field, with the distribution of facies considered from top to bottom across the study area. In addition, the study includes a quantitative assessment of porosity, permeability and clay content to comprehensively evaluate the reservoir potential. Well log analysis allowed interpretation of the effective porosity of the rocks and their shale content, providing a clearer understanding of reservoir heterogeneity. The main objective of the study reported in this paper is to demonstrate lithofacies variability in both horizontal and vertical directions using cross section and lithofacies modeling techniques. The developed facies model is thus demonstrated on a number of surfaces, providing a predictive framework for identifying favorable reservoir zones. The resulting regularities are discussed, highlighting the implications of facies variability for hydrocarbon exploration and production strategies.

Keywords: oil; gas; Pirallahi field; lithofacies feature; facies composition; facies model; correlation.

Date submitted: 12.09.2024 **Date accepted:** 23.01.2025

© 2025 «OilGasScientificResearchProject» Institute. All rights reserved.

Introduction

The exploration potential for oil and gas in Azerbaijan mainly related with the deeper offshore areas. However, besides numerous drill-ready prospects, still huge volume of oil reserves remains in the brown fields [1].

Most discovered oil and gas reservoirs here are associated with clastic rocks. Determining the depositional environment and facies types of the terrigenous layers allows to make an assessment for the porosity and permeability of the rocks in the study area [2]. This process is critical for identifying high-potential reservoir zones, optimizing development strategies, and predicting production performance. Detailed sedimentological and petrophysical studies can significantly enhance reservoir characterization, providing valuable insights into the spatial distribution of reservoir properties.

It is known from the experience, that most terrigenous reservoirs are never completely homogeneous. The individual sub-layers differ in porosity, permeability, pressure, temperature and other critical parameters [2]. These variations are often a result of depositional and post-depositional processes, including compaction, diagenesis, and tectonic activity, which alter the initial reservoir properties over time. The heterogeneity impacts fluid flow behavior, necessitating advanced modeling techniques for accurate reservoir performance prediction.

The identification of lithology and lithofacies plays a crucial role in determining the permeability and sealing characteristics of tectonic faults. The permeability or sealing nature of faults is influenced by several factors, including fault throw, tectonic activity of the basin, geological characteristics of the area, fault type (normal, reverse, or strike-slip), the lithological composition of the fault plane, and the degree of fault gouge cementation. Lithological and reservoir properties directly affect the sealing and permeability of faults at different throw and depth values. Therefore, a comprehensive understanding of lithology and lithofacies is essential for accurately assessing fault behavior, including fluid migration

**E-mail:* servan.heydarli@gmail.com

http://dx.doi.org/10.5510/OGP20250101038

and hydrocarbon accumulation, which is essential for effective exploration and production strategies [3].

Lithofacies classification derived from well logs has been instrumental in analyzing such heterogeneities.

Lithofacies represent discrete categories of rock quality, often distinguished by unique petrophysical properties that influence subsurface fluid flow. The classification process involves identifying small- to intermediate-scale variations within the geological formations, which are critical for understanding reservoir behavior. While core samples are generally limited, well logs provide a continuous dataset that enables more comprehensive lithofacies analysis. Such classifications offer valuable insights for reservoir characterization and enhance the accuracy of hydrocarbon exploration [4].

Therefore, the lithofacies of the reservoirs should be determined in advance, and their lateral and vertical distribution should be specified. For this purpose, based on geophysical data, particularly well geophysical survey (WGS) data, the lithology and facies of Lower Pliocene sediments in the Pirallahi uplift zone were investigated and analyzed. This analysis integrates seismic data, core samples, and petrophysical logs to construct a comprehensive facies model, which serves as the foundation for understanding reservoir architecture and guiding field development decisions. This field was under development for many years.

The Productive Series (PS), a key geological unit, is characterized by regional lithofacies variations.

Found across the western South Caspian Basin (SCB), PS sediments exhibit distinct types, such as Volga (Absheron), Gobustan, and Kur lithofacies, among others. These facies zones are marked by features like thick terrigenous sediment accumulation and a notable lack of mollusk and microfauna remains. The South-Caspian lithofacies zone is particularly notable for uniting characteristics from all other zones, forming a transitional area extending to the basin's shelf. Understanding these features is essential for precise reservoir modeling and effective resource extraction strategies [5].

The studied Pirallahi field, is the fold located on the Garbi Absheron-Janub anticline line. The uplift is of complex structure and is divided into tectonic blocks by transverse and longitudinal faults. North Pirallahi (Blocks I and II) has an asymmetric structure and is separated from South Pirallahi by Fault No. 4. South Pirallahi (Blocks III, IV) is complicated by an overthrust fault and separated from Pirallahi V block by fault No. 7 (fig. 1). These faults play a significant role in the hydrocarbon accumulation and migration pathways within the field. Fault zones often act as both conduits and barriers to fluid flow, depending on their sealing capacity and lithological characteristics. The presence of overthrust in blocks III, IV and V complicates the structure of the field, thus affecting the distribution of oil reserves and the determination of lithofacies features [6-8].

The Pirallahi Island deposit was selected for this study due to its long history of operation, spanning over 125 years. Exploration activities in the field commenced in 1897 by private entities. That same year, several exploratory wells were drilled under the supervision of the Nobel brothers. The presence of hydrocarbons in the Kirmaky Suite (KS)

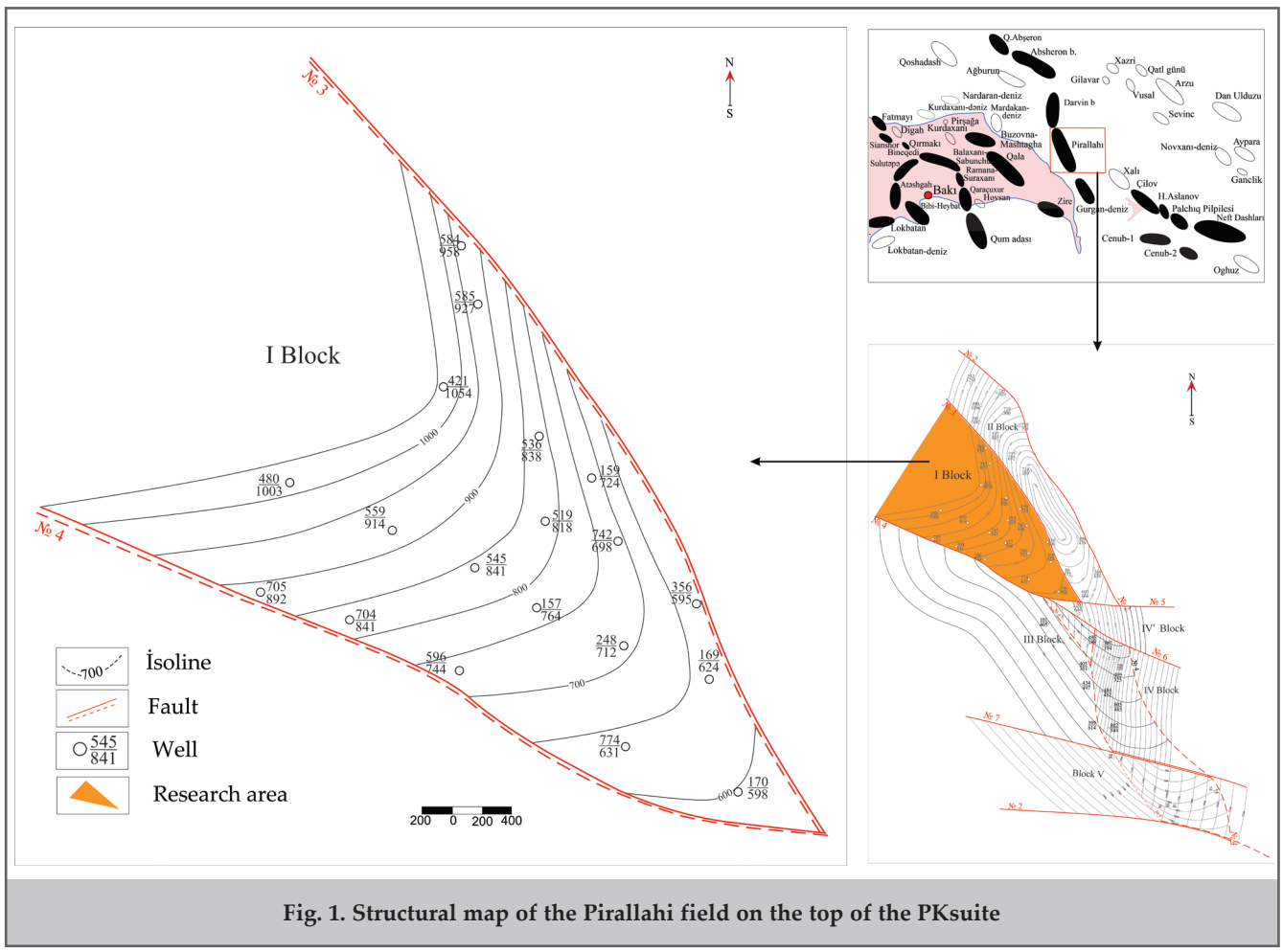


Fig. 1. Structural map of the Pirallahi field on the top of the PKsuite

was first confirmed in 1902 with the completion of well No. 44. Subsequent drilling operations led to the discovery of oil reservoirs within the sub-Kirmaky Suite and the Pre-Kirmaky Suite (PKS) formations [9]

The development and exploitation of the Pirallahi deposit started in the early 20th century, marking it as one of the earliest oil fields in the region. The oil-bearing horizons of the deposit are primarily located in the lower sections of the productive strata, specifically within the Kirmaky Suite and sub-Kirmaky Suite formations. These formations represent the main hydrocarbon reservoirs of the field and have been the focus of extensive exploration and production activities throughout its operational history [10, 11].

Advancements in lithofacies identification techniques have further refined subsurface exploration.

Conventional instance-based methods often overlook sequential well log data, missing essential geological insights. Newer approaches, such as graph-based feature extraction, enable the integration of temporal and spatial relationships within well logs. By aggregating neighboring data points through advanced network layers, these methods enhance the classification process and improve predictive accuracy. When applied to datasets like those from Krishna-Godavari Basin, such techniques outperform conventional models, offering significant potential for application in fields like Pirallahi [12].

The geological structure of the North Pirallahi uplift contains sediments from the Pontian stage to the Absheron stage. This stratigraphic diversity reflects the complex depositional history of the region, influenced by fluctuating sea levels, tectonic movements, and sediment supply variations. Each sedimentary unit contributes uniquely to the reservoir's storage and flow properties, necessitating detailed stratigraphic correlation and facies mapping.

In the central arch of the uplift, like the Garbi Absheron, the Absheron Bank and Darwin Bank, the Productive Series (PS) sediments above Balakhani Suite (BS) are eroded. Consequently, the hydrocarbon reserves in the structure are associated with the Kirmaky Suite (KS), Pre-Kirmaky Suite (PKS), and Kalin Suite (KaS) of the Productive Series (PS) [1]. These suites represent key reservoir intervals, with their depositional and diagenetic characteristics controlling their quality and productivity. Advanced petrophysical analysis and 3D modeling are required to accurately evaluate their potential and optimize extraction techniques.

Research technique

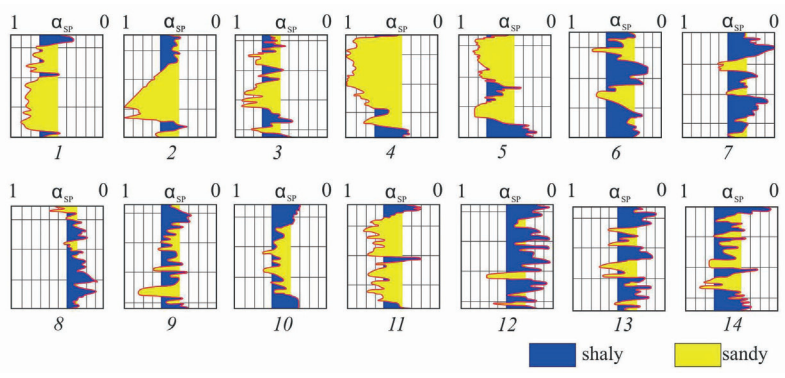
Complex WGS data is generally used to study the vertical and lateral variability of different parameters such as effective porosity, permeability, shale content, oil saturation coefficient, etc., that enables to achieve more accurate results to reconstruct the depositional history, geological structure, and to define the lithofacies features. The accuracy of the results depends on geophysical data quality.

To divide the geological cross-section into lithofacies intervals, resistivity and spontaneous potential (SP) logging data were used. The determination of facies was carried out according to using the methodology described in the works by V. S. Muromtsev [13], A. V. Ejova [14] and N. P. Yusubov [15] (fig. 2).

αsp values obtained from the SP curve were used to reconstruct the paleohydrodynamic environment and determine sedimentary environments. The range αsp=0–0.2 corresponds to shale and shale-siltstone rocks. The range of αsp=0.2–0.4 is character of siltstone and siltstone-shale rocks. The value of αsp=0.4–0.6 corresponds to mixed (sandy-siltstone-shale) rocks.The interval αps=0.6÷0.8 is divided into different amounts of clays and predominantly fine-grained sands, and the interval αps=0.8÷1.0 is divided into coarse-grained and medium-grained sands [16]. αps log curves in 356 wells of the field were analyzed and facies models were determined.

It is known that several factors (grain size, porosity, shale content, degree of mineralization of formation water, composition of drilling fluids, etc.) can affect the shape of logging curves during the interpretation of WGS materials. Therefore, the lithofacies analysis of sedimentary rocks based on the shape of the spontaneous potential (SP) curves can lead to errors.

To obtain more reliable results during the interpretation of WGS curves, it is important to consider how the certain values of effective porosity, and the relative shale content change with depth. In this regard, sand and shale distribution for productive horizons on each well section was determined, systematized and correlation schemes were developed using the complex log diagrams. [17, 18]. The purpose of this research is to monitor the lithofacies variability along the section in the Pirallahi field. The correlation schemes of sediments were developed by analyzing the variation in facies (sandy and shaly) based on the well log indicators across the area and cross-section (fig. 3).



1) channel shallowness of limited meandering rivers;
2) transgressive bars along the coast;
3) facies of channel shallows of intensively meandering rivers;
4) barrier islands;
5) career bars;
6) head sections of fault currents;
7) trough (stormy sands);
8) channel and intra-channel shallowness (trough);
9) water plain of delta complex;
10) river dunes;
11) the submarine slope of a channel or delta complex;
12) sands of floods;
13) shallow-water shelf;
14) submarine plain of the delta complex

Fig. 2. The main types of lithofacies determined on the basis of αsp curves

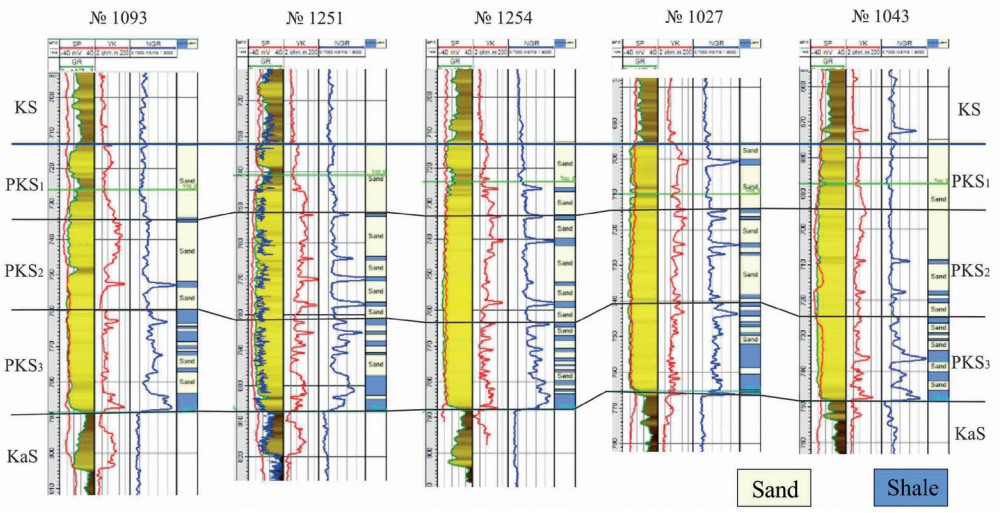


Fig. 3. Lithofacial correlation scheme of PK suite of Pirallahi field

Therefore, it is important to determine the deposition environment in which the layers were formed and spread for their study and analysis. To analyze facies of the Productive Series sediments in the Pirallahi Island field, we considered the facies alternation of different origins from top to bottom along the all well logs drilled in the field. Five wells (1093, 1251, 1254, 1027, 1043) were selected for comparison.

We consider that the PK formation consists of coastal and bar (coastal bar), shallow-water shelf, and delta plain facies, primarily consisted by sand and shale. As it is obvious from the correlation, sand content decreases gradually from top to bottom, while shale materials increase. Based on the lithofacies variability, the PK suite is divided into three horizons: PKS_1, PKS_2, and PKS_3. 80–90% of the PKS_1 horizon is composed of sand, which increases the effective porosity of the layer. This corresponds to the second type of facies (transgressive bars along the coast) shown in figure 2.

Accordingly, the horizon exhibits high oil saturation and oil recovery factors. The PK_2 horizon has a lower sand content than the PK_1 horizon. On average, this horizon on the field has 70–80% sand content. PK_2 corresponds to the facies of channel shallows of intensively meandering rivers and the plain facies of the delta complex (fig. 2, par. 3, 9).

However, the PK_3 horizon has a higher percentage of shale and a lower sand content than two other horizons. This part of the horizon corresponds to the shallow-water shelf facies type (fig. 2, par. 13). The mentioned facies are the main predominant ones, but along with these, other facies are also found in the area.

This regularity was first proven through correlation in the PK suite. In order to trace this pattern across the field, 3D models were created, and individual surfaces were identified and analyzed.

A model was created to follow the distribution across the area (fig. 4). The layer is modeled in the form of several surfaces. The thickness of this layer is 50–70 m and increases in the direction of the buried areas of the fold [19]. According to the structural model and the average thickness of the formation (60 m), it was divided into 60 surfaces (average 1 m). By selecting several surfaces from the obtained ones, we determined the regularity of the lithofacies variation on the field. As is evident from the figure, sandiness decreases from top to bottom. Similarly, the correlation scheme indicates an increase in shale content from top to bottom of the formation. By using the lithofacies model, it becomes possible to track the changes occurring in facies both horizontally and vertically in the field. This provides comprehensive and accurate information, which in turn, affects the location of newly drilled wells and the development process of the project.

Based on both the correlation and the lithofacies model, it is clear that the rocks at the bottom of the layer are fine-grained, and the grain size increases towards the top. In addition, coarse-grained sediments are found in shallower areas than fine-grained sediments [20]. These observations prove the sea depth decreasing during the sedimentation process of the PK suite in the deposit and coastal bars, shallow channels,

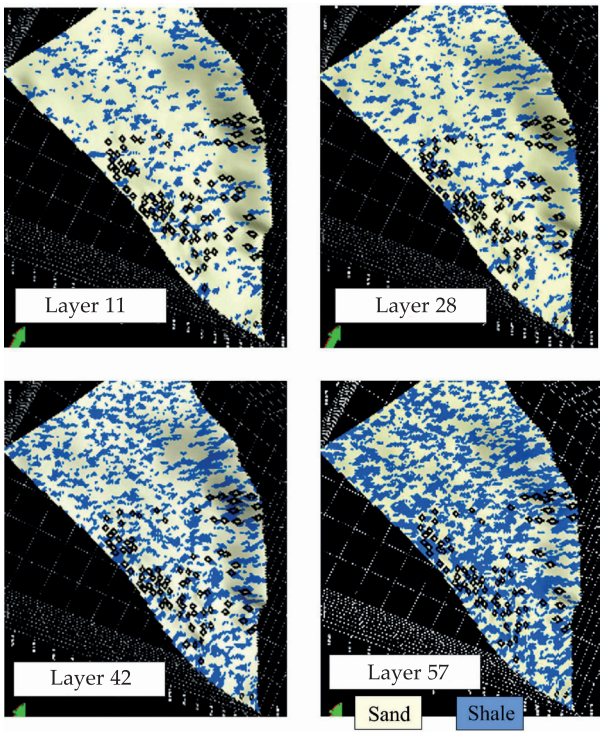


Fig. 4. Litofacies model of PK suite of Pirallahi field

and delta plain facies to the end of the period. Here, the SP curve has a shape corresponding to these facies.

By analyzing the facies characteristics of layers in different wells in the field, we can say that, KS formation is composed of an alternation of fine-grained, gray and brown sands and shales. Solid or loose sandstone layers are often encountered here. Towards the top of the suite, the thickness of the shale layer increases up to 65 m, while towards the bottom, the sand content increases. In the column of this KS suite, we observe a decrease in the amount of shale from top to bottom and an increase in the amount of sand and siltstone and in the composition of this layer we have identified 7 sandy-siltstone horizons separated by shale layers with a thickness of 3-5 m (KS_1, KS_2, KS_3, KS_4, KS_{4a}, KS_5, KS_{5a}). The total thickness of the KS suite ranges from 240 m to 280 m, increasing from the crest to the flanks.

The sediments of the Kirmaky suite formed at low, medium, and high hydrodynamic levels and probably formed in a delta plain and shallow basin environment. About 80–90% of the PK suite is mainly composed of medium and large-grained quartz sand-sandstones and its thickness varies between 50–70 meters from the hinge to the direction of the limbs. This formation is the main oil horizon of the field, containing 66.8% of the first recoverable reserve, and it has been in development for over a century. Here, facies change is related to the horizontal and vertical succession of the stratum in accordance with the rise and fall of the sea level, and this, in turn, creates the concept that the facies and subfacies are genetically related to each other in the sedimentary rock mass.

Conclusions

1. The studied field, despite being in its final development stage, retains sufficient residual oil reserves of practical importance.
2. Facies and lithofacies features of the Lower Pliocene (KS, PKS) sediments were analyzed using geological and WGS data.
3. In the KS suite, the sand ratio increases from top to bottom, with delta plain and shallow-water basin facies predominating.
4. For the first time, the PK suite was divided into three layers by analyzing lithofacies variability.
   - Each layer has distinct facies, with the sand rate decreasing from top to bottom.
   - PKS_1 (80–90% sand) corresponds to transgressive bars along the coast.
   - PKS_2 (70–80% sand) corresponds to the plain facies of the delta complex.
   - PKS_3 (50–60% sand) corresponds to shallow-water shelf facies.
5. A facies model was constructed to trace the distribution of facies across the field.

References

1. Jafarov, R. R., Hajiyev, E. S. (2012). About discovery of new tectonic blocks and stratigraphic sections in the fields under the final stage of development (The example of Darvin bank and Pirallahi island fields). *Azerbaijan Oil Industry*, 9, 5-10.

2. Kerimova, K. A. (2008). Analysis of lithological-facies features of deposits in Productive Series at the Absheron-Pribalkhanskaya uplift zone based on comples of geophysical studies. *Azerbaijan Oil Industry*, 1, 64-69.

3. Baghirov, B. A., Salmanov, A. M., Heydarli, S. O., Rajabli, O. V. (2024) Determining tectonic fault characteristics in oil and gas field structures using juxtaposition diagrams: a case study of the Darvin bank. *SOCAR Proceedings*, SI1, 1-6.

4. Alizadeh, A., Guliyev, I., Mamedov, P., et al. (2024). Pliocene hydrocarbon sedimentary series of Azerbaijan. *Springer*.

5. Ma, Y. Z. (2019) Quantitative geosciences: data analytics, geostatistics, reservoir characterization and modeling. *Springer*.

6. Heydarli, S. O. (2022). Contemporary problems of long-developed deposits and solved issues (on the example of Darwin, Pirallahi, Gurgan deposits). *Scientific Petroleum*, 1, 36–41.

7. Heydarli, S. O. (2022). Specification of structural-tectonic configuration and geological risks in the estimation of reserves in Darvin kupesi field. *Azerbaijan Oil Industry*, 3, 4–9.

8. Kerimov, S. V., Suleymanova, V. M., Heydarli, S. O. (2022). Refinement of the structure of the Pirallahi-south area and the prospects for oil and gas potential of the Qala Suite. *Scientific Petroleum*, 1, 25–30.

9. Ismailov, F. S., Salmanov, A. M., Maharramov, B. I., Shakarov, H. I. (2024). Oil-gas fields and prospective structures of Azerbaijan. Vol. 1. *Baku: MSV press.*

10. Ismailov, N. M., Rzayeva, F. M. (1998). Biotechnology of oil production. Principles and application. *Baku: Elm*.

11. Eminov, A. Sh., Suleymanova, V. M., Heydarli, S. O., Jabizade, N. I. (2022). Determination of properties of tectonic faults on the basis of cluster analysis (on the example of the Darwin bank field). *PAHTEI Proceedings of Azerbaijan High Technical Educational Institutions*, 8, 58-65..

12. Deepan, D., Mamata, J., Aurobinda, R., Sanjai, K. S. (2024). Enhancing lithofacies interpretation in well logs with graph-based feature extraction. *IEEE Geoscience and Remote Sensing Letters*, 21, 3003005.

13. Muromtsev, V. S. (1984). Electrometric geology of sand objects of oil-gas lithological traps. *Leningrad: Nedra.*

14. Yezhova, A. V. (2009). Lithology: a textbook. 2nd ed. *Tomsk: Tomsk Polytechnic University.*

15. Yusubov, N. P., Guliyev, I. S. (2015). Lithologic-facies models of Garadagh, 8 Marta, Sangachal-Deniz, Duvanny-

Deniz, Bulla Adasi and Bulla-Deniz fields, confined to Pereriva Suite on well logging data. *Azerbaijan Oil Industry*, 5, 3-8.

16. Shikhova, L. F. (2017). Litho-facial models of Pirallahi field's oil deposits on geophysical well logging data. *Geophysical Journal*, 39(2), 126-136.

17. Gurbanov, V. Sh., Sultanov, L. A. (2019). Petrophysical aspects of deep reservoirs in the Absheron and Baku archipelago. *Perm Journal of Petroleum and Mining Engineering*, 19(3), 204-215.

18. Gurbanov, V. Sh., Mustafayev, Y. R., Heydarli, S.O. (2022). Clarification and comparison of lithofacies properties of complex-structural deposits (on the example of the deposits of Darwin Bank and Pirallahi Island). *Perm Journal of Petroleum and Mining Engineering*, 22(4), 152-157.

19. Kheyirov, M. B., Khalilova, L. N. (2006). Reservoir properties of sandy-silty rocks of the upper part of the PT of the Northern Absheron uplift zone. *Azerbaijan Oil Industry*, 8, 4-11.

20. Naghiyev, X. V. (2004). Lithofacies and collector features of Productive Series sediments in the Northern Absheron uplift zone. *Azerbaijan Oil Industry*, 8, 4-7.