

Criteria and Cutoff Values for Distinguishing Reservoir Rocks in Deeply Buried Zones of the South Caspian Basin

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Abstract. Reliable discrimination between reservoir and non-reservoir rocks is essential for reserve estimation and field-development planning in the deeply buried productive intervals of the South Caspian Basin. This study evaluates lithological and petrophysical data from the Gunashli, Bahar, and Bulla-Deniz fields to define field-specific cutoff values for porosity, permeability, clay content, and carbonate content. The dataset comprises core descriptions and laboratory measurements from productive-series deposits, including 270 samples and more than 1,200 determinations from Gunashli, horizon-specific core datasets from Bahar, and 47 core samples from Bulla-Deniz. Distribution curves, cross-parameter comparisons, and reservoir/non-reservoir classifications were used to identify threshold values. At Gunashli, the porosity distributions of reservoir and non-reservoir rocks intersect at approximately 10%, while a 9% operational boundary is supported by the broader dataset. For the Bahar productive intervals, porosity cutoffs are generally about 8% and permeability cutoffs about $0.003 \mu\text{m}^2$. For sandy-silty rocks of Bulla-Deniz Horizons V and VII, the adopted criteria are porosity greater than 7.5%, permeability greater than 1 mD, carbonate content below 20%, and clay content below 36%. The results demonstrate that cutoff values are not universal constants; they must be calibrated to lithofacies, burial depth, analytical scale, and production context.

Keywords: South Caspian Basin, reservoir rock, porosity cutoff, permeability cutoff, clay content, carbonate content, core analysis

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Cənubi Xəzər hövzəsinin dərin yatımlı zonalarında kollektor süxurların fərqləndirilməsi üçün meyarlar və sərhəd qiymətləri

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Xülasə. Kollektor və qeyri-kollektor süxurların etibarlı şəkildə fərqləndirilməsi Cənubi Xəzər hövzəsinin dərin yatımlı məhsuldar intervallarında ehtiyatların hesablanması və yataqların işlənmə layihələrinin hazırlanması üçün mühüm əhəmiyyət daşıyır. Tədqiqatda Günəşli, Bahar və Bulla-Dəniz yataqlarına aid litoloji və petrofiziki məlumatlar təhlil edilərək məsaməlilik, keçiricilik, gillilik və karbonatlılıq üzrə yatağa xas sərhəd qiymətləri müəyyənləşdirilmişdir. Məlumat bazasına Günəşli yatağından 270 kern nümunəsi və 1200-dən artıq laboratoriya təyini, Bahar yatağı üzrə horizontlara

aid kern məlumatları, həmçinin Bulla-Dəniz yatağından 47 kern nümunəsi daxildir. Sərhəd qiymətlərinin əsaslandırılması üçün paylanma əyrilərindən, parametrlərarası müqayisələrdən və süxurların kollektor və qeyri-kollektor qruplarına ayrılmasından istifadə edilmişdir. Günəşli yatağında kollektor və qeyri-kollektor süxurların məsaməlilik paylanmaları təxminən 10% səviyyəsində kəşisir, geniş məlumat bazası isə 9%-lik əməli sərhədi dəstəkləyir. Bahar yatağında məsaməlilik üçün ümumi sərhəd təxminən 8%, keçiricilik üçün isə 0,003 μm^2 -dir. Bulla-Dəniz yatağının V və VII horizontlarında məsaməlilik >7,5%, keçiricilik >1 mD, karbonatlılıq <20% və gillilik <36% meyarları qəbul edilmişdir. Nəticələr göstərir ki, sərhəd qiymətləri universal deyil və litofasial xüsusiyyətlər, yatım dərinliyi, analiz miqyası və hasilat şəraiti nəzərə alınmaqla kalibrlənməlidir.

Açar sözlər: Cənubi Xəzər hövzəsi, kollektor süxur, məsaməlilik sərhədi, keçiricilik sərhədi, gillilik, karbonatlılıq, kern analizi

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Introduction

The identification of net reservoir intervals is a central task in petroleum geology because the selected cutoff values directly affect net-to-gross ratio, volumetric reserve estimates, well placement, completion design, and development economics. A cutoff is not merely a descriptive threshold; it is a decision boundary linking geological observations to engineering and economic performance. Consequently, no single porosity or permeability limit can be transferred uncritically from one field or horizon to another (Worthington & Cosentino, 2005; Worthington, 2010).

This problem is especially important in the South Caspian Basin, where productive-series reservoirs occur at considerable burial depths and are affected by rapid facies variation, tectonic compartmentalization, mud volcanism, compaction, cementation, and variable clay content. These factors modify pore structure and fluid-flow capacity and may cause rocks with similar porosity to exhibit markedly different permeability. Regional geological syntheses emphasize the heterogeneity and complex petroleum systems of the basin (Ali-Zade et al., 1972; Guliyev et al., 2014; Kocharli, 2015; Yusifov & Aslanov, 2018).

The objective of this study is to compare the lithological and reservoir properties of deeply buried Productive Series rocks in the Gunashli, Bahar, and Bulla-Deniz fields and to determine practical cutoff values for porosity, permeability, clay content, and carbonate content. The study also clarifies how these thresholds should be interpreted when geological reserves are estimated and field-development decisions are made.

Materials and Methods

The analysis used core descriptions, grain-size measurements, porosity and permeability tests, carbonate-content determinations, and clay-content data from productive intervals of the three fields. At Gunashli, 270 core samples recovered from the 1,700–4,760 m interval in exploration Wells 1, 2, 3, 4, 5, 6, 11, 14, 15, 16, 18, 21, 22, and 23 were evaluated. More than 1,200 laboratory determinations were available. The Bahar dataset was grouped by Horizons VI–X, the Fasila Suite, and NKP. At

Bulla-Deniz, 47 core samples from 15 wells were analyzed for porosity, permeability, carbonate content, and clay content.

Reservoir and non-reservoir populations were compared using frequency distributions and parameter relationships. A cutoff was selected at the intersection or practical separation point of the two populations and was checked against horizon-specific lithology and available field evidence. Because permeability is strongly scale- and facies-dependent, it was evaluated together with porosity and clay content rather than as an isolated variable. Statistical and fuzzy-regression approaches are useful for representing the uncertainty inherent in deep-reservoir property estimation (Gurbanov et al., 2022). Porosity is reported as a percentage. Permeability is reported in μm^2 or millidarcies (mD), following the units in the source datasets; 1 μm^2 is approximately 1,013 mD. Clay and carbonate contents are expressed as weight percentages. For quality-control purposes, higher porosity and permeability were treated as favorable, whereas higher clay and carbonate contents were treated as limiting factors. The resulting thresholds were interpreted as field-specific operational criteria rather than universal constants.

Results

Regional and Field Setting

Gunashli lies in the southeastern part of the Absheron Archipelago, approximately 120 km from Baku and 12 km southeast of Neft Dashlari. The structure is associated with the Absheron–Pribalkhan tectonic zone and is affected by mud volcanoes and transverse faults. Bahar occupies a transitional structural zone and is divided by longitudinal and transverse faults into tectonically sealed blocks. Bulla-Deniz is situated in the northern Baku Archipelago on the Kanizadag–Babek anticlinal trend. These structural differences provide an important geological context for the observed variation in reservoir quality.



Figure 1

Regional overview of the Gunashli, Bahar, and Bulla-Deniz area in the Azerbaijani sector of the Caspian Sea

Note. Field names on the source map are shown in Russian; the figure is reproduced from the material supplied by the authors.

Gunashli Field

The Productive Series at Gunashli consists of interbedded clay, sand, sandstone, and siltstone. The principal development targets are the Fasila Suite and Horizon X, which contain most of the field's reported oil reserves. Grain-size analysis showed that 78 of the recovered samples contained more than 50% clay and were therefore classified as clay rocks. Sandy-clayey siltstone represented more than 70% of the determinations, whereas silty sand represented approximately 20%. Porosity in sandy-silty rocks ranges from 4% to 40%, with horizon averages of 12–22%. The reservoir and non-reservoir distribution curves intersect at approximately 10%; this value represents the graphical separation point. A 9% porosity value was retained as the operational boundary when the wider dataset and sampling variability were considered. Permeability ranges from 0.001 to 1.730 μm^2 . The highest mean values occur in the Fasila Suite (0.180 μm^2) and Horizon X (0.108 μm^2). Carbonate content is comparatively restricted: more than 80% of measurements are below 14%, and suite averages are 8–11%.

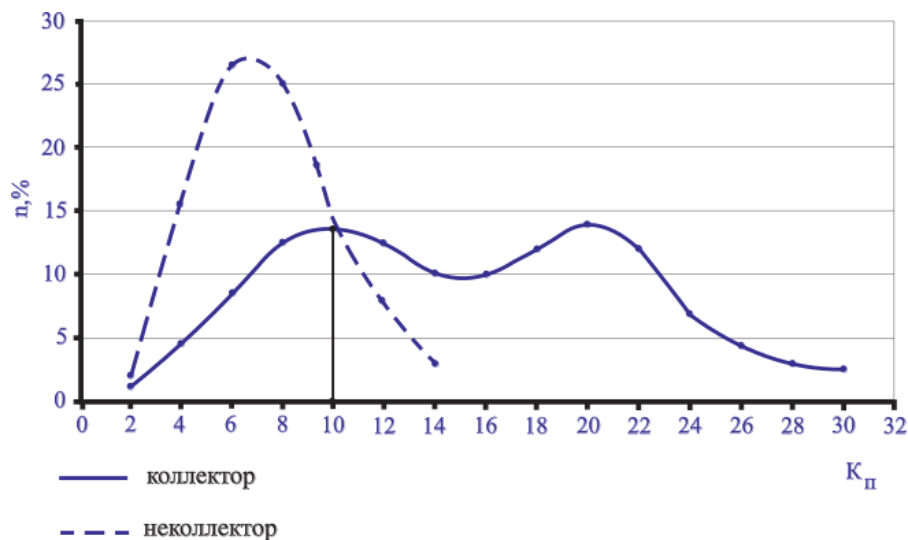


Figure 2

Porosity-distribution curves for reservoir and non-reservoir rocks at Gunashli

Note. The solid curve represents reservoir rocks and the dashed curve represents non-reservoir rocks. The vertical line marks the approximate 10% intersection point.

Bahar Field

The Bahar succession includes recent, Ancient Caspian, Absheron, Akchagyl, and Productive Series deposits. Productive intervals are composed of interbedded sand, sandstone, siltstone, and clay. Across the studied section, average clay content is 22.4%, although individual horizons and wells contain values exceeding 40%. Average carbonate content generally ranges from 7.2% to 11.3%. Porosity commonly lies between 8% and 24%, while permeability varies from 1 to $500 \times 10^{-15} \text{ m}^2$. The mean permeability values calculated from available core samples are $51 \times 10^{-15} \text{ m}^2$ for Horizon VI, $141 \times 10^{-15} \text{ m}^2$ for Horizon VII, $74 \times 10^{-15} \text{ m}^2$ for Horizon IX, $69 \times 10^{-15} \text{ m}^2$ for Horizon X, and $53 \times 10^{-15} \text{ m}^2$ for the Fasila Suite.

Table 1*Operational cutoff values for Bahar reservoir rocks by horizon*

Horizon	Porosity, %	Permeability, μm^2	Maximum clay content, %	Maximum carbonate content, %
VI	≥ 8	≥ 0.003	30	18
VII	≥ 8	≥ 0.003	28	22
VIII	≥ 8	≥ 0.003	32	18
IX	≥ 8	≥ 0.003	36	20
X	≥ 8	≥ 0.003	28	20
Fasila Suite	≥ 8	≥ 0.003	26	18
NKP	≥ 8	≥ 0.003	28	14

Bulla-Deniz Field

At Bulla-Deniz, the main development targets are Horizons V, VII, and VIII. The upper part of the section is dominated by Quaternary, Absheron, and Akchagyl clays with thin sandstone interbeds and has limited commercial significance. The 47 analyzed core samples were divided into reservoir and non-reservoir groups; 25 samples were classified as reservoir rocks and 22 as non-reservoir rocks. For the sandy-silty rocks of Horizons V and VII, the adopted limits are porosity greater than 7.5%, permeability greater than 1 mD, carbonate content below 20%, and clay content below 36%.

Table 2*Reservoir properties of Bulla-Deniz Horizons V and VII*

Horizon	Parameter	No. of analyses	Observed range	Mean
V	Porosity, %	36	8.9–23.4	14.6
V	Permeability, mD	22	4–100	27
V	Carbonate content, %	38	2.5–18.5	10.7
V	Clay content, %	34	3.5–49.4	26.6
VII	Porosity, %	9	15.8–18.3	17.2
VII	Permeability, mD	7	20–76	42
VII	Carbonate content, %	11	6.5–16.2	11.7
VII	Clay content, %	10	5.4–45.5	18.3

Only ten wells penetrated Horizon VIII. Because its direct dataset is limited, the preliminary criteria were adopted by analogy with the lithological and reservoir properties of the nearby Sangachal–Duvanny–Khara-Zira field. This transfer should be treated cautiously and updated when additional core, well-log, and production-test data become available.

Discussion

The results confirm that reservoir cutoffs in the South Caspian Basin are field- and horizon-dependent. Gunashli shows a porosity separation near 9–10%, Bahar commonly uses an 8% porosity and $0.003 \mu\text{m}^2$ permeability boundary, and Bulla-Deniz uses a lower porosity threshold of 7.5% with a permeability threshold of 1 mD. The differences reflect lithofacies, burial history, pore-throat geometry, diagenesis, clay distribution, and the scale of measurement. They should not be interpreted as analytical inconsistency.

Cutoffs must also be linked to the purpose of the study. Geological cutoffs identify rock capable of storing hydrocarbons, while dynamic or economic cutoffs identify intervals capable of producing at technically and economically acceptable rates. Integrated reservoir studies therefore require joint interpretation of core, well-log, pressure, fluid, production, and economic data (Worthington & Cosentino, 2005; Worthington, 2010). A single threshold based only on porosity may overestimate net reservoir thickness in clay-rich intervals or underestimate fractured and low-porosity productive rock.

The deep burial and structural complexity of the studied fields increase uncertainty. High pressure, temperature, corrosion risk, sand production, and equipment limitations complicate development of difficult wells (Humbatova, 2025). At the same time, mathematical modeling of production trends can connect static reservoir classification with expected field performance and resource-management decisions (Humbataliyev et al., 2025). These considerations support periodic recalibration of cutoffs as new core, log, pressure, and production data become available.

The main limitation of the present analysis is the unequal sample density among fields and horizons. Gunashli is supported by a substantially larger dataset than Bulla-Deniz Horizon VIII. In addition, some source measurements use different permeability units and analytical scales. Future work should harmonize units, integrate routine and special core analysis with calibrated well logs, quantify uncertainty around each cutoff, and validate classifications against well tests and sustained production.

Conclusion

The study establishes practical criteria for distinguishing reservoir from non-reservoir rocks in deeply buried Productive Series deposits of the Gunashli, Bahar, and Bulla-Deniz fields. The principal findings are as follows:

1. At Gunashli, reservoir and non-reservoir porosity distributions intersect at approximately 10%, while 9% is a defensible operational boundary for the broader dataset.
2. At Bahar, the principal productive intervals generally support a porosity cutoff of about 8% and a permeability cutoff of about $0.003 \mu\text{m}^2$, with horizon-specific limits for clay and carbonate content.
3. At Bulla-Deniz, Horizons V and VII are classified using porosity $>7.5\%$, permeability $>1 \text{ mD}$, carbonate content $<20\%$, and clay content $<36\%$.
4. Cutoff values must be calibrated by field and horizon and updated through integrated core, log, pressure, and production analysis.

Data Availability

The study is based on the core-analysis and field materials supplied by the authors and on the published sources cited in the reference list.

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