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Provenance and petroleum potential of oil-bearing rocks in the Beridash field (Southern Gobustan, Azerbaijan): A mineralogical and geochemical assessment

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ABSTRACT

This research presents a complex formational analysis of the extensively exposed Lower Pliocene Productive Series (PS) unconventional reservoir rocks in the Beridash field (Southern Gobustan, Azerbaijan). Utilizing lithological, mineralogical, and geochemical proxies, the study assesses their sedimentary environment, provenance, and petroleum potential, emphasizing the mineralogical control on hydrocarbon accumulation.

Problem statement: Despite Azerbaijan's extensive conventional hydrocarbon extraction, unconventional oil-bearing surface exposures remain geologically underexplored. A comprehensive formational, mineralogical, and geochemical characterization is required to determine the primary factors controlling hydrocarbon enrichment within these specific stratigraphic units.

Purpose: This research aims to delineate the provenance and hydrocarbon potential of the Beridash field through an integrated mineralogical and geochemical assessment, with a specific focus on the mechanisms controlling oil enrichment.

Methods: The analytical methodology integrated detailed surface mapping, mineralogical characterization via X-ray diffraction (XRD), and geochemical assessment of major

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oxides using X-ray fluorescence (XRF) and ICP-MS. Oil content was calculated gravimetrically following moisture correction.

Results: Detailed surface mapping identified eight distinct, predominantly calcareous oil-bearing sand and sandstone units localized within the 1245–1480 m stratigraphic interval from the top of the Lower PS. Mineralogically, the rocks represent a mixed carbonate-terrigenous sequence dominated by calcite (avg. 24.97%) and quartz (avg. 23.57%), alongside clay minerals. Geochemical proxies indicate deposition in a shallow marine-lagoonal environment along an active continental margin from mixed felsic and mafic sources. The average oil content is 7.64%, increasing from northwest to southeast. A weak correlation ($r = 0.02$) between moisture (avg. 1.14%) and oil saturation demonstrates that mineralogy, specifically the ratio of fluid-blocking clays to brittle minerals, acts as the primary control on hydrocarbon accumulation.

Conclusions: Based on extensive surface mapping, the eight delineated calcareous sand and sandstone units represent a highly promising non-conventional hydrocarbon resource. Their specific provenance has produced a mineralogical framework highly conducive to hosting hydrocarbons, functioning largely independent of moisture influence. These findings provide a robust formational evaluation model for regional non-conventional resources.

Keywords:

Azerbaijan, Productive Series, oil-bearing rocks, mineralogy, geochemistry, provenance, oil enrichment, moisture, petroleum potential.

Introduction and current state of research

Given the declining dynamics of Azerbaijan's nearly two-century-old conventional oil and gas production, attention has increasingly shifted toward unconventional hydrocarbon resources [11–13; 15; 28; 30; 32; 41; 45; 46]. In this regard, oil shales and oil-bearing rocks, exhibiting substantial prospective resources across more than a hundred surface exposures, are of particular importance [2; 3; 8–10; 36]. In recent years, based on complex geological, mineralogical, and geochemical studies, extensive research has been conducted not only on the genesis of oil shales but also on the potential for obtaining synthetic hydrocarbons (shale oil and shale gas) from kerogen-rich sediments of low thermal maturity [1; 4]. However, except for a few recent studies [e.g., 19], oil-bearing rocks remain poorly investigated. Previous works have primarily focused on the geological characteristics of oil bearing areas, including the evaluation of effective reservoirs and the preliminary study of certain physicochemical parameters of the rocks [5; 7; 37; 43]. Nevertheless, the provenance of these heavy hydrocarbon-bearing sediments that evolved from the Miocene to the Pliocene, and particularly the factors controlling hydrocarbon enrichment, have been insufficiently assessed compared to countries such as Canada and Venezuela, where this field is considerably more advanced [22; 26; 27; 44].

The present study, for the first time, investigates the formation conditions and hydrocarbon potential of oil-bearing rocks widely exposed at the surface within the Beridash area of the Shamakhi-Gobustan oil-gas-bearing region in Eastern Azerbaijan, based on comprehensive geological, mineralogical, and geochemical analyses.

Geological framework of the study area.

The location of Eastern Azerbaijan within the collision zone of the African and Arabian

plates facilitated the accumulation of organic-rich sediments (mainly from the Middle Eocene to the Upper Miocene), their transformation into hydrocarbons, and the vertical migration of these hydrocarbons, which primarily accumulated in the productive Pliocene deposits, particularly creating favorable conditions for the formation of mud volcanoes [14; 16–18; 20; 21; 34; 39; 40]. Tectonic activity provided conditions for the uplift of layers composed of immature source rocks (mainly oil shales) and hydrocarbon-bearing sediments to the surface across tectonic zones with varying geological settings. Such zones generally differ significantly in terms of the size and activity of mud volcanoes.

The Beridash area, identified within the southern segment of Eastern Azerbaijan, is characterized by numerous oil-bearing outcrops extending southeastward from the Durandagh mud volcano toward the Gotur mud volcano (Fig. 1). Historically, based on extensive surface mapping supplemented by shallow exploratory pitting and trenching, the Beridash area has been classified and documented as a distinct oil-bearing field in classical regional geological literature [5–7; 42]. Given the current absence of deep exploratory wells, the structural geometry of the area is primarily delineated through these surface investigations.

From a tectonic perspective, the Beridash structure is situated along a major anticlinal axis identified in the Gobustan region [7]. This tectonic feature, known as the Alat Ridge, separates two structural zones – Gobustan and Southeastern Shirvan. Along this tectonic line, several anticlines such as Alat, Dashgil-Dilangaz, Gyrdagh, Goturdagh, Ayrantoken, and Solakhay have been identified, most of which are characterized by numerous oil-bearing outcrops.

Structurally, the northwest-southeast trending Beridash structure is oriented almost transversely, forming the western undulation of the Alat Ridge anticlinal line. Similar to other structures along this ridge, Beridash is markedly

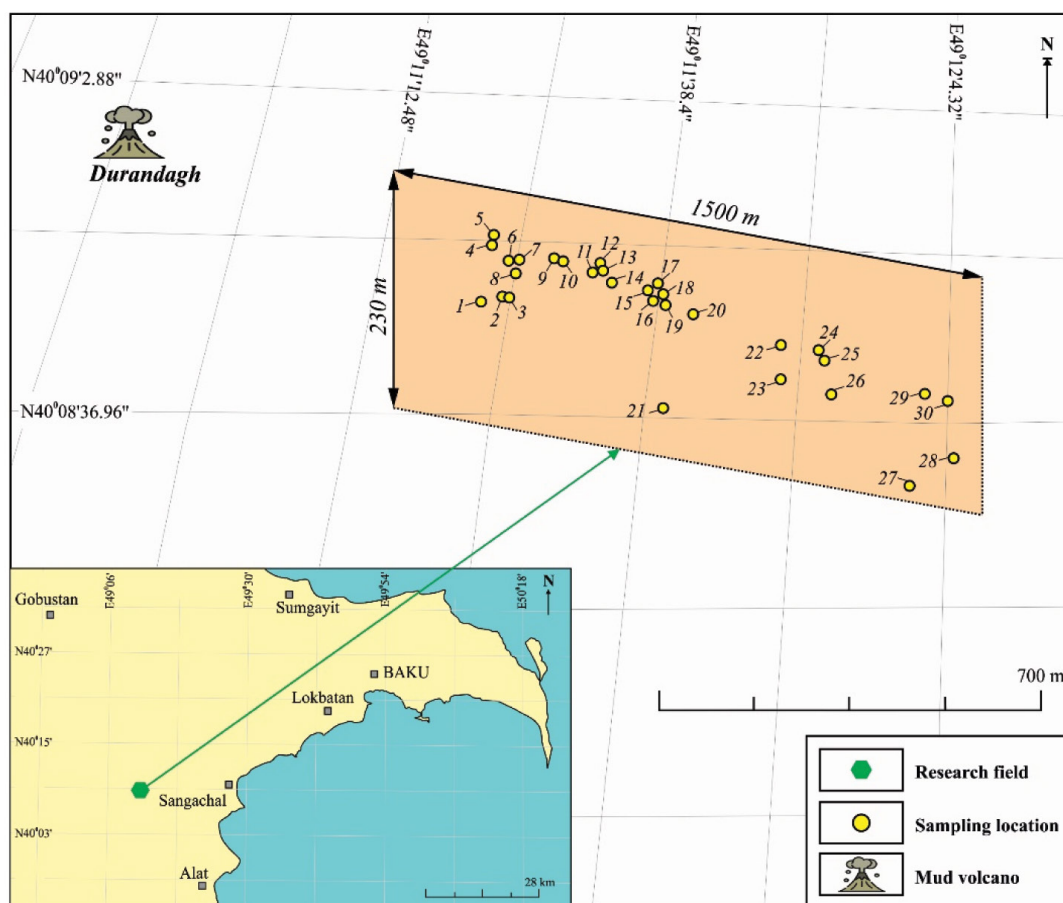


Fig. 1. Location map of study areas

asymmetric: its northern limb dips at angles of 40-60°, while the southern limb is steeply inclined, reaching angles of 80-85°, and is prone to overturning in several areas. The oil-bearing rocks of Beridash, constrained by the Alat Ridge to the northwest, are associated with several tectonic dislocations. The most prominent of these occurs on the northern limb of the structure, characterized by a significant downthrow of 100-120 m. Associated with these structural features, the exposed sequence comprises multiple parallel oil-bearing beds. As documented in historical records, these strata are specifically localized in the lower part of the Productive Series section, within the interval of 1245-1480 m from its roof. Within this specific package, the most massive and significant hydrocarbon accumulations are distinguished primarily by their considerable thickness.

The geological structure of the area, mapped as a surface representation of the formational boundaries, comprises the PS and Aghchagil deposits of the Pliocene, as well as Quaternary sediments (Absheron and Lower Caspian) and mud-volcano breccias (Fig. 2).

Lower Pliocene PS deposits associated with oil-bearing rocks are exposed on both limbs of the anticline, including its crest. These deposits consist

mainly of clays, sands, and siltstones. Overall, the Pliocene strata that host hydrocarbons in the uplifted zone have undergone extensive erosion. The thickness of the PS in this area ranges from 1500 to 1800 m. The Aghchagil deposits are observed along a relatively narrow belt, with thicknesses varying between 50 and 60 m. They are characterized by an alternation of gray clays and sands. The Absheron deposits, together with the lithofacies of the Lower Caspian, are exposed on the southern limb of the anticline. These sediments, composed of limestones, sands, and clays, generally do not exceed 60 m in thickness. Additionally, a prominent layer of mud-volcano breccia, reaching a thickness of 50-60 m, is widely distributed at the base of the localized sections.

Exposures of oil-bearing rocks

Field investigations conducted over an area of 62 hectares identified extensive surface outcrops of oil-bearing rocks beginning approximately 700 m southeast of the Durandagh mud volcano's crater zone.

In the lower exposed part of the PS, a 221.9 m thick section comprising 27 alternating layers has been identified, characterized by a frequent and monotonous interbedding of clays, sands, silts and

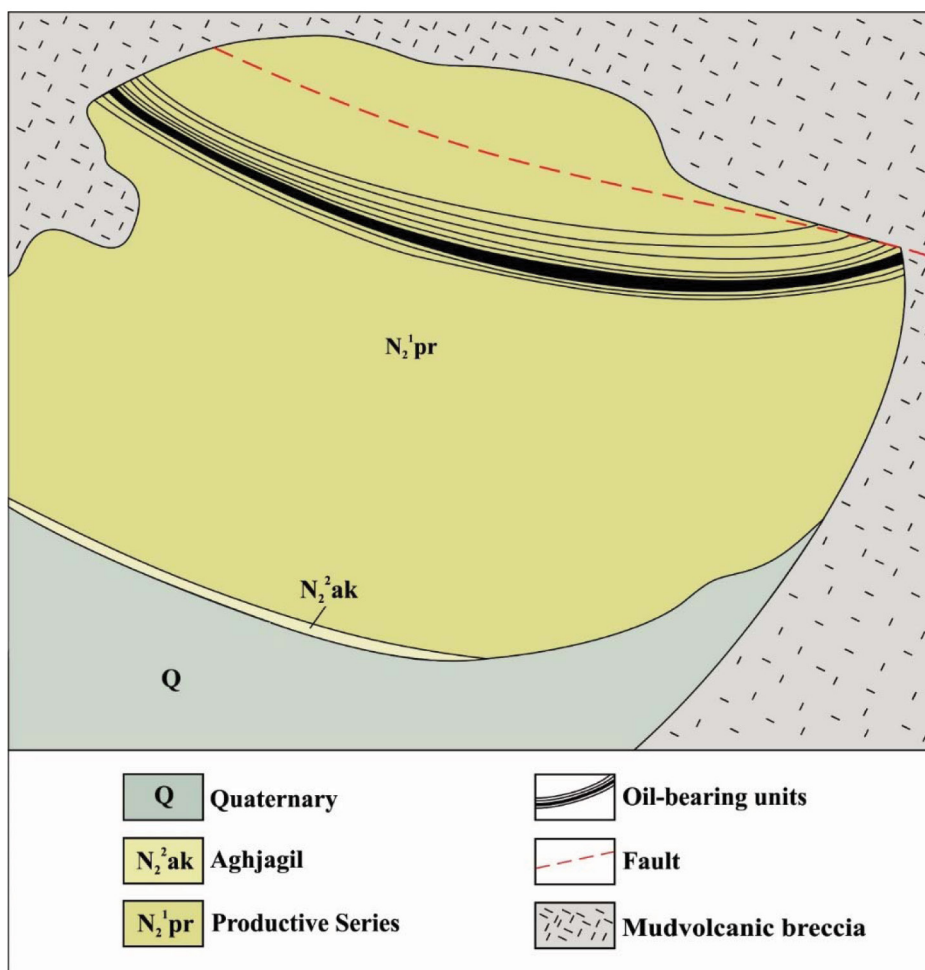


Fig. 2. Surface geological map of the Beridash area, illustrating the distribution and formational boundaries of the Lower Pliocene PS, the main tectonic fault, and prominent outcrops of the oil-bearing strata (modified from [43])

sandstones. While the overall sequence maintains a predominantly clayey character, the sandy and silty lithotypes within this section exhibit a distinctly calcareous composition. Within this sequence, specifically localized in the stratigraphic interval between 1245 m and 1480 m from the top of the PS, eight primary oil-saturated units, separated by predominantly clayey and silty inter-layers, are delineated (Fig. 3) [43]. These units possess a cumulative thickness of 57 m and demonstrate remarkable lateral persistence for up to 1 km.

Visually, Unit 1 and Unit 2 consist of brown, fine-grained sandstones. Unit 3 and Unit 4 are represented by brownish-grey and brown, fine-to-medium grained sands. Notably, Unit 3 exhibits the most pronounced visual oil saturation and thickness, with individual oil-saturated layers in this part of the section reaching up to 26 m (Fig. 4). The sequence continues with Units 5, 6, and 7, which are dominated by brownish-grey to brown, fine-grained, loose sands, and is terminated at the base by Unit 8, identified as a brownish-grey, and poorly sorted sandstone. Overall, despite their primary colors, many of these units appear dark

brown to nearly black in the field due to heavy oil impregnation and surface bitumen tarring. The base of the entire exposed sequence is marked by a massive, 150-170 m thick clay-shale package, which contains thin (0.3-0.5 m) lenses and interlayers of fine-grained sand and sandstone [43].

Samples and analyzes

Thirty oil-bearing rock samples were collected from the study area for analytical investigation (Fig. 1), with select visual characteristics presented in Table 1.

Chemical composition was analyzed using both an S8 TIGER Series 2 and an Agilent 7700 Series ICP-MS, while mineralogical characteristics were determined using a MiniFlex 600 X-ray diffractometer.

The oil content was determined by gradual heating of the samples in an oven and calculated from the total weight loss after moisture correction, following the procedure described by [25].

Sample moisture was measured by oven drying in the same institute according to ASTM D2216.

Table 1

Visual characteristics of selected oil-bearing rock samples

Sample	Image	Description
B-5		Carbonate-sandy rock with low clay content. Emits a weak oil odor
B-7		Carbonate-sandy rock showing an oil scent
B-12		Carbonate-sandy rock exhibiting higher oil saturation
B-19		Light-colored carbonate-sandy rock with a weak oil scent
B-25		Carbonate-bearing sandstone, readily splitting along parallel surfaces and exhibiting a pronounced oil
B-30		Poorly compacted carbonate-sandy rock with a detectable oil scent

Mineralogical analysis

Eight minerals from different classes were identified (Table 2). Among silicates, quartz accounts for an average of 23.57%, while feldspars average 15.6%. The carbonate fraction is dominated by calcite, with a mean concentration of 24.97%. Clay minerals, including montmorillonite (9.6%), kaolinite (8.3%), and illite (4.43%), collectively comprise an average of 22.33% of the samples. Other components include hematite (6.3%) and gypsum (0.23%). Overall, the mineral distribution in terms of concentration follows the order: calcite > quartz > feldspar > montmorillonite > kaolinite > hematite > illite > gypsum.

Mineralogical classification indicates that, due to the high content of calcite (see Table 2), the studied rocks are not exclusively siliceous but also exhibit a tendency toward carbonate lithotypes (Fig. 5).

Major oxides

Based on chemical composition analysis, the samples contain average concentrations of 44.77% SiO₂, 9.98% Al₂O₃, 6.75% Fe₂O₃, 16.22% CaO, 2.03% Na₂O, 1.68% K₂O, 2.34% MgO, 0.19% MnO, 0.52% SO₃, 0.72% TiO₂, 0.15% P₂O₅, 0.11% BaO, and 0.08% SrO (Table 3). The following abundance sequence of major oxides is established: Si > Ca > Al > Fe > Mg > Na > K > Ti > S > Mn > P > Ba > Sr

Provenance

The observed mineral assemblage, dominance of calcite, substantial quartz and feldspar, plus clay minerals such as montmorillonite, kaolinite, and illite, with minor hematite and gypsum (see Table 2), is consistent with deposition in a shallow marine-lagoonal environment under oxidizing, low-to-moderate weathering conditions [e.g., 48; 49].

The positioning of the samples in the Wacke – Shale – Fe-shale range on the log (Fe₂O₃/K₂O) vs. log (SiO₂/Al₂O₃) diagram (Fig. 6A) indicates a mixed provenance with moderate chemical weathering. It suggests contributions from both felsic and mafic sources, reflecting an intermediate tectonic setting. Furthermore, the geochemical classification diagram based on log (Na₂O/K₂O) vs. log (SiO₂/Al₂O₃) (Fig. 6B) shows their location at the intersection of the Greywacke and Litharenite fields, reflecting

Distance from the top of the Lower PS, m	Lithological column	Description
1240		Silt
		Unit 1. Brown fine-grained sandstone
1250		Clay
1260		Unit 2. Brown fine-grained sandstone
1270		Clay
1280		
1290		Unit 3. Brownish-grey, fine- to medium-grained sand
1300		Clay
1310		Unit 4. Brown to brownish-grey, fine- to medium-grained sand
1320		Clay
		Unit 5. Brownish-grey, fine-grained, loose sand
1330		Clay
1340		Silt
1350		Clay
1360		Silt
1370		Clay
		Unit 6. Brownish-grey to brown, fine-grained, loose sand
1380		Clay
1390		Silt
1400		Clay
1410		Silt
1420		Clay
1430		Unit 7. Brown, fine-grained, loose sand
1440		Clay
1450		Silt
		Clay
1460		Silt
		Clay
1470		Unit 8. Brownish-grey sandstone
1480		Silt

Fig. 3. Lithological-stratigraphic column of the Lower Pliocene Productive Series (PS) oil-bearing sequence at the Beridash area, showing the eight primary units identified within the 1245–1480 m interval from the top of the PS [43]

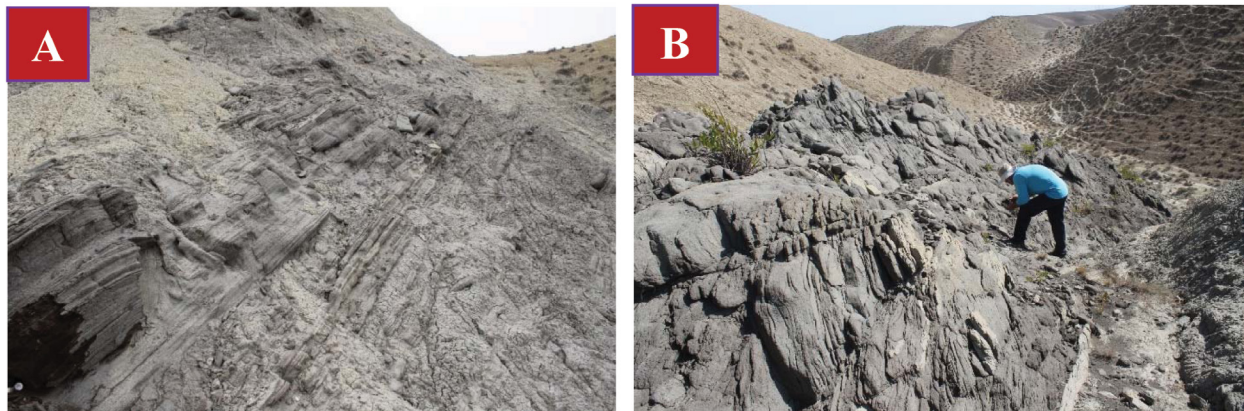


Fig. 4. Field photographs showing the surface exposures of the principal, massive oil-bearing stratum in the Beridash area

Table 2

Mineralogical characteristics of the samples (%)

Sample	Quartz	Feldspar	Calcite	Montmorillonite	Kaolinite	Illite	Hematite	Gypsum	Other mineral components
1	26	18	21	9	8	5	6	0	2
2	25	17	23	9	7	5	7	0	2
3	24	14	26	9	9	5	6	0	2
4	25	14	25	9	9	5	6	0	2
5	22	16	32	8	7	5	3	0	2
6	20	15	28	10	8	5	7	0	2
7	24	14	26	9	9	5	6	0	2
8	24	15	25	10	8	5	6	0	2
9	22	16	24	11	9	5	6	0	2
10	23	15	27	9	8	5	6	0	2
11	24	16	25	7	9	5	7	0	2
12	20	14	28	10	7	3	11	0	2
13	37	15	14	11	8	3	5	0	2
14	22	20	27	8	8	3	5	0	2
15	24	17	20	10	10	5	7	0	2
16	21	15	30	9	8	3	7	0	2
17	20	15	25	9	10	6	8	0	2
18	27	15	24	11	8	3	5	0	2
19	28	17	22	10	8	3	5	0	2
20	23	15	29	8	7	5	6	0	2
21	24	18	23	11	8	3	6	0	2
22	24	14	24	10	10	5	6	0	2
23	21	17	28	9	8	3	7	0	2
24	22	15	26	9	8	5	8	0	2
25	22	17	25	10	7	5	7	0	2
26	22	16	25	10	9	5	6	0	2
27	21	15	21	9	9	5	6	7	2
28	25	14	25	9	9	5	6	0	2
29	22	15	25	12	8	5	6	0	2
30	23	14	26	13	8	3	6	0	2

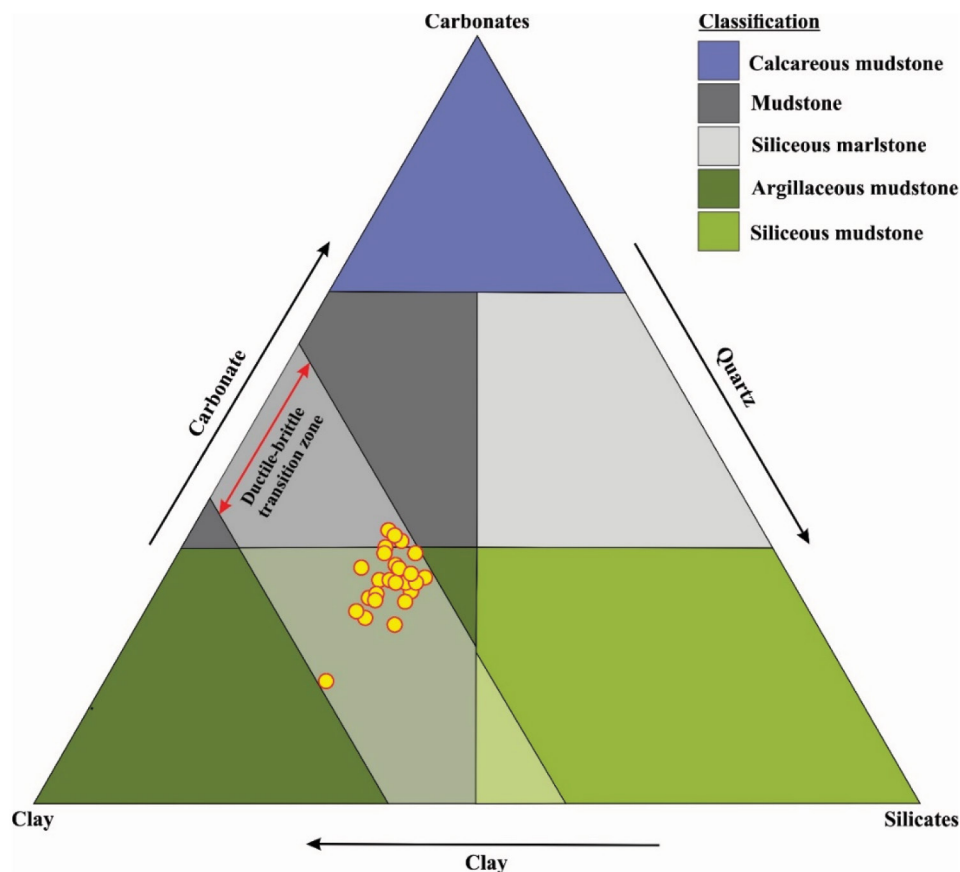


Fig. 5. Mineralogical classification of oil-bearing rock samples, showing the ductile-brittle transition zone as a mix of clay, quartz, and carbonate [4; 19]

Table 3

Concentrations of major oxides in the samples (%)

Sample	Na ₂ O	MgO	Al ₂ O ₃	SiO ₂	P ₂ O ₅	SO ₃	K ₂ O	CaO	TiO ₂	MnO	Fe ₂ O ₃	BaO	SrO
1	3.37	2.92	10.34	47.57	0.18	0.28	1.65	13.25	1.05	0.25	6.56	0.09	0.06
2	2.25	2.81	10.55	46.92	0.18	0.27	1.76	15.66	0.65	0.18	7.08	0.12	0.08
3	2.17	2.34	9.52	43.98	0.13	0.21	1.53	19.36	0.56	0.22	6.25	0.09	0.07
4	2.20	2.63	9.70	44.66	0.16	0.52	1.66	15.42	0.73	0.21	6.28	0.12	0.07
5	2.26	1.33	8.24	41.26	0.13	0.39	1.28	25.36	0.42	0.23	3.66	0.01	0.06
6	2.12	2.26	10.03	43.46	0.17	0.51	1.59	15.13	0.82	0.15	7.88	0.10	0.08
7	1.73	2.18	9.71	44.31	0.14	0.56	1.72	17.06	0.64	0.18	6.66	0.11	0.09
8	2.07	2.12	9.68	45.62	0.16	0.58	1.75	16.14	0.59	0.18	6.58	0.07	0.08
9	2.38	2.32	10.44	45.91	0.16	0.42	1.66	15.82	0.71	0.17	6.72	0.07	0.07
10	1.88	2.20	10.03	43.49	0.14	0.42	1.68	16.30	0.99	0.18	6.29	0.09	0.08
11	2.37	2.27	10.16	44.45	0.17	0.54	1.56	16.59	0.77	0.18	7.90	0.07	0.07
12	2.04	2.37	8.94	39.32	0.15	0.44	1.43	16.40	0.65	0.21	11.12	0.09	0.08
13	3.14	1.87	10.53	56.36	0.14	0.39	1.79	9.23	0.53	0.13	5.17	0.10	0.07
14	1.91	2.19	10.06	44.41	0.15	0.40	1.79	16.71	0.63	0.18	5.86	0.11	0.08
15	1.67	2.00	10.48	46.87	0.16	0.58	1.85	12.37	0.63	0.17	7.35	0.10	0.08
16	1.55	2.24	9.74	42.59	0.16	0.28	1.66	18.01	0.71	0.23	7.06	0.10	0.07

Continuation Table 3 / Продовження Таблиці 3

17	1.73	2.35	10.01	42.02	0.16	0.58	1.61	16.72	0.94	0.21	8.27	0.08	0.08
18	1.73	2.31	10.73	46.13	0.15	0.38	1.86	14.39	0.69	0.15	5.77	0.11	0.08
19	2.33	2.25	10.48	47.51	0.14	0.66	1.92	13.89	0.69	0.14	5.60	0.09	0.07
20	1.75	2.27	9.35	42.55	0.15	0.43	1.63	20.16	0.68	0.21	6.33	0.06	0.09
21	1.93	2.05	10.18	46.18	0.13	0.62	1.82	13.99	0.61	0.16	6.22	0.19	0.09
22	1.60	2.98	10.01	45.07	0.17	0.32	1.70	16.86	0.73	0.20	6.97	0.01	0.08
23	1.76	1.92	9.18	41.69	0.11	0.56	1.71	16.41	0.79	0.18	7.03	0.18	0.09
24	1.92	3.04	10.09	42.12	0.16	0.22	1.49	17.13	1.18	0.19	8.34	0.07	0.07
25	2.01	3.08	10.20	44.34	0.12	0.33	1.68	17.05	0.78	0.21	7.18	0.08	0.08
26	2.25	2.81	10.29	43.93	0.17	0.29	1.66	18.01	0.58	0.22	6.21	0.06	0.06
27	1.64	2.56	9.70	42.95	0.15	3.02	1.74	17.44	0.59	0.17	6.18	0.01	0.09
28	1.86	2.11	10.31	46.33	0.15	0.42	1.58	16.34	0.70	0.17	6.22	0.07	0.08
29	1.97	2.33	11.00	47.82	0.16	0.26	1.89	14.05	0.71	0.15	6.73	0.12	0.08
30	1.45	2.11	9.70	43.25	0.13	0.66	1.73	15.45	0.74	0.17	6.88	0.11	0.08

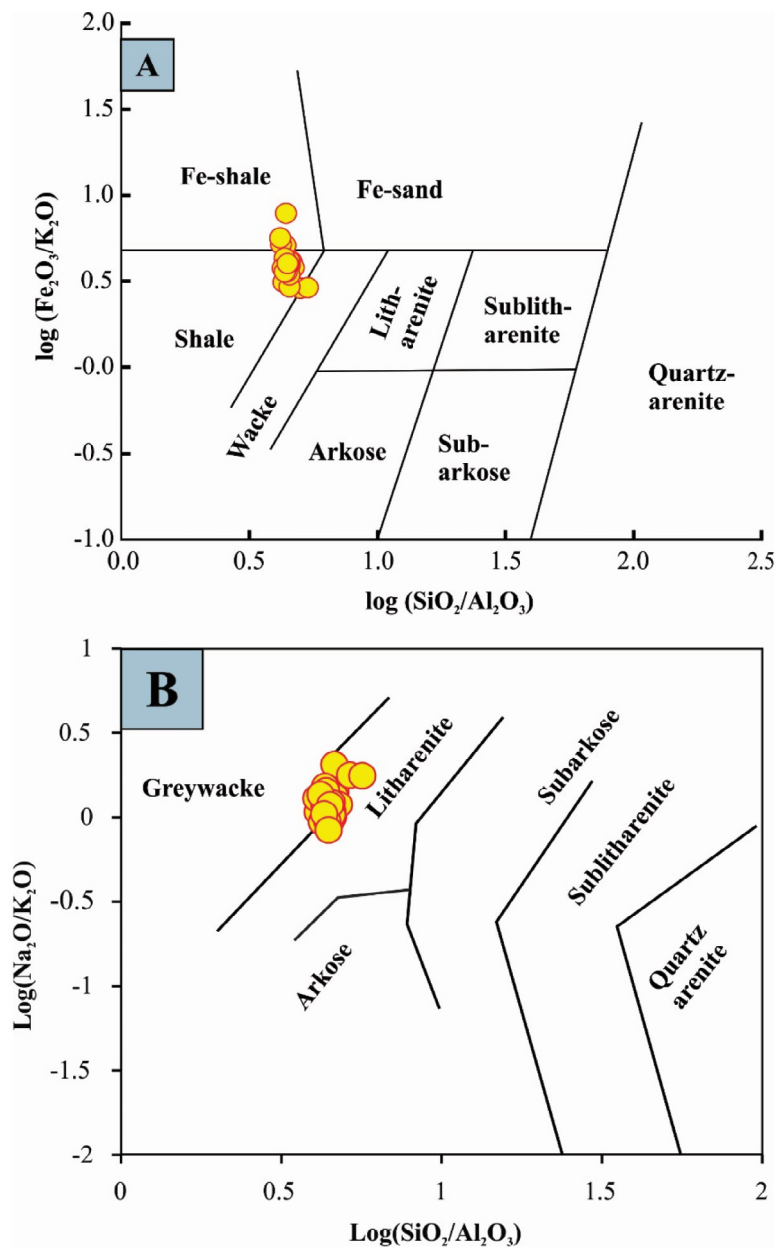


Fig. 6. Geochemical classification of samples using A) $\log(\text{Fe}_2\text{O}_3/\text{K}_2\text{O})$ vs. $\log(\text{SiO}_2/\text{Al}_2\text{O}_3)$ and B) $\log(\text{Na}_2\text{O}/\text{K}_2\text{O})$ vs. $\log(\text{SiO}_2/\text{Al}_2\text{O}_3)$ diagrams [29]

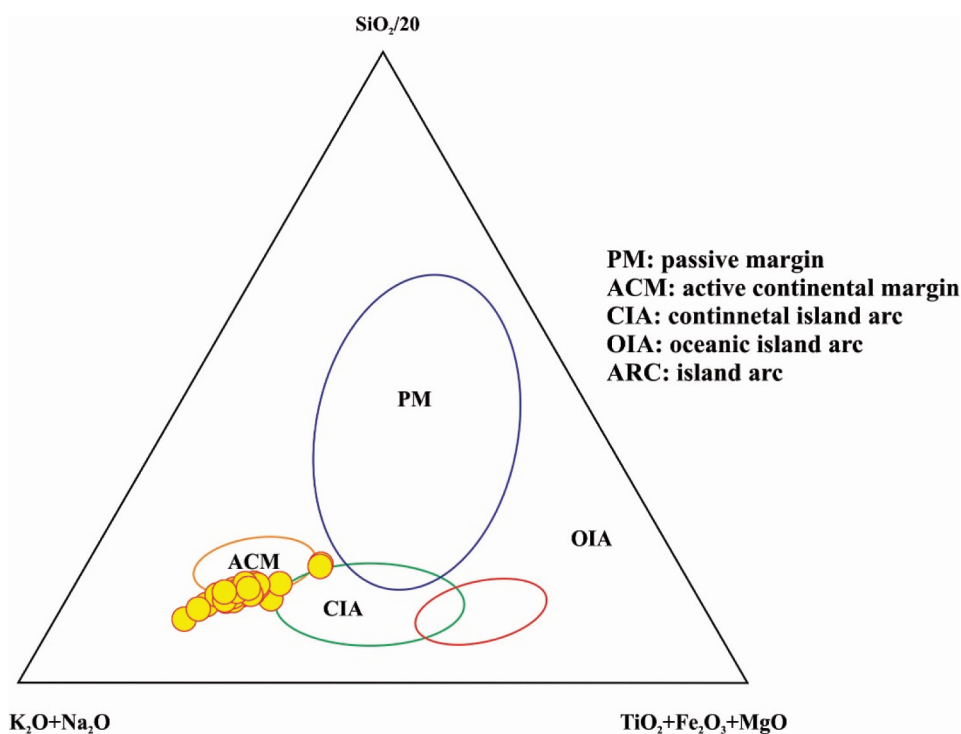


Fig. 7. Discriminant diagram for the tectonic setting of the samples [after 20]

the dominance of terrigenous components and a relatively low mineralogical maturity [29]. However, the significantly high calcite content in the mineralogical composition (Table 2) also points to a mixed carbonate-terrigenous origin for the sediment.

The ternary diagram provided in Fig. 7, which utilizes major element concentrations to infer the tectonic setting in which the oil-saturated rocks were deposited, shows the majority of the samples clustering predominantly within the active continental margin field, with only a minor scatter or inclination towards the adjacent continental

island arc field. This strong localization indicates that the source materials were overwhelmingly derived from a convergent margin setting, typical of regions where continental crust is being actively consumed or uplifted, implying tectonic instability and rapid erosion, which is consistent with the generally immature nature observed in the Fig. 6B.

The clustering of the Beridash samples, along with the DF1 and DF2 data points (Fig. 8), within the defined provenance fields indicates a complex sediment source. The primary presence within the intermediate igneous provenance field suggests a

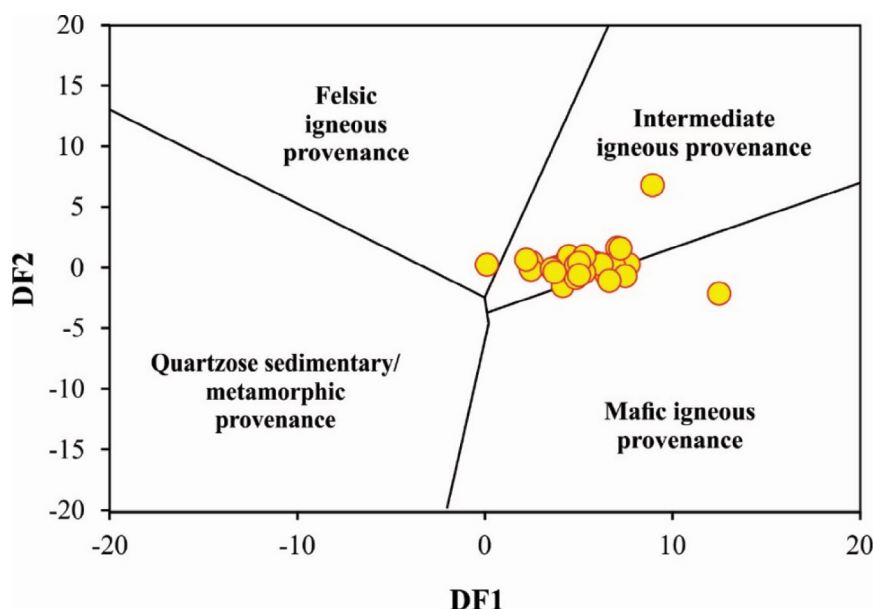


Fig. 8. Classification plot of discriminant functions DF1 and DF2 for the studied samples. Provenance fields are from [42]

dominant contribution from rocks like andesites or diorites. However, the proximity or mixing with the felsic igneous and mafic igneous provenance fields points to an additional, mixed source component. This implies that the sediments were not derived from a single, uniform rock type but from a terrane where both silicic and more basic igneous rocks were being eroded, **a setting consistent with the dynamic tectonic environment of an active continental margin.**

Oil abundance

In addition to geological parameters, the economic potential of oil-bearing sandstones is largely determined by their hydrocarbon composition and physico-chemical properties. Specifically, along with factors such as burial depth, thickness, and mineralogical composition, the amount of hydrocarbons contained within these rocks serves as a key indicator of their suitability for industrial exploitation. Studies have shown that the presence of approximately 6% hydrocarbon compounds in the rock composition indicates economically viable conditions for utilization [33].

The oil content in the analyzed samples ranges from 3.74% to 11.94% (Table 4), with an average value of 7.64%, which is considered to be of commercial significance [33]. Analysis of the spatial distribution of oil saturation across the study area (Fig. 9) reveals a progressive increase in oil impregnation from the northwest toward the southeast.

Moisture

Based on the mineralogical classification presented in Figure 5, the positioning of the oil-bearing rock samples within the ductile-brittle transition zone indicates that they contain both clay minerals and a relatively high proportion of carbonates, primarily calcite. Such a mineralogical composition exerts dual effects on the mechanical behavior of the rocks. Expanding clay minerals, such as montmorillonite, can block pore spaces, thereby reducing porosity and permeability. In wet conditions, the pores of montmorillonite expand due to water molecules, restricting the movement of the liquid phase, which negatively impacts oil saturation [23; 31]. This process is also strongly dependent on pore size, as micropores are easily blocked by adsorbed water [19].

Conversely, a significant concentration of quartz (mean 23.57%) together with the predominance of the calcite phase (mean 24.97%) induces notable changes in the physical properties of the rocks, including fragmentation, creating favorable conditions for the retention and storage of hydrocarbons [24; 35; 38; 47].

Table 4

Moisture and oil content characteristics of the samples

Sample	Moisture. %	Oil content. %
1	1.06	6.37
2	1.19	6.07
3	1.16	6.96
4	1.32	10.24
5	0.92	5.37
6	1.29	9.67
7	1.40	9.23
8	0.93	8.63
9	1.30	7.99
10	1.37	9.64
11	1.32	5.51
12	0.92	8.83
13	1.36	6.02
14	1.01	8.05
15	1.30	9.72
16	1.13	7.14
17	1.21	7.52
18	0.85	7.36
19	1.16	10.28
20	0.88	8.77
21	1.43	6.25
22	0.93	9.86
23	1.34	6.53
24	1.00	11.94
25	1.12	5.87
26	1.10	5.12
27	1.00	3.74
28	1.19	7.66
29	0.93	6.81
30	1.16	6.12
Average value	1.14	7.64

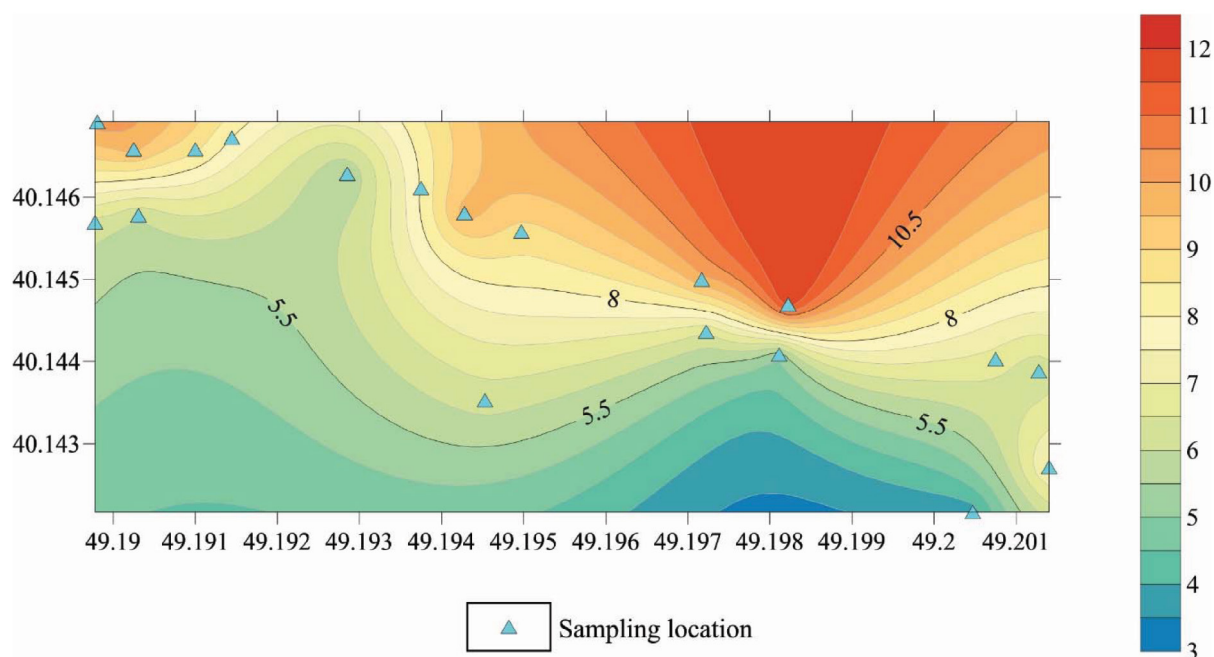


Fig. 9. Spatial distribution map of oil content concentrations in the oil-bearing rocks of the Beridash area

Furthermore, the weak correlation ($r = 0.02$) between moisture content (0.85%-1.43%) and oil enrichment indicates that moisture is not a primary factor influencing oil saturation. Instead, mineralogical composition, particularly the ratio of montmorillonite to calcite, plays a decisively dominant role (Fig. 10). This finding is also consistent with the spatial distribution of moisture across the study area (Fig. 11). A detailed analysis of the spatial distribution models (Fig. 9 and Fig. 11) further confirms the direct genetic link between the local lithological framework and fluid productivity. Across the mapped sequence, a distinct lateral mineralogical

variation is observed along the strike of the beds. In the northwestern sector of the Beridash outcrop (see Fig. 1; e.g., Samples 7, 9, 10), the rock matrix exhibits an increase in ductile clay minerals (up to 25% in Sample 9). This specific lithological composition promotes elevated moisture retention (1.30-1.40%) and restricts maximum hydrocarbon accumulation due to pore-blocking. Conversely, a lateral facies shift occurs towards the central and southeastern sectors (e.g., Samples 19, 22, 24), where the mineralogical composition becomes heavily dominated by brittle components, specifically quartz and calcite. This southeastern zone corresponds precisely with

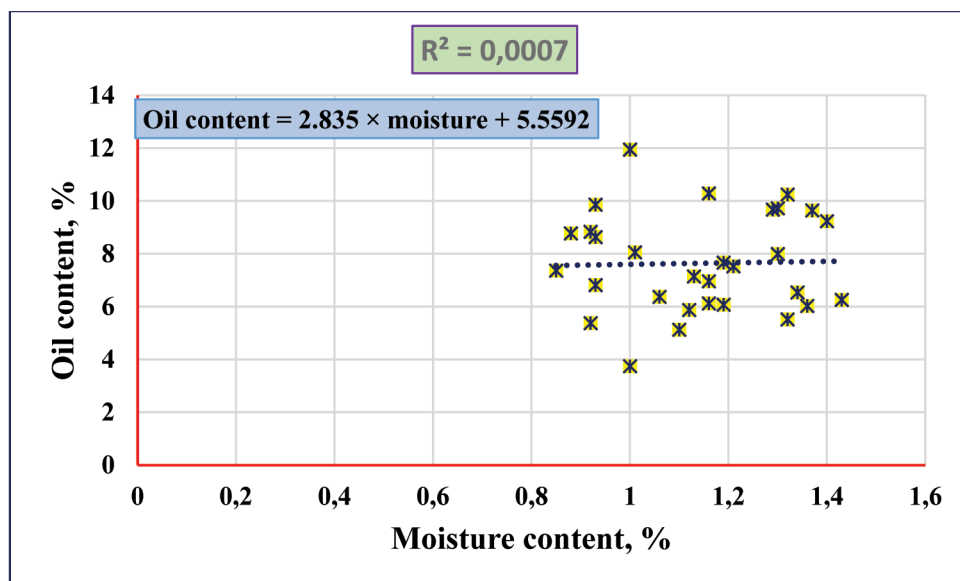


Fig. 10. Correlation diagram showing the relationship between oil content and moisture in the samples

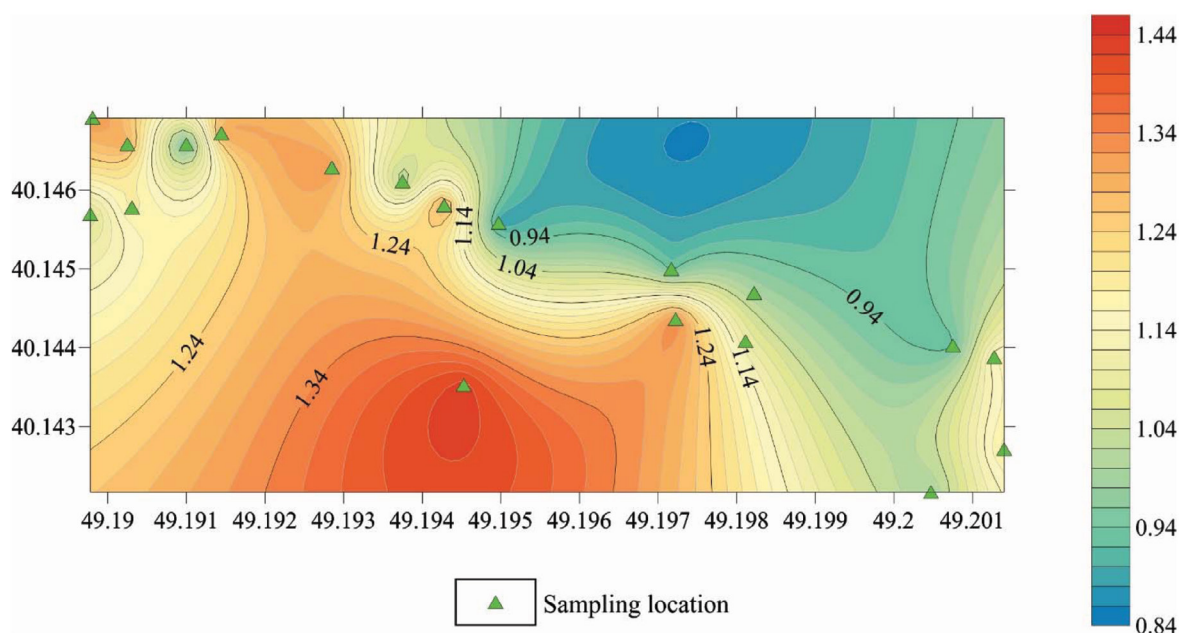


Fig. 11. Spatial distribution map of moisture across the study area

the areas of minimum moisture content (0.88–1.00%) and maximum oil impregnation, reaching peak values of 10.28% (Sample 19) and 11.94% (Sample 24). Finally, towards the far southern and southeastern boundaries (e.g., Samples 21, 27), the depletion of calcite (dropping to 21%) alongside high moisture (up to 1.43% in Sample 21) leads to minimum oil contents (3.74–6.25%). Thus, the spatial productivity is strictly controlled by the lateral variation in the rock's fundamental mineralogical composition.

Conclusions

The integrated formational analysis of the extensively exposed lower Pliocene Productive Series in the Beridash field establishes its substantial potential as a non-conventional hydrocarbon resource. Field mapping confidently delineated eight massive, predominantly calcareous sand and sandstone units localized within the 1245–1480 m interval from the top of the Lower PS.

Geochemical and mineralogical proxies demonstrate that these mixed carbonate-terrigenous sediments were deposited in a shallow marine-lagoonal setting along an active continental margin, originating from moderately weathered felsic and mafic sources.

The studied strata exhibit robust commercial potential, with oil saturation averaging 7.64% and reaching peak accumulations of 11.94% in the southeastern sector. The data establishes a near-zero correlation between background moisture and oil enrichment. Instead, lateral productivity is strictly dictated by the internal rock matrix: zones dominated by brittle components (where calcite and quartz reach up to 52%) provide an optimal framework for peak oil storage. Conversely, a lateral increase in ductile, swelling clays (e.g., montmorillonite) towards the northwestern sector physically impedes hydrocarbon accumulation. These findings offer a robust predictive evaluation model for exploring similar regional unconventional outcrops.

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АНОТАЦІЯ

ІНФОРМАЦІЯ ПРО СТАТЮ:

У цьому дослідженні представлено комплексний формаційний аналіз широко розкритих нетрадиційних порід-колекторів нижнього пліоцену продуктивної серії (PS) на родовищі Берідаш (Південний Гобустан, Азербайджан). Використовуючи літологічні, мінералогічні та геохімічні показники, дослідження оцінює їхнє осадове середовище, походження та нафтовий потенціал, наголошуючи на мінералогічному контролі накопичення вуглеводнів. Незважаючи на великий видобуток традиційних вуглеводнів в Азербайджані, нетрадиційні нафтоносні поверхні залишаються геологічно недостатньо дослідженими. Це дослідження має на меті окреслити походження та вуглеводневий потенціал родовища Берідаш за допомогою інтегрованої мінералогічної та геохімічної оцінки, з особливим акцентом на механізмах контролю збагачення нафти. Аналітична методологія інтегрувала детальне картування поверхні, мінералогічні характеристики за допомогою рентгенівської дифракції (XRD) і геохімічну оцінку основних оксидів за допомогою рентгенівської флуоресценції (XRF) та ICP-MS. Вміст олії розраховували гравіметрично після поправки на вологість. Детальне картографування поверхні виявило вісім окремих, переважно вапняних нафтоносних піщаних і піскових одиниць, локалізованих у стратиграфічному інтервалі 1245-1480 м від вершини Нижнього ПС. Мінералогічно породи являють собою змішану карбонатно-теригенну товщу, в якій переважають кальцит (середнє 24,97%) і кварц (середнє 23,57%), а також глинисті мінерали. Геохімічні проксі вказують на відкладення в мілководному морсько-лагунному середовищі вздовж активної континентальної окраїни зі змішаних кислих і мафічних джерел. Середній вміст нафти становить 7,64%, зростаючи з північного заходу на південний схід. Слабка кореляція ($r = 0,02$) між вологістю (в середньому 1,14%) і нафтонасиченням демонструє, що мінералогія, зокрема співвідношення флюїдоблокуючих глин і крихких мінералів, діє як основний контроль накопичення вуглеводнів. На основі детального картографування поверхні вісім окреслених блоків вапняного піску та пісковика представляють собою дуже перспективний нетрадиційний ресурс вуглеводнів. Їх специфічне походження створило мінералогічний каркас, який дуже сприятливий для розміщення вуглеводнів, функціонуючи в основному незалежно від впливу вологи. Ці висновки забезпечують надійну формувальну модель оцінки регіональних нетрадиційних ресурсів.

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Азербайджан, продуктивна серія, нафтоносні породи, мінералогія, геохімія, походження, збагачення нафти, вологість, нафтоносність.