ГЕОЛОГІЯ

https://doi.org/10.26565/2410-7360-2025-62-01
UDC 552.14+553.98

Received 12 February 2025
Accepted 17 March 2025

Mineralogical and geochemical proxies of Miocene sediments of Eastern Azerbaijan: Provenance and oil-bearing

Elnur Baloglanov [1]
Researcher of Department of Mud Volcanism, [1] Institute of Geology and Geophysics,
Ministry of Science and Education of the Republic of Azerbaijan, Baku, Azerbaijan,
e-mail: b.elnur2016@gmail.com, https://orcid.org/0009-0004-3620-0052;
Ulviyya Yolchuyeva [2, 3]
PhD (Chemistry), Associate Professor, Head of Laboratory, [2] Institute of Petrochemical Processes
of Ministry of Science and Education Republic of Azerbaijan, Baku, Azerbaijan;
Department of Chemical Engineering, School of Engineering and Applied Science,
[3] Khazar University, Baku, Azerbaijan,
e-mail: u.jeyhunzade@gmail.com, https://orcid.org/0000-0003-4419-1016;
Ruslan Akhundov [1]
Researcher of Department of Mud Volcanism,
e-mail: ruslanaxundoff@gmail.com, https://orcid.org/0009-0003-6447-1952;
Elmar Samedov [1]
Engineer of Department of Mud Volcanism,
e-mail: samedovelmar@gmail.com, https://orcid.org/0009-0002-6835-0229;
Kamal Mustafayev [4]
Manager, [4] AZLAB Exploration and Research Center, Baku, Azerbaijan,
e-mail: kamal@azlab.az, https://orcid.org/0009-0001-4945-8683

ABSTRACT

Problem statement. This study explores unconventional hydrocarbon resources in East Azerbaijan, focusing on oil-bearing rocks in the Cheyildere and Gyrgyshlag-Girdagh areas. It examines the spatial and temporal distribution of minerals and chemical compositions in Miocene formations. Terrigenous quartz types identified in the Maikop (Lower Miocene), Chokrak (Lower Miocene), and Diatom (Middle to Upper Miocene) formations provide insights into sedimentological maturity. Geochemical classification and tectonic discriminant diagrams help interpret the protoliths of these sediments. The study also evaluates how mineralogy and moisture affect oil-bearing potential, offering useful data for future exploration and resource management.

Purpose. This study aims to explore the genesis and potential of oil-bearing deposits of the Miocene age in East Azerbaijan by characterizing the geological, mineralogical, and geochemical proxies of samples collected from outcrops across various regions.

Methods. The mineralogical composition of samples was analyzed using a MiniFlex 600 diffractometer. Chemical composition was determined using S8 TIGER Series 2 and Agilent 7700 Series ICP-MS spectrometers.

Results. The geological characteristics of oil-bearing deposits from the Miocene stratigraphic unit were thoroughly analyzed, providing new insights into the distribution patterns of oil-bearing formations and strata within the studied areas. The mineralogical composition was examined in detail, focusing on the spatial and temporal variations in mineral distribution across different formations of Miocene. The chemical composition reveals significant differences between formations in terms of elemental signatures. The study of the chemical proxies enabled the identification of specific terrigenous quartz types. Additionally, the research assessed the influence of mineralogical composition, moisture and oil content on the oil-bearing capacity. The results demonstrated a clear relationship between the mineralogical characteristics and the oil-bearing potential of the rocks.

Conclusions. The Chokrak Formation is of particular interest due to its significant oil-bearing potential, with total thicknesses of up to 40 meters in Miocene outcrops studied in the areas of Cheyildere and Gyrgyshlag-Girdagh. Compared to other areas, the Chokrak Formation is dominated by quartz minerals (>70%), while the oil-bearing rocks of this formation contain fewer clay minerals and no carbonate minerals. The Upper Maikop deposits are characterized by calcite, and the Diatom deposits by dolomite.

Most oil-bearing rocks of Maikop and Diatom age correlate with greywacke and litharenite, while Chokrak rocks with higher silicon content show a connection with subarkose and sublitharenites. For Diatom oil-bearing rocks, in addition to quartzitic sedimentary sources, some moderate and acidic magmatic rocks can also be considered. Chokrak horizon deposits, rich in quartz, have a more mature mineralogical nature. These deposits, associated with passive continental margins, are typically linked to the interior of cratons or recycled orogenic regions, suggesting long-distance transport.

Relatively moist samples containing clay and carbonate minerals exhibit a significantly higher oil accumulation potential than samples with high quartz content. From this perspective, the marly rocks of the Meotis are of particular interest.

Keywords: *Miocene, oil-bearing rock, mineralogy, geochemistry, classification, sedimentological maturity, provenance area and oil-bearing capacity.*

© *Baloglanov Elnur, Yolchuyeva Ulviyya, Akhundov Ruslan, Samedov Elmar, Mustafayev Kamal, 2025*

This work is licensed under a Creative Commons Attribution 4.0 International License

In cites: Baloglanov Elnur, Yolchuyeva Ulviyya, Akhundov Ruslan, Samedov Elmar, Mustafayev Kamal (2025). Mineralogical and geochemical proxies of Miocene sediments of Eastern Azerbaijan: Provenance and oil-bearing. Visnyk of V. N. Karazin Kharkiv National University. Series Geology. Geography. Ecology, (62), 11-24. https://doi.org/10.26565/2410-7360-2025-62-01

Introduction and research status. The hydrocarbon-generating deposits of Eastern Azerbaijan belong to the Paleogene-Miocene (Maikop) [6; 21], while the oil and gas reservoirs are part of the Productive Series (Pliocene). Numerous studies have been conducted on the geochemistry, and oil and gas potential of sediments identified as source rocks for hydrocarbons [4; 9; 11; 22]. There are detailed results of studies on the genesis and reservoir properties of Pliocene deposits, which currently contain more than 90% of the oil produced in Azerbaijan [13; 14]. In addition, several studies focused on the Paleogene-Miocene deposits of Eastern Azerbaijan provide a general understanding of the genesis of these sediments through the analysis of mineralogical-geochemical and petrographic data [15; 18].

The literature review highlights that, within the reservoir sediments of East Azerbaijan, the Pliocene Productive Series deposits have received the most attention. However, the genesis of older sediments, including Miocene oil-bearing rocks, which are predominantly studied as source rocks for hydrocarbons, has not been sufficiently explored. Furthermore, the mineralogical and other factors influencing the hydrocarbon potential of these sediments have not been adequately assessed. This study aims to address these gaps by focusing on the oil-bearing reservoir rocks of the Lower Maikop, Chokrak, and Diatom formations of the Miocene.

Geology and tectonics: a general overview. During the Cenozoic era, alongside the formation of oil shale [1; 7; 25] and oil and gas, there was a significant development of mud volcanoes in Eastern Azerbaijan [3; 12; 16; 17; 28] which was closely linked to the process of intense sedimentation [27]. The Shamakhi-Gobustan oil and gas region, characterized by a high concentration of tectonic faults and mud volcanoes [24], provides an ideal setting for studying the surface deposits of oil-bearing rocks [2; 10]. Numerous outcrops of oil-bearing rocks of different geological ages have been recorded in the tectonic zones of this region. The focus of this study is on the Cheyildere (Southern Gobustan) and Gyrgyshlag-Girdagh (Central Gobustan) areas (see Fig. 1), located in two separate tectonic zones of Gobustan, where oil-bearing rocks of the Lower, Middle and Upper Miocene are widespread.

Cheyildere. This area is located on the southern limb of the Cheildagh anticline, which extends in its widest direction, covering the extreme eastern part of the Sundi-Cheildagh anticlinorium zone in South Gobustan [26]. The characteristic deposits of this region include Paleogene, Miocene, and Pliocene strata. The area is also home to the Western and Eastern Cheildagh mud volcanoes (Fig. 2).

Gyrgyshlag-Girdagh. Tectonically, the studied area is considered part of a tectonic structure consisting of the Donguzdug-Shakhgay anticlines, within which distinct structures such as the Gyrgyshlag and Girdagh are identified [30]. The geological structure includes Maikop and Quaternary deposits (Fig. 3). The Gyrgyshlag is an uplift trending northwest-southeast. The core of this structure consists of Maikop deposits, where thick clay layers alternate with thin layers of sand and sandstone, with a thickness of up to 3.5 meters. The Maikop deposits on the flanks of the fold are surrounded by layers of Chokrak and Diatom deposits. In the Gyrgyshlag area, three major outcrops of dense oil manifestations have been identified alongside mud volcanic gryphons. These exposures are associated with Diatom (Meotian) dolomites. In the case of the Girdagh structure, located about 2 kilometres north of Girdagh Mountain, there is a mud volcano of the same name. The core of the Girdagh fold consists of Maikop-aged deposits. The anticline is asymmetrical and oriented along a latitudinal strike.

Oil-bearing deposits. In Cheildere, the oil-bearing rocks of Miocene age, particularly from the Upper Maikop and Chokrak formations, are of significant interest (Fig. 4A və 4B).

Significant deposits of oil sands from the Chokrak Formation are observed on the southern limb of the Cheyildagh fold, on the right and left slopes of the ravines in the Cheyildere valley. The thickness of the sandstone layers, primarily observed on the right slopes of ravines along the valley and areas with high oil concentrations, reaches several tens of meters, and in some places, it even extends up to 40 meters. These thick bituminous sections gradually dip, extending roughly towards the Eastern Cheyildagh mud volcano. In addition to the slopes, the directions of bedding of the oil-bearing sandstone layers are clearly visible in certain water-washed areas of the valley. In the Cheyildere area, several active oil-seeping gryphons have led to the formation of a hardened bitumen cover on the surface. This phenomenon suggests a high oil-bearing potential of the underlying layers at lower intervals.

The secondary oil-bearing area of Cheyildere is situated south of the West Cheildagh mud volcano and west of the East Cheyildagh mud volcano. This area is characterized by several layers exhibiting varying degrees of bituminosity. The sand layers of the Upper Maikop Formation extend along the valley in a northwest-southeast orientation.

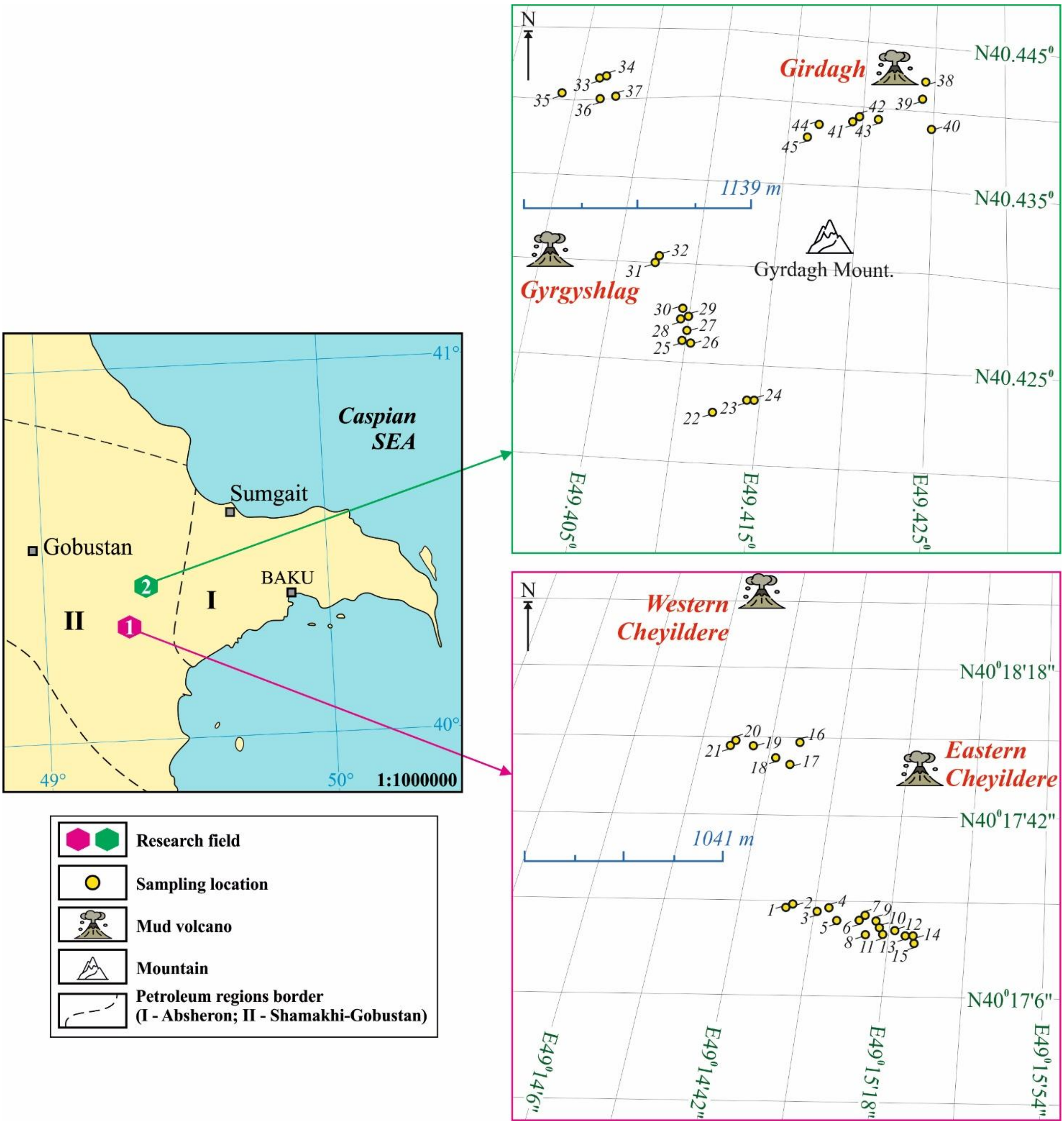

Fig. 1. Location map of study areas

Oil-bearing rocks in the Gyrgyshlag-Girdagh area are primarily associated with the sandstones of the Chokrak deposits (Fig. 5A). Of particular interest are the oil seeps in the marl rocks, which are linked to the Diatom Formation, especially in regions where mud volcanoes emitting oil are present (Fig. 5B).

Oil-bearing layers in the Gyrgyshlag-Girdagh area, which extend approximately 3.5 km in a northwest-southeast direction, are part of the Chokrak Formation. These layers are found along the northeastern limb of the fold of the same name and are divided into several distinct units, each containing significant volumes of oil. Additionally, to the north of the Gyrgyshlag wintering site and Girdagh mountain, strong oil flows are observed within the interlayers of Diatom-aged marly rocks, extending from west to east. The most substantial oil flows in the Gyrgyshlag-Girdagh region are associated with marly rock formations.

Samples and analyzes. Fig. 1 shows the sample locations from the studied areas. A total of 45 samples were analyzed for this study. The visual assessment analysis indicates that the Chokrak samples from Cheyildere contain a higher sand content compared to the Maikop samples (Table 1). Notably, the Maikop samples have a significantly higher proportion of fine-grained fractions. The Chokrak samples from the Gyrgyshlag area contain negligible amounts of clays. In contrast, the oil content in the Diatom-aged

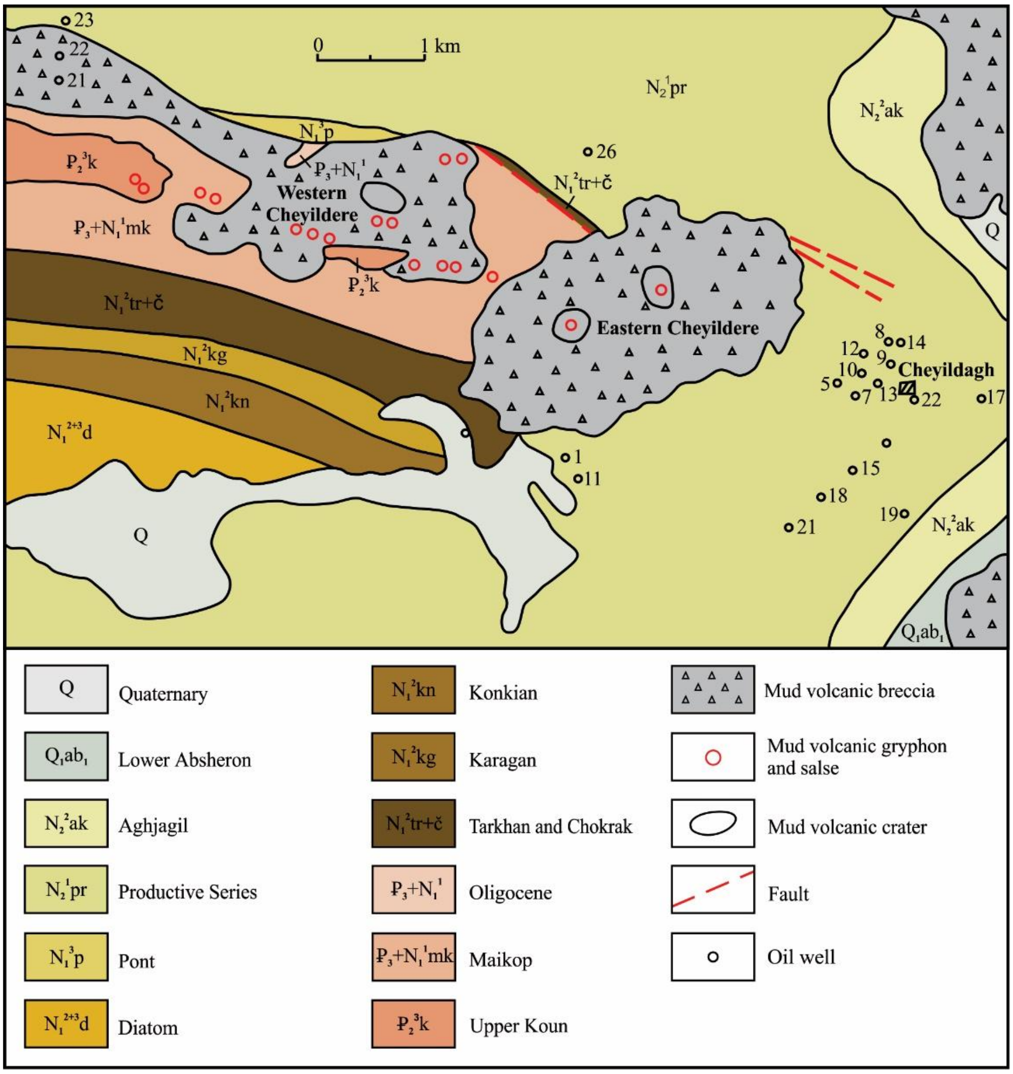

Fig. 2. Geological map of the Cheyildere area [5]

marl samples from the same area significantly surpasses that of the Chokrak samples. These marl samples are also characterized by a higher presence of clay compounds in addition to carbonates. Visual analysis suggests that the oil capacity of the fractured Diatom-aged rocks is comparable to, and in some cases even exceeds, that of the sandy rocks found in Chokrak and Maikop.

The mineralogical composition of oil-bearing samples was determined using X-ray diffraction (XRD) with a Rigaku MiniFlex 600. Samples were wet-ground to approximately 5 µm and mounted on zero-background holders. Diffraction patterns were acquired over a 2θ range of 5–65° using Cu–Kα radiation (40 kV, 15 mA) and a D/tex detector, with 0.02° steps and a scan rate of 2°/min. Data analysis was performed using CRYSTAL IMPACT's Match! software, and mineral abundances were quantified using RockJock XRD pattern fitting [9].

Bulk rock geochemistry was determined via wavelength-dispersive X-ray fluorescence spectrometry (WDXRF) on a Bruker S8 TIGER Series 2. Samples were prepared using a hydraulic press at 25 tons. Loss on ignition (LOI) was measured at 1000 °C. Data quality was validated by analyzing the certified reference material SRM 2709 [9].

The loss-on-ignition (LOI) method was employed to quantify moisture and organic matter content in the samples. Samples were dried at 105°C for 24 hours to eliminate moisture, and then combusted at 550°C using a SNOL 30/1100 muffle furnace (50-1100°C). Moisture and oil percentages were determined from weight loss measurements. Triplicate analyses were performed to guarantee reproducibility.

Mineralogy. The mineralogical analysis results are in good agreement with the visual assessments. The Chokrak samples show the highest concentration of quartz (>70%), lower concentration of clay minerals, including montmirillonite, illit and kaolinite (<10%), and no detectable carbonates. The Gyrgyshlag-Girdagh samples exhibit relatively lower clay minerals than Cheyildere. The Upper Maikop samples are characterized by the presence of calcite, while dolomite is a distinguishing feature of the Diatom-aged samples. Additionally, the Diatom samples exhibit a significant clay mineral content, as illustra-

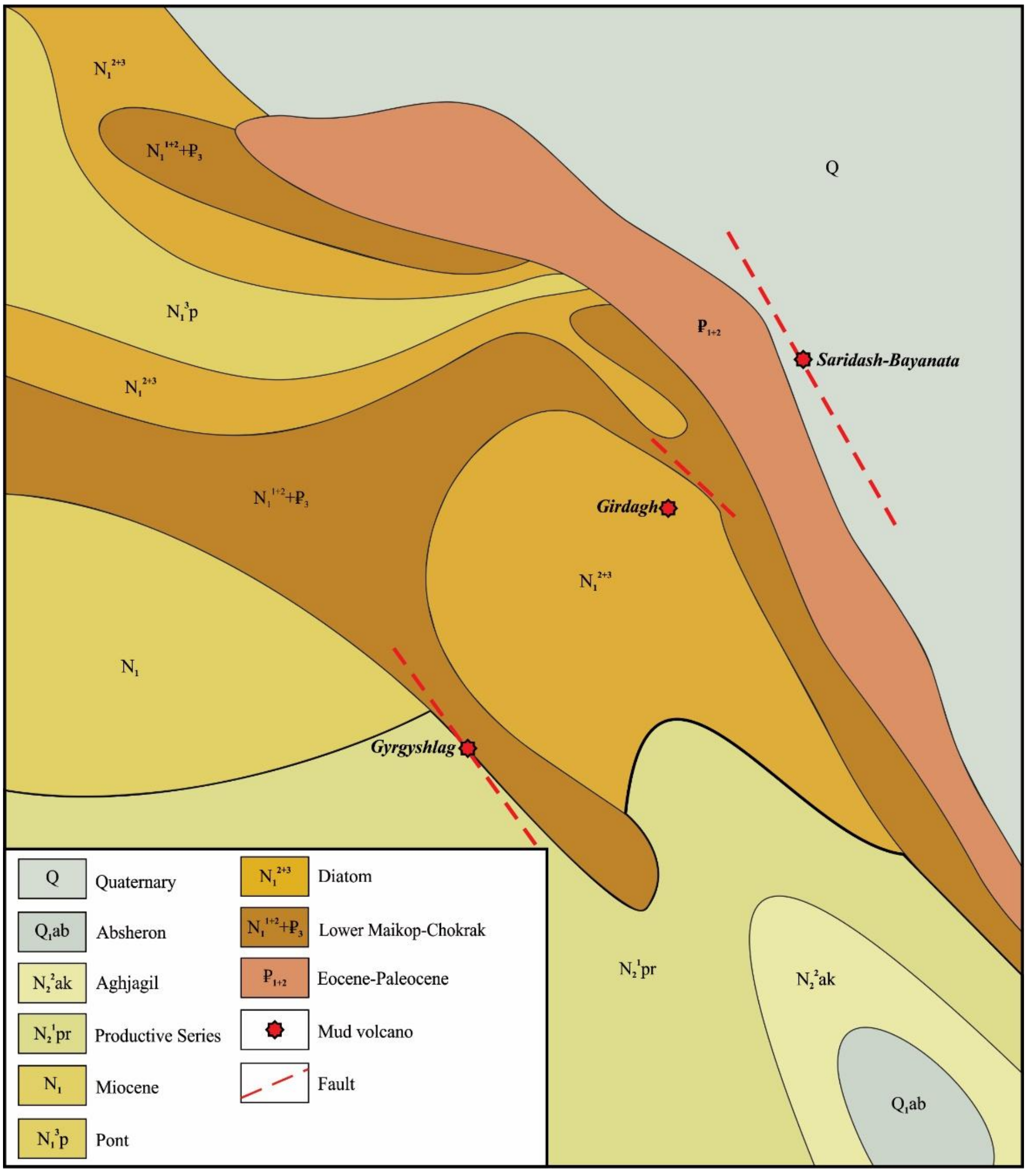

Fig. 3. Geological map of the Gyrgyshlag-Girdagh areas (after [31])

ted in Table 2 and Fig. 6.

Major oxides. A high amount of Si is present in the chemical composition of the Chokrak samples, whereas the Cheyildere samples are noticeably different, with an average value of 80%. The mineralogical composition of the Cheyildere samples shows a lower average quartz content compared to Gyrgyshlag-Girdagh, which indicates that the higher Si content in the latter is concentrated not only in quartz but also in other silicate minerals. The amount of Al in the Chokrak samples is significantly higher in the Gyrgyshlag-Girdagh samples. The Maikop and Diatom-aged samples contain little Si but a substantial amount of Ca (average value = 11.33%). In addition, upon comparing Tables 2 and 3, the highest Ti concentration is observed in the quartz-rich, clay-deficient Chokrak samples. Despite the absence of detectable Ti-bearing minerals like rutile or titanite, and considering hematite is a minor component, the elevated Ti is likely attributed to its incorporation within undetected trace minerals or, potentially, adsorption onto the abundant quartz surfaces. Quartz, while not a typical host for Ti, can adsorb trace elements, particularly if it exhibits surface alterations or microfractures [e.g., 20]. Conversely, some clay-rich samples exhibit lower Ti concentrations, potentially due to the dilution effect of clay minerals and variations in Ti partitioning during sedimentation [e.g., 32]. The variations observed between the stratigraphic units in terms of Si, Al, Ca, Fe, Ti, and other chemical compositions result from different genesis conditions.

Provenance. In the geochemical classification diagram (Fig. 7), the samples correspond to different types of terrigenous quartz, indicating distinct provenance sources or depositional environments. The predominance of Fe and Mg in the Maikop and Diatom samples indicates a close association with greywackes and litharenite. However, two Diatom samples are positioned within the arkosic region of the classification diagram due to their low Na/K concen-

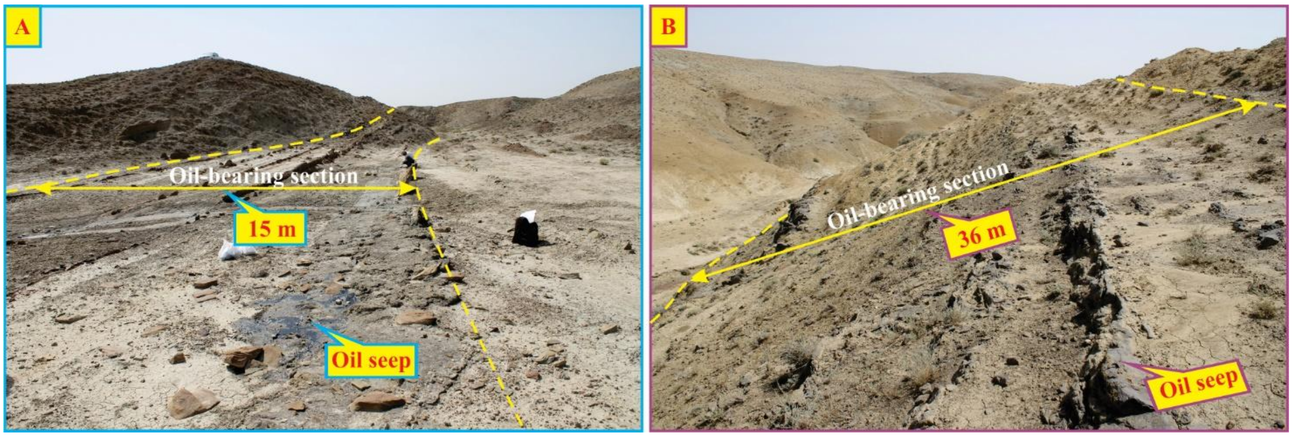

Fig. 4. Oil seeps in the Maikop (A) and Chokrak (B) oil-bearing sections in the Cheyildere area

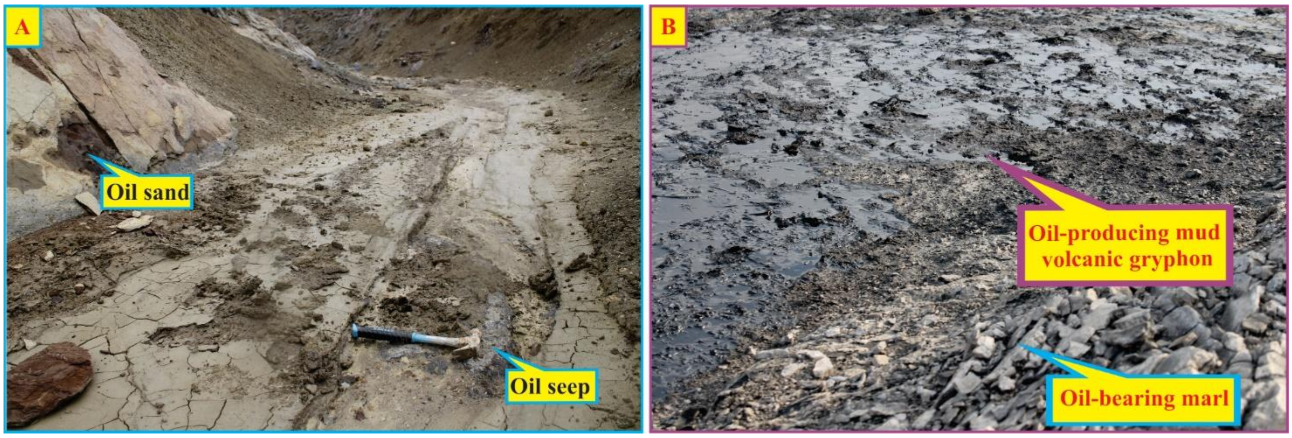

Fig. 5. Oil-bearing outcrops of Chokrak (A) and Meotian (B) formations in the Gyrgyshlag-Girdagh areas

Table 1

Description of some of the analyzed samples

Area	Sample	Age	Description
Cheyildere	Ch-1	Chokrak	Sandstone that erodes relatively quickly and smells of oil
	Ch-9	Chokrak	Fine-grained sand with a slight smell of oil
	Ch-18	Upper Maikop	Sandy rock mixed with clay, with a strong smell of oil
	Ch-20	Upper Maikop	Sandy carbonate rock saturated with oil
Gyrgyshalg-Girdagh	GG-25	Chokrak	Oil-saturated relatively hard sandstone
	GG-31	Chokrak	Rapidly eroding sandstone with a faint smell of oil
	GG-36	Diatom	Dolomite rock with excess oil in the intermediate layers

trations [8]. Most of the Chokrak samples show dual localization due to their Si and Na/K ratios. From this perspective, the Gyrgyshlag-Girdagh samples are classified as subarkoses, while the majority of the Cheyildere samples are categorized as sublitharenites.

The discriminant function diagram in Fig. 8 indicates that the Chokrak samples are predominantly influenced by sediments derived from quartzose sources. However, the possibility of contributions from both intermediate and felsic magmatic sources, in addition to quartzose sedimentary sources, to the formation of Miocene oil-bearing samples cannot be excluded [8].

Geochemical analyses of the Chokrak samples revealed a higher concentration of potassium K compared to sodium Na, with these samples primarily composed of subarkosic and sublitharenitic quartz (see Fig. 7). The Chokrak samples, which exhibit a more mature mineralogical nature with a higher quartz content, are linked to passive continental margins. These deposits are typically associated with the interior parts of cratons or recycled areas of orogens, reflecting long-distance sediment transport [19]. Additionally, these deposits, potentially linked to intense weathering, polycyclic sand fractions, and also granite-gneiss terranes, may have originated from pre-existing sedimentary terranes. The paleoclimatic conditions of these deposits suggest a humid climate during their formation.

Oil Richness. Along with moisture, the bitumen

Table 2

The results of a mineralogical analysis of samples

Area (age)	Sample	Quartz	Feldspar	Calcite	Dolomite	Mont-miril-	Kaolinite	Illit	Pyrite	Hematite	Diopside	Gypsum	Halite	Anhydrite
Cheyildere (Chokrak)	**Ch-1**	75	12	-	-	-	-	-	2	1	-	-	-	-
	Ch-2	75	13	-	-	-	-	-	-	1	-	-	-	-
	Ch-3	69	14	-	-	3	2	-	-	2	-	-	-	-
	Ch-4	49	12	-	-	9	5	6	-	2	5	-	-	1
	Ch-5	75	12	-	-	-	-	-	-	1	-	-	-	4
	Ch-6	74	6	-	-	6	-	3	-	2	-	-	-	-
	Ch-7	55	12	-	-	12	-	8	-	4	-	-	-	2
	Ch-8	75	6	-	-	6	-	3	-	1	-	-	-	-
	Ch-9	69	14	-	-	4	-	2	-	1	-	-	3	-
	Ch-10	72	7	-	-	7	-	3	-	1	-	-	-	1
	Ch-11	75	6	-	-	6	-	3	-	1	-	-	-	-
	Ch-12	73	6	-	-	6	-	3	-	2	-	-	-	1
	Ch-13	74	6		-	6		3	-	2	-	-	-	1
	Ch-14	72	7	-	-	6	-	3	-	2	-	-	-	1
	Ch-15	81	3	-	-	5	-	2	-	-	-	-	1	1
Average value		***70.9***	***9.1***	***0.0***	***0.0***	***5.1***	***0.5***	***2.6***	***0.1***	***1.5***	***0.3***	***0.0***	***0.3***	***0.8***
Cheyildere (Upper Maikop)	**Ch-16**	12	10	55	-	5	5	-	-	3	-	-	-	-
	Ch-17	44	15	-	-	10	8	8	-	3	5	-	-	3
	Ch-18	34	12	-	-	12	5	-	-	3	-	-	-	2
	Ch-19	27	13	-	-	12	5	-	1	2	-	-	-	1
	Ch-20	31	10	35	-	3	5	-	-	4	-	-	-	-
	Ch-21	48	14	20	-	4	-	-	-	2	-	-	-	-
Average value		***32.7***	***12.3***	***18.3***	***0.0***	***7.7***	***4.7***	***1.3***	***0.2***	***2.8***	***0.8***	***0.0***	***0.0***	***1.0***
Gyrgyshlag-Girdagh (Chokrak)	**GG-22**	74	4	-	-	-	-	4	-	4	3	4	-	4
	GG-23	75	10	-	-	-	-	3	-	2	3	-	-	4
	GG-24	74	7	-	-	3	-	3	-	2	2	-	-	6
	GG-25	73	8	-	-	3	-	3	-	1	2	2	-	5
	GG-26	68	10	-	-	3	-	3	-	3	2	3	-	5
	GG-27	74	9	-	-	5	-	3	-	-	2	-	-	4
	GG-28	73	8	-	-	3	3	3	-	1	3	-	-	3
	GG-29	54	14	-	-	3	3	4	-	3	2	2	-	10
	GG-30	72	9	-	-	5	-	3	-	1	2	-	-	5
	GG-31	73	8	-	-	5	-	3	-	2	3	-	-	3
	GG-32	74	7	-	-	5	-	3	-	2	3	-	-	3
Average value		***72.1***	***8.3***	***0.0***	***0.0***	***3.2***	***0.5***	***3.2***	***0.0***	***1.8***	***2.4***	***0.9***	***0.0***	***4.3***

Continuation of table 2

Gyrgyshlag-Girdagh (Diatom)	**GG-33**	81	5	-	-	3	-	3	-	1	2	-	-	-
	GG-34	71	10	-	-	4	3	3	-	1	-	-	-	-
	GG-35	69	10	-	-	4	3	3	-	2	3	-	-	-
	GG-36	7	3	-	69	4	3	3	-	2	3	-	-	-
	GG-37	6	4	3	71	-	-	-	-	3	-	-	-	-
	GG-38	37	10	-	-	20	5	5	-	4	3	8	-	-
	GG-39	20	10	5	5	10	6	5	-	4	-	22	-	-
	GG-40	39	15	-	-	10	5	5	-	3	5	9	-	-
	GG-41	27	10	-	-	20	12	12	-	4	5	1	-	-
	GG-42	38	15	3	16	6	-	5	-	5	-	3	-	-
	GG-43	43	18	-	8	10	5	5	-	3	-	-	-	-
	GG-44	39	15	20	3	5	3	3	-	2	3	-	-	-
	GG-45	26	7	-	-	25	10	15	-	5	3	1	-	-
Average value		***35.2***	***10.6***	***2.6***	***14.3***	***9.8***	***4.6***	***5.3***	***0.0***	***3.2***	***2.1***	***3.7***	***0.0***	***0.0***

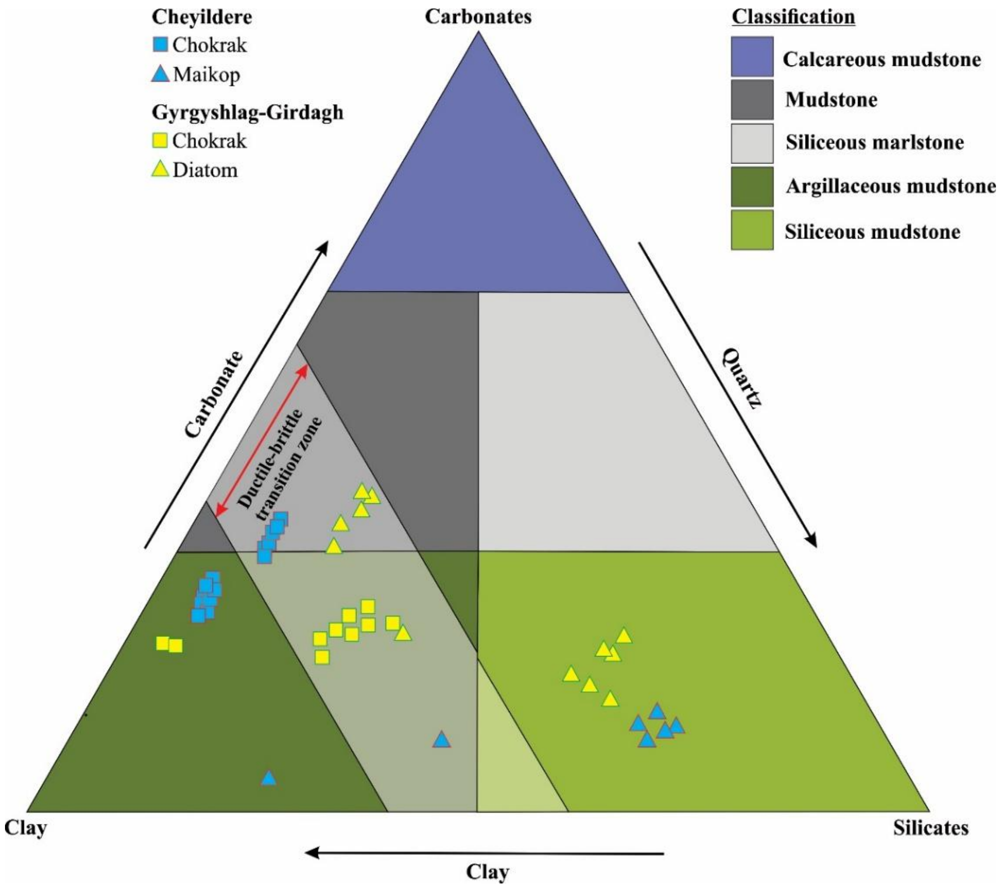

Fig. 6. Mineralogical classification diagram of samples (after [4])

content in the Chokrak samples (averaging 7.63% for Chiyldere and 6.4% for Gyrgyshlag-Girdagh) is nearly half of that found in the Maikop samples (with an average of 14.78% for Childere) and Diatom samples (averaging 14.7% for Gyrgyshlag-Girdagh). The results suggest that samples with relatively high moisture content, along with clay and carbonate minerals, demonstrate a higher oil storage potential compared to those with higher quartz content. In particular, Diatom marls stand out in this context (Table 4), as they exhibit favorable characteristics for hydrocarbon accumulation.

Conclusions. The Chokrak oil-bearing rocks stand out due to the total thickness of the oil-bearing

Table 3

The chemical composition of the samples, %

Area (age)	Sample	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	K_2O	CaO	TiO_2	MnO	Fe_2O_3
Cheyildere (Chokrak)	**Ch-1**	0.68	0.76	4.36	82.06	0.09	2.93	1.45	0.83	0.81	0.04	2.25
	Ch-2	0.58	0.59	4.72	83.16	0.08	0.28	1.65	1.71	0.72	0.02	1.91
	Ch-3	0.55	0.62	5.08	82.4	0.10	0.43	1.86	1.50	0.45	0.02	2.32
	Ch-4	1.98	1.01	9.04	71.65	0.11	0.67	2.71	1.13	0.98	0.03	2.97
	Ch-5	0.41	0.36	4.50	82.69	0.16	2.77	1.61	1.54	0.71	0.01	1.65
	Ch-6	0.49	0.48	4.35	85.66	0.01	0.35	1.45	0.55	0.52	0.02	2.57
	Ch-7	0.54	1.04	9.88	71.15	0.01	1.32	2.84	1.92	0.88	0.04	4.19
	Ch-8	0.55	0.44	4.45	84.91	0.08	0.44	1.68	0.46	0.43	0.01	1.82
	Ch-9	3.39	0.43	5.05	82.06	0.03	0.38	1.73	0.25	0.50	0.07	1.67
	Ch-10	1.51	0.48	5.06	83.82	0.01	0.58	1.80	0.41	0.45	0.01	1.87
	Ch-11	0.65	0.43	4.94	85.96	0.01	0.25	1.72	0.33	0.47	0.01	1.72
	Ch-12	0.55	0.43	4.97	85.24	0.06	0.56	1.69	0.34	0.59	0.02	2.18
	Ch-13	0.39	0.39	4.55	82.27	0.08	2.07	1.27	1.02	0.71	0.01	2.11
	Ch-14	1.62	0.58	5.68	80.42	0.06	0.57	2.04	0.59	0.58	0.02	2.04
	Ch-15	0.32	0.19	1.73	91.86	0.01	0.60	0.52	0.29	0.36	0.01	0.81
Average value		***0.95***	***0.55***	***5.22***	***82.35***	***0.06***	***0.95***	***1.73***	***0.86***	***0.61***	***0.02***	***2.14***
Cheyildere (Upper Maikop)	**Ch-16**	0.86	2.39	7.10	28.18	0.18	0.15	1.34	28.54	0.42	0.15	3.79
	Ch-17	1.24	0.90	12.77	70.83	0.29	2.50	2.92	1.34	0.63	0.02	3.23
	Ch-18	1.31	1.40	8.85	49.84	0.13	0.88	1.60	2.29	0.45	0.07	3.76
	Ch-19	1.37	1.07	9.99	43.79	0.14	1.90	1.73	1.38	0.50	0.04	3.01
	Ch-20	0.73	1.03	5.95	39.93	0.19	0.37	1.69	21.45	0.53	0.07	4.89
	Ch-21	1.09	1.27	6.31	59.47	0.18	0.38	1.64	12.99	0.26	0.03	2.30
Average value		***1.10***	***1.34***	***8.50***	***48.67***	***0.19***	***1.03***	***1.82***	***11.33***	***0.47***	***0.06***	***3.50***
Gyrgyshlag-Girdagh (Chokrak)	**GG-22**	0.91	0.61	4.38	74.29	0.007	3.54	1.46	0.94	0.46	0.006	4.19
	GG-23	1.27	0.90	6.51	80.42	0.006	0.01	1.82	0.94	0.74	0.007	2.20
	GG-24	0.85	0.01	5.53	79.55	0.009	0.01	1.75	0.76	0.62	0.006	2.21
	GG-25	0.97	0.57	5.95	79.47	0.009	1.03	1.83	0.37	0.01	0.009	1.74
	GG-26	1.74	1.30	6.56	71.11	0.008	1.61	1.78	1.21	0.36	0.009	2.89
	GG-27	1.01	0.70	6.07	81.03	0.007	0.43	1.47	0.48	0.51	0.007	2.33
	GG-28	1.06	0.01	4.33	87.36	0.005	0.01	1.24	0.01	0.01	0.006	1.74
	GG-29	1.39	1.06	8.43	69.68	0.004	1.14	1.97	1.02	0.54	0.003	3.12
	GG-30	1.04	0.75	6.09	80.43	0.008	0.41	1.52	0.62	0.47	0.010	1.68
	GG-31	1.51	0.81	6.01	82.32	0.007	0.01	1.67	0.78	0.29	0.008	1.99
	GG-32	1.63	0.77	5.77	82.75	0.009	0.01	1.52	0.49	0.29	0.009	2.02
Average value		***1.22***	***0.68***	***5.97***	***78.95***	***0.01***	***0.75***	***1.64***	***0.69***	***0.39***	***0.01***	***2.37***
Gyrgyshlag-Girdagh (Diatom)	**GG-33**	1.38	0.67	4.11	86.2	0.009	0.01	1.54	1.57	0.01	0.008	1.40
	GG-34	1.18	0.01	5.72	81.22	0.003	1.28	1.85	0.72	0.01	0.005	1.57
	GG-35	0.01	1.07	6.19	82.57	0.004	0.98	1.41	0.75	0.53	0.004	2.06
	GG-36	0.02	17.79	2.89	10.24	0.006	0.01	0.36	29.07	0.01	0.56	2.87
	GG-37	0.01	16.04	3.26	10.92	0.005	0.01	0.40	27.94	0.01	0.33	3.86
	GG-38	1.93	2.65	14.97	55.22	0.007	4.84	2.69	2.49	0.43	0.008	5.06
	GG-39	2.08	1.98	9.99	38.96	0.009	11.08	1.94	13.79	0.01	0.006	4.49
	GG-40	2.49	1.69	12.52	59.18	0.006	5.53	2.43	3.42	0.01	0.010	3.91
	GG-41	1.96	3.34	15.56	57.34	0.008	0.67	3.53	1.08	0.75	0.006	5.35
	GG-42	1.60	4.02	9.43	49.95	0.007	2.34	2.03	10.32	0.42	0.009	5.27
	GG-43	1.62	2.53	10.24	59.18	0.008	0.73	2.34	9.54	0.52	0.009	3.69
	GG-44	1.95	1.55	7.81	53.53	0.009	0.01	1.96	15.48	0.01	0.010	2.07
	GG-45	3.08	3.16	15.84	55.26	0.010	0.84	3.57	1.10	0.51	0.008	5.70
Average value		***1.49***	***4.35***	***9.12***	***53.83***	***0.01***	***2.18***	***2.00***	***9.02***	***0.25***	***0.07***	***3.64***

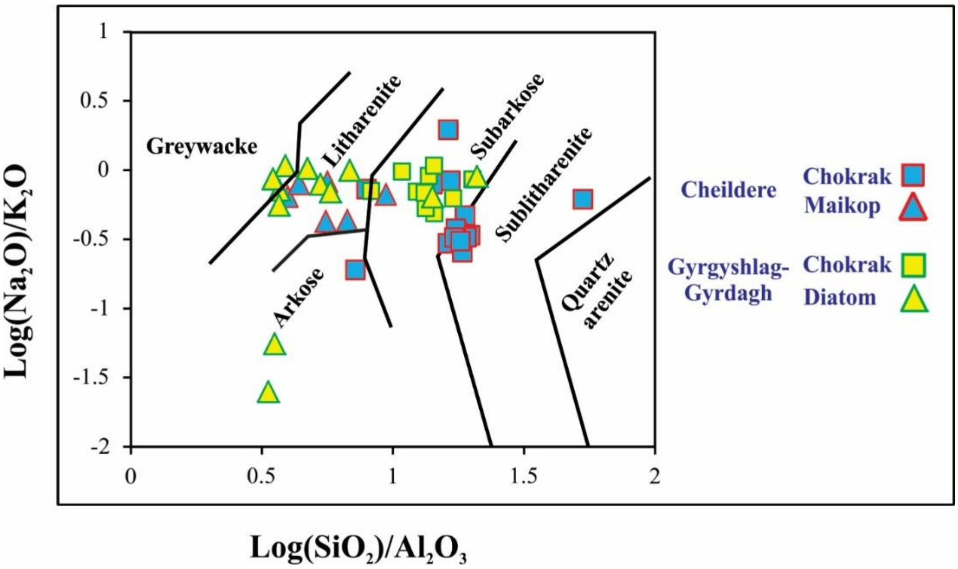

Fig. 7. Diagrams showing the chemical classification [23]

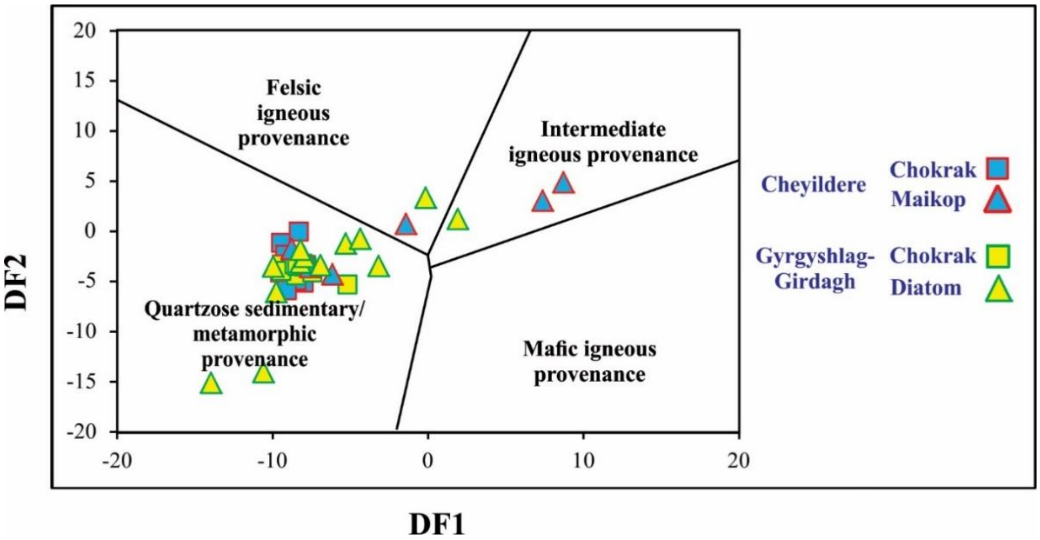

Fig. 8. Classification plot of discriminant functions DF1 and DF2 for the studied samples. Provenance fields are from [29]

Table 4

Concentration of moisture and oil content in oil-bearing rock samples

Area/Age	Sample	Moisture, %	Oil content, %
Cheyildere (Chokrak)	Ch-1	0.54	6.29
	Ch-2	0.38	5.15
	Ch-3	0.79	20.04
	Ch-4	1.35	5.64
	Ch-5	0.41	8.66
	Ch-6	0.42	8.18
	Ch-7	1.07	13.71
	Ch-8	0.33	4.81
	Ch-9	0.59	5.02

Continuation of table 4

Cheyildere (Chokrak)	Ch-10	0.52	6.44
	Ch-11	0.27	6.28
	Ch-12	0.38	5.46
	Ch-13	0.99	4.76
	Ch-14	0.34	4.7
	Ch-15	0.33	9.27
Average		0.58	7.63
Cheyildere (Upper Maikop)	Ch-16	1.16	2.77
	Ch-17	0.87	14.56
	Ch-18	1.64	20.62
	Ch-19	1.94	24.27
	Ch-20	0.52	13.26
	Ch-21	1.04	13.21
Average		1.19	14.78
Gyrgyshlag-Girdagh (Chokrak)	GG-22	0.33	5.2
	GG-23	0.43	5.16
	GG-24	0.36	8.73
	GG-25	0.42	9.5
	GG-26	0.86	6.08
	GG-27	0.71	5.03
	GG-28	0.47	6.6
	GG-29	0.83	14.48
	GG-30	0.45	6.54
	GG-31	0.72	3.96
	GG-32	0.71	3.99
Average		0.57	6.84
Gyrgyshlag-Girdagh (Diatom)	GG-33	9.79	2.95
	GG-34	0.52	11.33
	GG-35	2.57	34.22
	GG-36	0.98	22.67
	GG-37	1.34	25.71
	GG-38	5.73	10.46
	GG-39	4.21	18.31
	GG-40	1.86	9.68
	GG-41	4.29	13.12
	GG-42	1	18.5
	GG-43	2.17	13.31
	GG-44	0.45	6.98
	GG-45	4.27	6.17
Average		3.01	14.87

section, which reaches up to 40 meters in the Miocene outcrops observed in the Cheyildere and Gyrgyshlag-Girdagh areas. When comparing the areas, Chokrak is particularly notable for its high quartz content, which exceeds 70%. The oil-bearing rocks in this formation are characterized by a relatively low clay mineral content and a complete absence of carbonate minerals. In contrast, the Upper Maikop oil-bearing formation contains calcite, while the Diatom oil-bearing formation is rich in dolomite. The Diatom formation also exhibits a significant increase in clay mineral content, with an average of 19.75%.

Most oil-bearing rocks of Maikop and Diatom ages are associated with greywacke and litharenite, while the Chokrak formation, with its higher silicon content, is linked to subarkosic and sublitharenitic rocks. For the oil-bearing Miocene rocks, in addition to quartzose-rich sedimentary sources, certain intermediate and felsic igneous rocks should also be considered as potential contributors. The Chokrak oil-bearing formation, which is rich in quartz, exhibits a more mature mineralogical composition. Such deposits, typically associated with passive continental margins, the interior regions of cratons, or recycled orogenic areas, are characteristic of long-distance transport. Such deposits, which undergo relatively intensive weathering and are associated with granite-gneiss terranes and a polycyclic sand fraction, may have originated from previously existing sedimentary terranes.

Compared to the Upper Maikop and Diatom samples, the Chokrak samples contain half the oil concentration and moisture. Samples with higher clay and carbonate content show significantly greater oil accumulation potential than those with high quartz content. In this regard, the marly rocks of the Diatom (Meotian) are particularly noteworthy.

References

1. Abbasov, O.R. (2017). Distribution regularities and geochemistry of oil shales in Azerbaijan. Mineral resources of Ukraine, 2, 22-30.

2. Abbasov, Orhan, Aliyev, Adil. (2018). Organic geochemical characteristics of oil shale in Azerbaijan. The 36th National and the 3rd International Geosciences Congress, Tehran, Iran, 25-27 February. 12.

3. Abbasov, O.R. (2022). Eocene-Miocene oil shales in Azerbaijan: Stratigraphic controls on formation, distribution and hydrocarbon generation. Stratigraphy and sedimentology of oil-gas basins, 1, 39-55. https://doi.org/10.35714/ggistrat20220100004

4. Abbasov, Orhan R., Baloglanov, Elnur E., Yolchuyeva, Ulviyya J., Khuduzade, Arastun I., Akhundov, Ruslan V. (2025). Factors controlling the formation and oil generating potential of the middle Eocene shales of Eastern Azerbaijan. Boletín de la Sociedad Geológica Mexicana, 77(1), A020724. http://doi.org/10.18268/BSGM2025v77n1a020724

5. Aliyev Ad.A., Guliyev, I.S., Dadashev, F.G., Rahmanov, R.R. (2015). Atlas of mud volcanoes in the world. Baku: Publishing house "Nafta-Press", "Sandro Teti Editore", 321.

6. Aliyev, Ad.A., Abbasov, O.R., Ibadzade, A.J., Mammadova, A.N. (2018). Genesis and organic geochemical characteristics of oil shale in Eastern Azerbaijan. SOCAR Proceedings, 3, 4-15. http://doi.org/10.5510/OGP20180300356

7. Aliyev, A., Abbasov, O., Agayev, A. (2019). Mineralogy and geochemistry of oil shale in Azerbaijan: Classification, palaeoweathering and maturity features. Visnyk of V. N. Karazin Kharkiv National University, Series "Geology. Geography. Ecology, 50, 11-26. https://doi.org/10.26565/2410-7360-2019-50-01

8. Aliyev, Adil A., Abbasov, Orhan R. (2019). Nature of the provenance and tectonic setting of oil shale (Middle Eocene) in the Greater Caucasus southeastern plunge. Geodynamics, 1(26), 43-59. https://doi.org/10.23939/jgd2019.01.043

9. Aliyev, A.A., Abbasov, O.R. (2019). Mineralogical and geochemical proxies for the Middle Eocene oil shales from the foothills of the Greater Caucasus, Azerbaijan: Implications for depositional environments and paleoclimate. Mineralia Slovaca, 51(2), 157-174.

10. Aliyev, A.A., Abbasov, O.R. (2020). Distribution patterns, organic geochemistry and mineralogy of oil shales in Azerbaijan. Gornyi Zhurnal, 8, 13-18. https://doi.org/10.17580/gzh.2020.08.02

11. Aliyev, Ad.A., Abbasov, O.R., Aghayev, A.M., Khuduzade, A.I., Hasanov, E.H. (2022). Mineralogy, geochemistry and paleoweathering characteristics of Paleogene-Miocene oil shales in Azerbaijan. SOCAR Proceedings, 1, 24−36. https://doi.org/10.5510/OGP20220100625

12. Aliyev, A., Huseynov, D., Abbasov, O., Rashidov, T., Kangarli, I. (2024). Mud volcanoes of Azerbaijan: The unique natural objects of the geoheritage. Geoheritage, 16, 20. https://doi.org/10.1007/s12371-024-00931-3

13. Alizade, A.A., Guliyev, I.S., Mamedov, P.Z., Aliyeva, E.H., Feyzullayev, A.A., Huseynov, D.A. (2018). Productive strata of Azerbaijan, 1. M., Nedra. I, 305.

14. Alizade, A.A., Guliyev, I.S., Mamedov, P.Z., Aliyeva, E.H., Feyzullayev, A.A., Huseynov, D.A. (2018). Productive strata of Azerbaijan, 2. M., Nedra. II, 236.

15. Baldermann, Andre, Abbasov, Orhan Rafael, Bayramova, Aygun, Abdullayev, Elshan, Dietzel, Martin (2020). New insights into fluid-rock interaction mechanisms at mud volcanoes: Implications for fluid origin and mud provenance at Bahar and Zenbil (Azerbaijan). Chemical Geology, 537, 119479. https://doi.org/10.1016/j.chemgeo.2020.119479

16. Baloglanov, E.E., Abbasov, O.R., Akhundov, R.V. (2018). Mud volcanoes of the world: classifications, activities and environmental hazard (informational-analytical review). European Journal Natural History, 5, 12–26.

17. Baloglanov, E. (2023). Geochemical proxies of the gryphon breccia of mud volcanoes in East Azerbaijan: regularities in the distribution of chemical elements and spatial characteristics of sedimentation. Visnyk of V. N. Karazin Kharkiv

National University, Series "Geology. Geography. Ecology", (59), 8-17. https://doi.org/10.26565/2410-7360-2023-59-01

18. *Bayramova, Aygun, Abbasov, Orhan R., Aliyev, Adil A., Baloglanov, Elnur E., Stamm, Franziska M., Dietzel, Martin, Baldermann, Andre. (2023). Tracing water-rock-gas reactions in shallow productive mud chambers of active mud volcanoes in the Caspian Sea region (Azerbaijan). Minerals, 13(5), 696. https://doi.org/10.3390/min13050696*
19. *Cox, R., Lowe, D.R., Cullers, R.L. (1995). The influence of sediment recycling and basement composition on evolution of Mudrock chemistry in the Southwestern United States. Geochimica et Cosmochimica Acta, 59(14). 2919–2940. http://doi.org/10.1016/0016-7037(95)00185-9*
20. *Deer, W.A., Howie, R.A., Zussman, J. (1992). An introduction to the rock-forming minerals. Longman Scientific & Technical, 696.*
21. *Guliyev, I.S., Abdullayev, N.R., Huseynova, Sh.M. (2020). Distribution and volume of rocks in sedimentary basins – unusual case of the South Caspian basin. SOCAR Proceedings, 3, 4−10. https://doi.org/10.5510/OGP20200300439*
22. *Gurbanov, V.Sh., Narimanov, N.R., Nasibova, G.J., Mukhtarova, Kh.Z., Narimanov, R.N., Huseynova, Sh.M. (2021). Qualitative assessment of compressional stresses within the South Caspian megadepression and their impact upon structure formation and hydrocarbon generation. ANAS Transactions, Earth Sciences, 2, 39−49. https://doi.org/10.33677/ggianas20210200061*
23. *Herron, M.M. (1988). Geochemical classification of terrigenous sands and shales from core or log data. Journal of Sedimentary Research, 58(5), 820–829. http://doi.org/10.1306/212f8e77-2b24-11d7-8648000102c1865d*
24. *Liu, Jiarui., Treude, Tina, Abbasov, Orhan R., Baloglanov, Elnur E., Aliyev, Adil A., Harris, Carolynn M., Leavitt, William D., Young, Edward D. (2024). Clumped isotope evidence for microbial alteration of thermogenic methane in terrestrial mud volcanoes. Geology, 52 (1), 22–26. https://doi.org/10.1130/G51667.1*
25. *Muradova, P.A., Litvishkov, Yu.N., Abbasov, O.R. (2024). Thermogravimetric study of oil shales of some deposits in Eastern Azerbaijan by the method of microwave impact. ANAS Transactions, Earth Sciences, 2, 160−167. https://doi.org/10.33677/ggianas20240200134*
26. *Nadirov, S.G., Salayev, S.G., Zeynalov, M.M. (1959). Geological prerequisites for open-pit mining of oil-bearing rocks of the Oligocene-Miocene complex of the Kobystan region. Izv. Academy of Sciences of the AzSSR. Ser. geol.-geogr. sciences. 1959, 5.*
27. *Odonne, Francis, Imbert, Patrice Imbert, Dupuis, Matthieu, Aliyev, Adil A., Abbasov, Orhan R., Baloglanov, Elnur E., Vendeville, Bruno C., Gabalda, Germinal, Remy, Dominique, Bichaud, Victori, Juste, Rémy, Pain, Maëlys, Blouin, Arthur, Dofal, Anthony, Gertauda, Mathieu. (2020). Mud volcano growth by radial expansion: Examples from onshore Azerbaijan. Marine and Petroleum Geology, 112, 104051. https://doi.org/10.1016/j.marpetgeo.2019.104051*
28. *Odonne, Francis, Imbert, Patrice Imbert, Remy, Dominique, Gabalda, Germinal, Aliyev, Adil A., Abbasov, Orhan R., Baloglanov, Elnur E., Bichaud, Victori, Juste, Remy, Dupuis, Matthieu, Bonvalot, Sylvain. (2021). Surface structure, activity and microgravimetry modeling delineate contrasted mud chamber types below flat and conical mud volcanoes from Azerbaijan. Marine and Petroleum Geology, 34, 105315. https://doi.org/10.1016/j.marpetgeo.2021.105315*
29. *Roser, B.P., Korsch, R.J. (1988). Provenance signatures of sandstone-mudstone suites determined using discriminant function analysis of major-element data. Chemical Geology, 67 (1-2), 119–139. http://doi.org/10.1016/0009-2541(88)90010-1*
30. *Salayev, S.G., Kravchinskiy, Z.Ya., Selimkhanov, A.I., Nadirov, S.G., Sadikov, A.M., Aliyev, H.M. (1989). Oil sands and oil shale of Azerbaijan. Baku: Elm, 1989. 209.*
31. *Yagubov, A.A., Ali-zade, A.A., Zeynalov, M.M. (1971). Mud volcanoes of Azerbaijan. Atlas. Baku: Elm, 256.*
32. *Wedepohl, K.H. (1978). Handbook of geochemistry. Springer-Verlag, 442.*

Authors Contribution: All authors have contributed equally to this work
Conflict of Interest: The authors declare no conflict of interest

Мінералогічні та геохімічні показники міоценових відкладень Східного Азербайджану: походження та нафтоносність

Ельнур Балогланов [1]
наук. співробітник відділу грязьового вулканізму, [1] Інститут геології та геофізики,
Міністерство науки та освіти Азербайджанської Республіки, Баку, Азербайджан;
Ульвія Йолчуєва [2, 3]
к. хім. н., доцент, зав. лабораторії, [2] Інститут нафтохімічних процесів
Міністерства науки та освіти Азербайджанської Республіки, Баку, Азербайджан;
Кафедра хімічної інженерії, факультет інженерії та прикладних наук,
[3] Університет Хазар, Баку, Азербайджан;
Руслан Ахундов [1]
наук. співробітник відділу грязьового вулканізму,
Ельмар Самедов [1]
інженер відділу грязьового вулканізму;
Камал Мустафаєв [4]
менеджер, [4] центр досліджень та розробок AZLAB, Баку, Азербайджан

Це дослідження показує потенціал нетрадиційних вуглеводневих ресурсів у Східному Азербайджані, зосереджуючись на нафтоносних породах у районах Чейилдере та Гиргишлаг-Гірдаг. У дослідженні оцінюється просторовий та часовий розподіл мінералів та хімічного складу в міоценових стратиграфічних формаціях. Мінералогічні та хімічні дані дозволили ідентифікувати теригенні типи кварцу в Майкопській, Чокракській та Діатомових формаціях, що надає інформацію про їх седиментологічну зрілість. Крім того, у дослідженні використовуються результати геохімічної класифікації та діаграми тектонічних дискримінантних функцій для глибшого розуміння протолітів міоценових нафтоносних відкладень. Це дослідження також оцінює вплив мінералогічного складу та вологи на потенціал нафтоносності. Ці результати надають цінну інформацію для оцінки нафтоносного потенціалу міоценових відкладень у регіоні, що може суттєво вплинути на майбутні стратегії розвідки та управління ресурсами. Геологічні характеристики нафтоносних відкладень стратиграфічної одиниці міоцену були ретельно проаналізовані, що дало нове розуміння закономірностей розподілу нафтоносних формацій та пластів у досліджуваних районах. Мінералогічний склад було детально досліджено, зосереджуючись на просторових та часових варіаціях розподілу мінералів у різних формаціях міоцену. Хімічний склад виявляє значні відмінності між формаціями з точки зору елементних сигнатур. Вивчення хімічних показників дозволило ідентифікувати специфічні теригенні типи кварцу. Крім того, дослідження оцінило вплив мінералогічного складу, вологості та вмісту нафти на нафтоносність. Результати продемонстрували чіткий зв'язок між мінералогічними характеристиками та нафтоносним потенціалом порід. Відносно вологі зразки, що містять глинисті та карбонатні мінерали, демонструють значно вищий потенціал накопичення нафти, ніж зразки з високим вмістом кварцу. З цієї точки зору, особливий інтерес представляють мергелісті породи Меотису.

***Ключові слова**: міоцен, нафтоносна порода, мінералогія, геохімія, класифікація, седиментологічна зрілість, район походження та нафтоносність.*

Внесок авторів: всі автори зробили рівний внесок у цю роботу — Надійшла 12 лютого 2025 р.
Конфлікт інтересів: автори повідомляють про відсутність конфлікту інтересів — Прийнята 17 березня 2025 р.