

Mathematical Assessment of the Hydrogeochemical Evolution of Formation Waters and Salt Precipitation Risks in the Amirkhanli Area of the Siyazan Monocline

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ABSTRACT

This article presents a comprehensive study of the geological structure, hydrogeological characteristics, and chemical composition of formation waters in the Amirkhanli field, located within the Siyazan monocline. The primary objective of the research is to determine the relationship between the mineralization level of formation waters and geological factors—based on an analysis of the field's lithological-tectonic structure and groundwater chemistry—and to calculate quantitative indicators of salt precipitation processes using mathematical methods.

In terms of regional structure, the Amirkhanli field is situated southeast of the Zaghlī field and northwest of the Saadan field. The region is tectonically bounded by the Tengi-Beshbarmak anticlinorium to the south and the Talebi-Gaynarcha uplands to the north, while its eastern boundary is defined by the Gilgilchay River valley. The stratigraphic section of the field comprises Cretaceous deposits as well as Lower Paleogene sediments belonging to the Sumgayit, Govundagh, and Maykop series.

During the research process, laboratory analyses were conducted on 58 water samples collected from 48 wells spanning 16 geological horizons of the Amirkhanli field. It was determined that the genetic types of formation waters are primarily represented by calcium-chloride (CaCl_2), magnesium-chloride (MgCl_2), and sodium-bicarbonate (NaHCO_3) groups. The mineralization level of the groundwater varies across a wide range, from 3240 mg/L to 48907 mg/L. Minimum values for this parameter were found in the Upper Cretaceous complex, while maximum values were localized in the Maikop-Oligocene deposits. This differentiation is directly linked to lithological factors: Upper Cretaceous sandstones, characterized by high filtration capacity, facilitate the formation of waters with low mineralization, whereas Maikop clay-marl rocks, characterized by low permeability, foster the formation of highly mineralized waters. Based on the chemical analysis results of the field's formation waters, the study examined the salt composition distribution (calculated using the Fresenius method), hydrogeochemical characteristics, and potential technological complications that might arise during field development. The calculations indicate that the formation waters of the studied wells generally exhibit high mineralization and are characterized by complex ion-salt compositions. The research results enable the development of engineering and technical measures to prevent risks such as salt accumulation in the near-wellbore zone, equipment corrosion, and emulsion formation.

Keywords: Formation waters, formation complex, mineralization, horizon, sediment, groundwater, Fresenius method, desalination, hydrogeochemistry, salt precipitation

INTRODUCTION

The Siyazan oil and gas field is a monoclinical structure located in the northeastern part of the South Caucasus, specifically encompassing the northeastern limb of the Tengi-Beshbarmak anticlinorium. It is bounded by the Khizi synclinorium to the southwest and the Gusar-Davachi superimposed depression to the northeast. A striking feature of the monocline is the steep dip of the strata, ranging from 70° to 90° . The tectonic setting is largely defined by the Siyazan regional fault and associated structural faulting; at depth, Lower Paleogene and Upper Cretaceous deposits are thrust over the Maykop strata.

The stratigraphic section of the field comprises Cretaceous deposits as well as the Sumgayit, Govundag, and Maykop series of the Lower Paleogene. In the Amirkhanli area, the Maykop deposits consist of sandy layers - containing clayey conglomerate interbeds - and, to some extent, sandstones; the sandy intervals frequently exhibit signs of oil. The total thickness of the Maykop sequence reaches 645 meters. The Govundag unit is characterized by a more complex lithology, consisting of alternating layers of sand, sandstone, clay, and siltstone. The complex water-oil contact and water-encroachment dynamics formed during the final stage of oil and gas field development necessitate the assessment of the geochemical evolution of formation waters using mathematical methods [7, 8].

Fault angles range from 80° to 90°, and vertical displacement varies from a few meters to 1,000 meters. The monocline is divided into more than twenty tectonic blocks by these faults, creating areas conducive to oil saturation.

There are five main fields within the monocline: Chandahar-Zarat, Siyazan-Nardaran, Sadan, Amirkhanli, and Zaghli-Zeyva. The geological structure and stratigraphic characteristics of these fields are very similar. Paleogene-Miocene deposits are prevalent in the elevated areas, while Pliocene deposits dominate the plains.

Oil and gas manifestations are observed throughout the area. These occurrences are associated with the Maikop, Tortonian, and Sarmatian strata, as well as with oil migrating from deeper layers through fractures and gryphons.

This article focuses on geological and hydrogeological studies and the analysis of groundwater monitoring conducted in the Amirkhanli field of the Siyazan monocline. The Amirkhanli field is situated southeast of the Zaghli field and northwest of the Sadan field. The tectonic boundaries of the region are defined by the Tengi-Beshbarmak anticlinorium to the south and the Talebi-Gaynarcha uplands to the north. It is bounded to the east by the Gilgilchay valley. The stratigraphic section of the area comprises Cretaceous deposits, as well as sediments belonging to the Sumgayit, Govundag, and Maykop series of the Lower Paleogene [11, 12].

The geological section of the Amirkhanli area has a multi-layered structure. Well investigations have revealed the presence of Cretaceous, Sumgayit, Govundag, and Maykop-age sediments at depth.

The Cretaceous section begins with limestone layers 130 meters thick. Overlying these are clay deposits ranging from 18 to 20 meters in thickness, which are in turn covered by limestone layers reaching an average thickness of 160 meters. The Lower Cretaceous deposits comprise the Valanginian, Hauterivian, Barremian, and Lower Aptian stages. Deposits from the Upper Aptian, Albian, Cenomanian, and Lower Turonian stages were subjected to erosion prior to the Upper Turonian; consequently, Upper Turonian-Coniacian conglomerates rest unconformably upon the Lower Aptian clays. Although the Upper Cretaceous stratigraphic sequence is complete, a trend of thinning is observed in individual stratigraphic units (Fig. 1.).

In the Amirkhanli area, the sequence consists primarily of siltstones and marly clay layers, with minor sand intercalations. Within this section, the siltstone and marly clay complex has an average thickness of 215 meters, while the sand interval reaches 15 meters. The Govundag unit exhibits a more complex lithology, formed by alternating layers of sand, sandstone, clay, and siltstone (Fig. 1.). This unit appears primarily in the upper and lower zones of the section, with an average thickness of 188 meters. The Lower Maykop unit is composed of gray and dark gray sandy-clayey layers and contains conglomerate interbeds ranging in thickness from a few millimeters to 1–2 centimeters. The porosity of the unit varies between 15% and 20%. In the Upper Maykop group, a significant decrease in the frequency of sand and conglomerate interbeds is observed compared to the Lower Maykop. As one moves northwest from the Siyazan area, it has been observed that the number and thickness of sand and siltstone layers within the Maikop deposits gradually increase. Wells drilled in this area have revealed relatively coarser-grained and well-sorted sandstones. This minor variation in the lithological structure of the Maikop complex has positively influenced its oil-bearing potential. In the Amirkhanli area, the Upper Maikop deposits are distributed in a clay-marl facies, and oil indications have been recorded in some wells alongside fine-grained sand layers.

The Chokrak, Sarmatian, Pontian, and Productive Series sedimentary complexes are composed of sand and clay; characteristic features of this group include the dominance of clays and marls, interspersed with very thin sand interlayers. Traces of oil associated with Chokrak and Lower Sarmatian sandstone intervals have been detected in some structural mapping wells. One transverse and one diagonal fault system have been identified in the area, with the vertical displacement amplitude of the strata along these faults ranging from 200 to 400 meters. In the Amirkhanli area, the Siyazan thrust fault manifests more acutely compared to adjacent areas.

The thrust surface undulates, forming a wavy profile; consequently, the same stratigraphic complex is intersected multiple times within a single well. Analysis of well-logging data indicates that the thrust surface was located at a depth of approximately 100–150 meters below the surface, transitioned to a vertical orientation between 150 and 500 meters, and dipped toward the south-southwest at an angle of 45–80° at depths exceeding 500 meters (Fig. 2).

The sedimentary deposits constituting the lithological composition of the Amirkhanli area exhibit significant differences compared to adjacent areas. Within the area, Cretaceous and Lower Paleogene deposits overlie the more steeply dipping Maikop complex in a thrust-faulted position. While the angle of unconformity above the Maikop complex is 50–60°, this angle increases to 75–85° over the Miocene deposits [1].

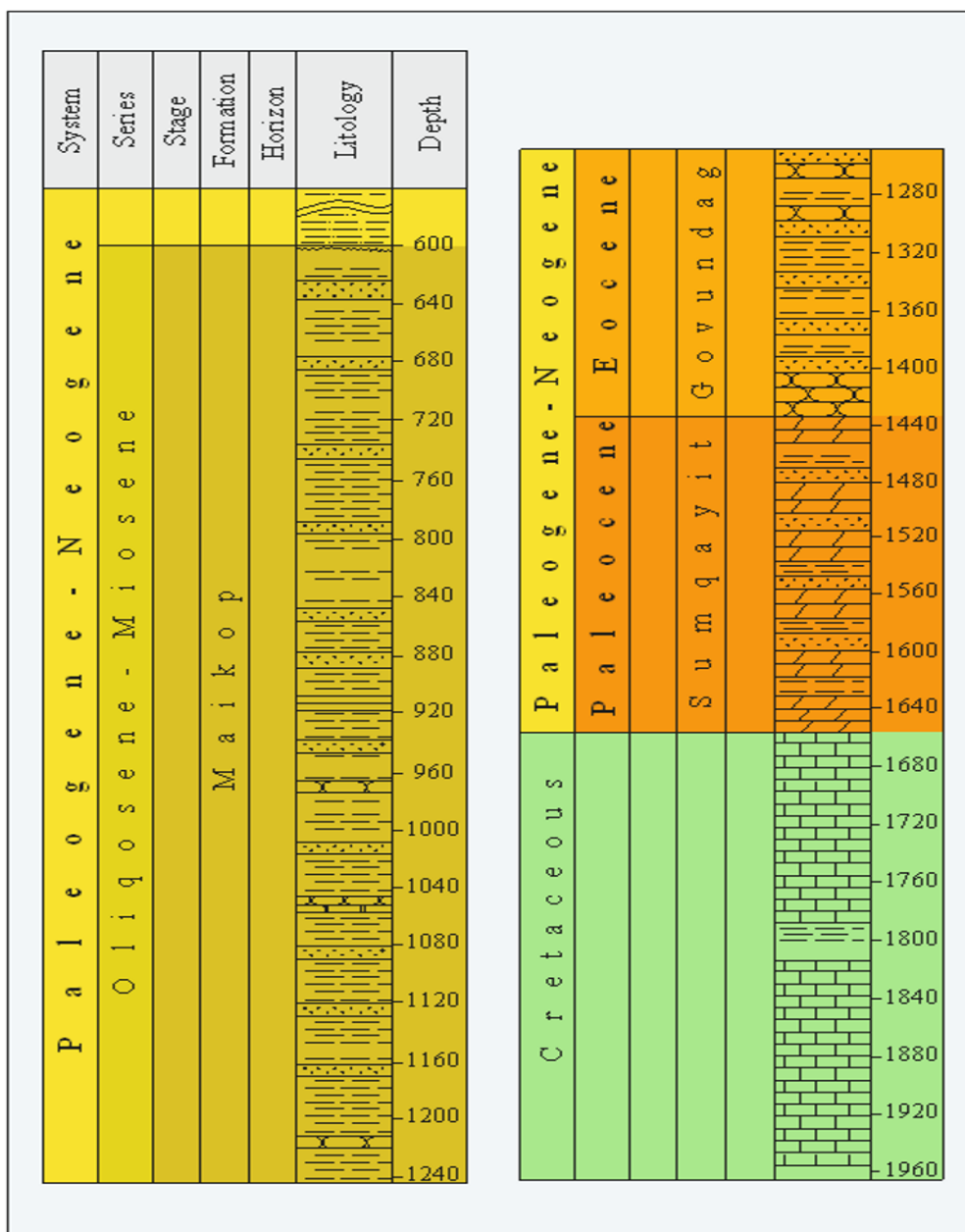


Fig. 1. Amirkhanli field. Generalized geological section.

Within the field, the Upper Cretaceous, Sumgayit, Govundag, and Maykop deposits are oil- and gas-bearing, while the Chokrak deposits are partially oil-bearing. The primary production horizons in the Amirkhanli field are horizons III-IV and V of the Maykop deposits. Several oil and gas occurrences associated with the Maykop and, to some extent, the Chokrak deposits are known in the Amirkhanli field.

Structural mapping wells drilled in the Amirkhanli field in 1940 (wells 4, 8, 28, 29, 37, 38, 40, 51, etc.) enabled the refinement of the geological structure and the discovery of oil and gas potential in the sub-Maykop deposits. The first flow of oil of commercial significance within the field (with a daily yield of 4–5 m³) was obtained that same year from the sandy-clayey deposits of the sub-Maykop interval in well No. 51.

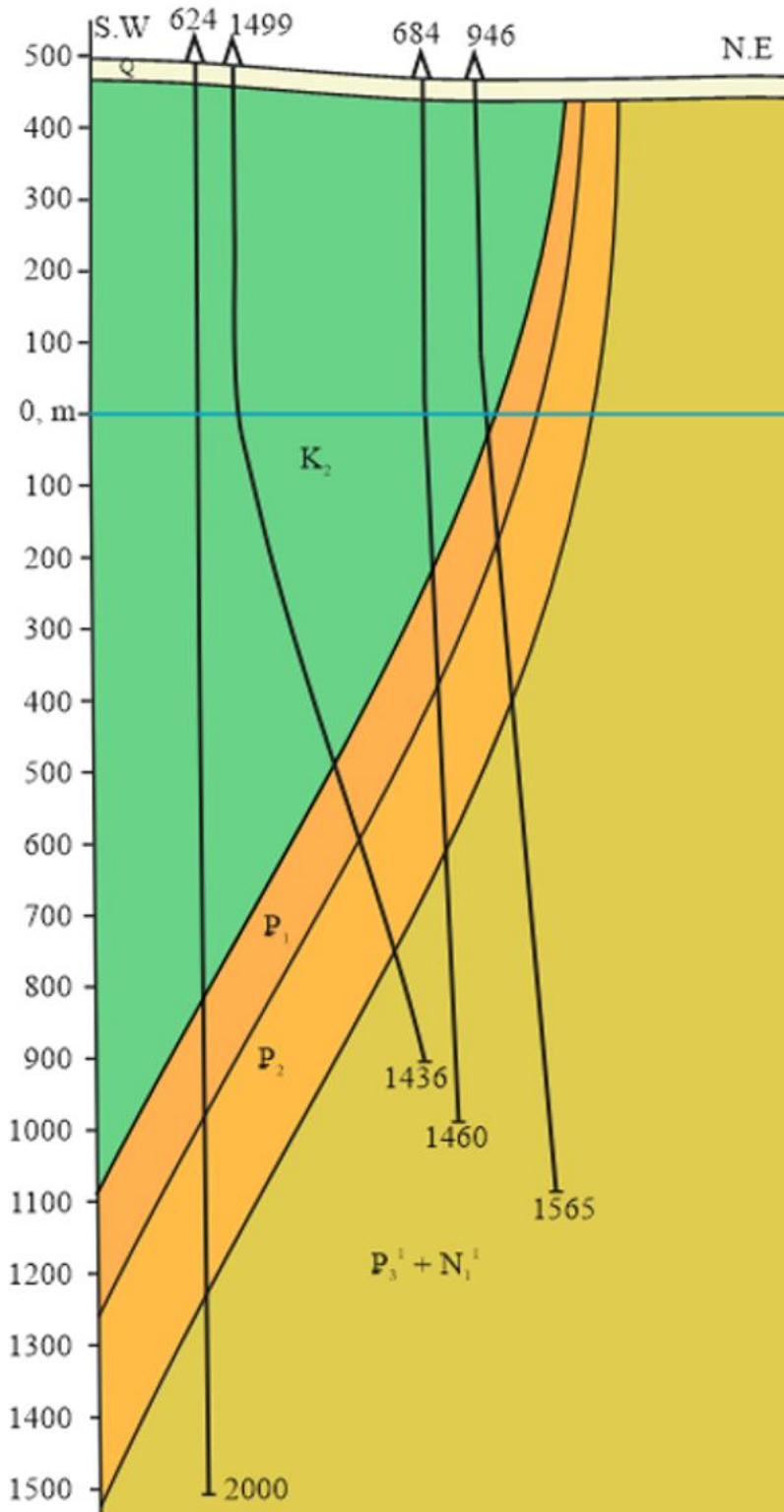


Fig. 2. Amirkhanli area. Geological profile along line I-I

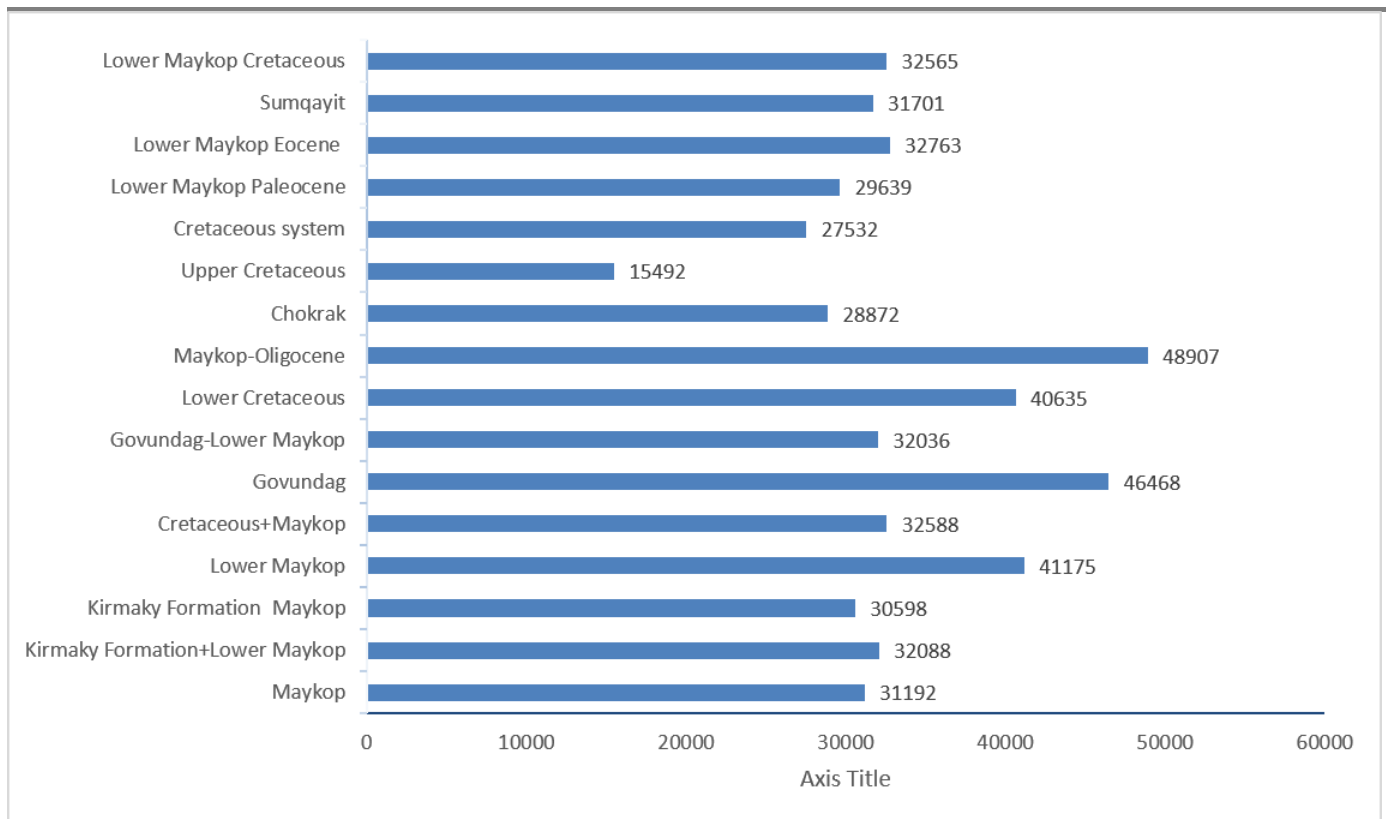


Fig. 3. Siyazan monocline. Histogram showing the variation in the mineralization level of groundwater across horizons in the Amirkhanli area (in mg/L).

RESEARCH METHODOLOGY

The study employs classical titration and spectral analysis methods on 58 water samples collected from 48 wells spanning 16 geological horizons of the Amirkhanli field (48 analyses for CaCl_2 and MgCl_2 types; 10 analyses for NaHCO_3 types). The genetic types of the formation waters were determined based on the Sulin and Fresenius classifications, and the ion-salt balance was quantitatively assessed in units of mg-eq/L.

It was determined that the formation waters are primarily of the calcium-chloride (CaCl_2), magnesium-chloride (MgCl_2), and sodium-hydrocarbonate (NaHCO_3) types. The mineralization level of the groundwater varies across a wide range, from 3,240 mg/L to 48,907 mg/L. The least mineralized formation waters were found in the highly permeable Upper Cretaceous sandstones (15,492 mg/L) (Fig. 3.), while the highest total mineralization was observed in the Maikop-Oligocene horizon (48,907 mg/L). This differentiation is attributed to lithological factors; the clayey nature of the Maikop complex restricts water circulation, thereby creating conditions conducive to high mineralization [6].

An analysis of the hydrogeological research and formation water test results indicates that, within the Amirkhanli field, the least mineralized formation waters occur in the Upper Cretaceous formation (15,492 mg/L). This result was obtained based on analyses of formation water from exploration wells Nos. 1294, 584, 864, 586, 609, 815, and 545, drilled between 1963 and 1976 within intervals of economic interest [13].

Regarding this indicator, minimum values are localized in the Upper Cretaceous complex, while maximum values are found in the Maikop-Oligocene deposits. Such differentiation is attributed to lithological factors: the highly permeable Upper Cretaceous sands facilitate the presence of weakly mineralized waters, whereas the low-permeability clay-marl rocks of the Maikop formation create conditions for the formation of highly mineralized waters [2, 5].

It has been determined that the formation waters are primarily of the calcium-chloride (CaCl_2), magnesium-chloride (MgCl_2), and sodium-bicarbonate (NaHCO_3) types.

Based on geological cross-section data, the Cretaceous section consists mainly of limestone layers, characterizing deposits of marine origin. When the limestone and carbonate reservoirs of the Cretaceous period possess sufficient porosity and fracturing, they act as highly permeable aquifers. The waters issuing from these layers are characterized—consistent with depth-related conditions—as hard, highly mineralized groundwaters of the calcium-chloride or magnesium-chloride type. Due to contact with carbonate deposits, the water's salinity and ionic composition depend directly on the degree of hydrogeological isolation of the structure.

The highest level of mineralization was observed in the Maikop-Oligocene horizon. During a study conducted in 1982, a total mineralization level of 48,907 mg/L was recorded in a formation water sample from exploration well No. 1046, drilled within the 620–930 meter interval. This represents the highest mineralization value identified for this area [5]. Geologically, the Maikop-Oligocene formation consists lithologically of alternating clay and clay-silt layers, with the presence of thin sandy interbeds observed throughout the section [14, 15]. The clay facies reflect deposition under deep-sea or basin conditions. The clayey composition and low permeability of the Maikop-Oligocene sediments impede water exchange; consequently, the formation waters in this complex are typically highly mineralized.

Studying the chemical composition of formation waters during the later stages of oil and gas field development is of exceptional importance for both assessing geological and hydrogeological conditions and ensuring the reliable operation of technological equipment.

The compositional makeup of formation waters sampled from wells drilled in the Amirkhanli field reflects the physicochemical characteristics of a closed hydrogeological regime and deep-seated basins [4].

Quantitative assessment of the salt composition of these waters using the Fresenius method enables precise monitoring of the geochemical processes occurring within the system (Table 1).

Classical chemical titration and spectral analysis methods were employed during the study. The genetic types of the formation waters were determined based on the Sulin and Fresenius classifications, and the ion-salt balance was quantitatively assessed in units of mg-eq/L [17, 18].

Quantitative calculations using the Fresenius method indicate that the reservoir waters are characterized by the following salt groups:

Sodium Chloride (NaCl): Constitutes the vast majority of the salt balance (averaging 436 mg-eq/L). This confirms that the waters formed under conditions of strong isolation.

Calcium and Magnesium Chlorides (CaCl₂, MgCl₂): High concentrations (up to 77 and 194 mg-eq/L, respectively) were recorded in wells covering the depth interval (e.g., Nos. 1744, 1742, 673), indicating a genetic connection.

Sulfates (Na₂SO₄, CaSO₄): Their minimal content confirms the presence of strongly reducing conditions and sulfate-reduction processes in the studied environment [9]. Quantitative analysis of salt composition using the Fresenius method confirms the prevalence of reducing conditions and calcium-chloride type waters. The results provide strategic engineering recommendations for preventing salt precipitation and corrosion in the near-wellbore zone. Based on the chemical analysis of formation waters, the study examined the distribution of salt composition (calculated via the Fresenius method), hydrogeochemical characteristics, and potential operational complications that may arise during field development. The calculations indicate that the formation waters of the studied wells are characterized primarily by high mineralization and complex ion-salt compositions [16].

The research findings enable the development of engineering and technical measures to prevent risks such as salt accumulation in the near-wellbore zone, equipment corrosion, and emulsion formation.

Table 1. Siyazan monocline. Calculation of the salt composition of subsurface formation waters in the Amirkhanli area using the Fresenius method (in mg-eq/L)

Well number	NaCl	MgCl ₂	CaCl ₂	Na ₂ SO ₄	MgSO ₄	CaSO ₄	NaHCO ₃	MgHCO ₃	CaHCO ₃	Na ₂ CO ₃	MgCO ₃	CaCO ₃	RCOONa	[RCOONa]Mg	[RCOONa]Ca	CaHCO ₃
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1560	482,19	53,17	21,24	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	10,40	0,00	0,00	0,00	0,00
893	477,51	71,44	21,53	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	14,40	0,00	0,00	0,00	0,00
886	560,08	65,84	5,59	0,00	0,00	0,00	0,00	0,00	10,23	0,00	0,00	0,00	0,00	0,00	0,00	0,00
185	425,03	84,12	19,22	0,00	0,00	0,00	0,00	0,00	8,43	0,00	0,00	0,00	0,00	0,00	0,00	0,00
1744	547,57	194,40	77,87	0,00	0,00	0,00	0,00	0,00	5,11	0,00	0,00	0,00	0,00	0,00	0,00	0,00
1547	548,27	42,17	0,00	0,00	0,00	0,00	0,00	5,81	16,62	0,00	0,00	0,00	0,00	0,00	0,00	0,00
568	404,01	29,94	0,00	0,00	0,00	0,00	0,00	1,09	16,62	0,00	0,00	0,00	0,00	0,00	0,00	0,00
573	492,39	73,00	13,48	0,00	0,00	0,00	0,00	0,00	11,02	0,00	0,00	0,00	0,00	0,00	0,00	0,00
896	462,38	42,88	14,69	0,00	0,00	0,00	0,00	0,00	8,26	0,00	0,00	0,00	0,00	0,00	0,00	0,00
1742	583,14	165,02	76,34	0,00	0,00	0,00	0,00	0,00	9,84	0,00	0,00	0,00	0,00	0,00	0,00	0,00
1547	415,37	57,94	21,40	0,00	0,00	0,00	0,00	0,00	13,38	0,00	0,00	0,80	0,00	0,00	0,00	0,00
1748	624,21	136,87	49,34	0,00	0,00	1,25	0,00	0,00	6,69	0,00	0,00	2,00	0,00	0,00	0,00	0,00
579	483,48	71,03	30,38	0,00	0,00	0,00	0,00	0,00	2,85	0,00	0,00	0,00	0,00	0,00	0,00	0,00
1675	441,66	50,04	13,51	0,00	0,00	0,00	0,00	0,00	12,59	0,00	0,00	0,00	0,00	0,00	0,00	0,00
682	428,39	67,41	24,95	0,00	0,00	0,00	0,00	0,00	6,69	0,00	0,00	0,00	0,00	0,00	0,00	0,00
567	443,13	40,97	0,00	0,00	0,00	0,00	0,00	1,08	13,47	0,00	0,00	0,00	0,00	0,00	0,00	0,00
879	408,25	52,43	8,73	0,00	0,00	0,00	0,00	0,00	10,23	0,00	0,00	0,80	0,00	0,00	0,00	0,00
527	441,48	31,03	13,94	0,00	0,00	9,04	0,00	0,00	6,43	0,00	0,00	0,00	0,00	0,00	4,95	1,22
526	430,20	27,74	25,52	0,00	0,00	0,00	0,00	0,00	10,31	0,00	0,00	0,00	0,00	0,00	3,27	1,42
558	474,23	31,77	5,21	0,00	0,00	0,00	0,00	0,00	2,77	0,00	0,00	0,00	0,00	0,00	0,40	0,70
635	554,03	38,11	18,05	0,00	0,00	0,00	0,00	0,00	4,61	0,00	0,00	0,00	0,00	0,00	2,51	0,93
1229	550,61	29,14	32,39	0,00	0,00	0,00	0,00	0,00	3,08	0,00	0,00	0,00	0,00	0,00	0,51	0,60
580	472,84	18,68	2,94	0,00	0,00	0,00	0,00	0,00	10,57	0,00	0,00	0,00	0,00	0,00	0,00	1,11
686	491,76	34,71	0,00	0,00	0,00	0,00	0,00	1,42	11,86	0,00	0,00	0,00	0,00	0,00	1,43	0,93
685	505,34	31,77	9,75	0,00	0,00	0,00	0,00	0,00	10,64	0,00	0,00	0,00	0,00	0,00	0,63	1,13
609	500,08	29,22	7,02	0,00	0,00	0,15	0,00	0,00	15,31	0,00	0,00	0,00	0,00	0,00	1,12	0,76
815	530,44	33,64	0,00	0,00	0,19	0,00	0,00	5,52	8,73	0,00	0,00	0,00	0,00	0,00	2,16	0,79
626	513,78	52,43	29,90	0,00	0,00	0,00	0,00	0,00	6,72	0,00	0,00	0,00	0,00	0,00	0,83	0,47
1294	84,73	0,00	0,00	26,26	0,00	5,70	0,00	0,00	5,77	0,00	0,00	0,40	0,00	0,00	1,87	0,08

Table 1(continued)

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
662	455,67	22,39	1,48	0,00	0,00	0,06	0,00	0,00	8,28	0,00	0,00	1,60	0,00	0,00	0,11	0,79
584	642,58	61,48	52,94	0,00	0,00	0,19	0,00	0,00	2,98	0,00	0,00	0,00	0,00	0,00	0,43	0,75
864	342,70	40,66	33,53	0,00	0,00	0,04	0,00	0,00	1,38	0,00	0,00	0,00	0,00	0,00	0,19	0,44
867	646,48	70,37	53,98	0,00	0,00	0,00	0,00	0,00	1,87	0,00	0,00	0,00	0,00	0,00	0,75	0,69
581	593,37	53,58	43,21	0,00	0,00	0,00	0,00	0,00	1,85	0,00	0,00	0,00	0,00	0,00	0,62	0,78
539	409,39	22,22	2,70	0,00	0,00	0,00	0,00	0,00	9,23	0,00	0,00	1,40	0,00	0,00	0,46	1,22
572	413,87	12,75	0,00	0,00	0,00	0,00	0,00	11,04	4,59	0,00	0,00	3,60	0,00	0,00	0,21	1,08
662	503,99	0,00	0,00	0,00	0,00	0,00	88,02	0,00	0,00	2,11	17,89	0,00	0,00	6,72	1,68	1,67
535	380,45	0,00	0,00	0,00	0,00	0,00	5,88	17,45	4,44	0,00	0,00	4,40	0,00	0,00	0,84	1,00
674	147,89	17,04	1,16	0,00	0,00	0,00	0,00	0,00	8,00	0,00	0,00	3,20	0,00	0,00	0,96	0,11
888	608,41	61,48	39,02	0,00	0,00	0,00	0,00	0,00	1,62	0,00	0,00	0,00	0,00	0,00	6,20	0,56
948	624,92	65,02	55,38	0,00	0,00	0,00	0,00	0,00	0,74	0,00	0,00	0,00	0,00	0,00	0,75	0,42
673	592,58	73,00	68,63	0,00	0,00	0,06	0,00	0,00	3,52	0,00	0,00	0,00	0,00	0,00	0,51	0,78
1046	682,27	85,27	50,02	0,00	0,00	0,00	0,00	0,00	17,70	0,00	0,00	0,00	0,00	0,00	4,68	0,70
1241	443,56	34,98	7,12	0,00	0,00	0,00	0,00	0,00	7,20	0,00	0,00	2,40	0,00	0,00	10,35	0,58
614	391,23	31,03	2,98	0,00	0,00	0,00	0,00	0,00	9,77	0,00	0,00	2,80	0,00	0,00	0,59	0,47
579	612,95	45,60	45,77	0,00	0,00	0,00	0,00	0,00	0,52	0,00	0,00	1,20	0,00	0,00	0,15	0,76
673	667,53	63,46	61,59	0,00	0,00	0,00	0,00	0,00	0,07	0,00	0,00	1,60	0,00	0,00	0,15	0,81
1255	211,27	0,00	0,00	0,00	0,00	0,00	34,30	21,40	0,13	0,00	0,00	1,20	0,00	0,00	2,08	0,93
1137	248,47	38,36	0,00	0,00	0,00	0,00	0,00	2,13	8,30	0,00	0,00	3,20	0,00	0,00	0,83	0,35
639	554,03	38,11	18,05	0,00	0,00	0,00	0,00	0,00	4,61	0,00	0,00	0,00	0,00	0,00	2,51	0,93
586	19,89	0,00	0,00	0,42	0,00	0,00	15,45	4,86	4,89	0,00	0,00	0,00	0,00	0,00	0,00	0,00
609	155,73	0,00	0,00	1,90	0,00	0,00	6,98	12,84	10,98	0,00	0,00	0,00	0,00	0,00	0,48	0,32
815	190,28	15,97	0,99	0,00	0,00	0,00	0,00	0,00	2,59	0,00	0,00	0,00	0,00	0,00	2,24	0,37
609	43,72	0,00	0,00	0,08	0,00	0,00	29,66	4,76	0,00	0,00	0,00	0,00	0,00	0,67	3,65	0,34
545	390,94	0,00	0,00	0,21	0,00	0,00	21,43	10,86	4,62	0,00	0,00	0,00	0,00	0,00	0,96	1,36
586	23,35	0,00	0,00	0,21	0,00	0,00	21,72	4,77	3,54	0,00	0,00	0,00	0,00	0,00	0,28	0,17
586	30,97	0,00	0,00	1,40	0,00	0,00	11,28	6,58	5,50	0,00	0,00	0,00	0,00	0,00	0,24	0,05
609	500,08	29,22	7,02	0,00	0,00	0,15	0,00	0,00	15,31	0,00	0,00	0,00	0,00	0,00	1,12	0,76

Based on the conducted research, the existing salt composition of the formation waters in the Amirkhanli field suggests that it could lead to several serious technical problems during production operations. The presence of CaCl_2 and MgCl_2 salts in the water, combined with changing thermobaric conditions, results in the formation of sparingly soluble calcium carbonate and sulfate deposits in the near-wellbore zone and tubing

strings. Furthermore, high chloride ion concentrations accelerate electrochemical corrosion in metal equipment, thereby shortening the service life of downhole installations[19, 20].

Analysis of the Amirkhanli field's formation waters using the Fresenius method revealed high levels of sodium chloride and significant hardness-causing salts. To ensure efficient and trouble-free field development, the implementation of the following measures is recommended:

Periodic injection of scale inhibitors and anti-corrosion reagents into the near-wellbore zone and pipelines. Implementation of special chemical flushing operations to timely remove salt plugs forming in the pipes.

Prioritizing corrosion-resistant materials when selecting production strings.

CONCLUSION

- The variation in the mineralization levels of formation waters across the 16 geological horizons of the Amirkhanli area (within the Siyazan monocline) is directly linked to lithological factors. Minimum values were recorded in Upper Cretaceous sandstones characterized by high filtration capacity (15,492 mg/L), while maximum values were observed in Maikop-Oligocene clay-marl rocks characterized by low permeability and a closed hydrodynamic regime (48,907 mg/L).
- Hydrogeochemical analyses confirm that the groundwater is primarily represented by calcium-chloride (CaCl_2), magnesium-chloride (MgCl_2), and sodium-bicarbonate (NaHCO_3) groups. The variation in total mineralization—ranging from 3,240 mg/L to 48,907 mg/L—indicates the presence of water exchange zones of varying intensity across the section.
- Quantitative calculations of salt composition using the Fresenius method have established that sodium chloride (NaCl) constitutes the vast majority of the salt balance in the studied wells (averaging 436 mg-eq/L). This predominance indicates the prevalence of a closed hydrogeological regime in the deep zones of the reservoir.
- The minimal presence or complete absence of sulfate ions (SO_4^{2-}) in the studied environment confirms the existence of strong reducing conditions and active sulfate-reduction processes within the reservoir.
- The application of mathematical-geochemical deconvolution methods—based on the hydrochemical baseline data obtained in this study—is crucial for the precise identification of water encroachment sources during the final stage of reservoir development. This approach enables the quantitative monitoring of mixing dynamics for waters originating from different horizons.
- The presence of calcium and magnesium chlorides in the formation waters demonstrates active cation exchange processes between the groundwater and the rock complex, reflecting the metamorphism of ancient marine waters.
- The complex ion-salt composition and high chloride content of the formation waters lead to the precipitation of sparingly soluble salts in the near-wellbore zone and within the tubing strings, driven by drastic changes in thermobaric conditions (pressure and temperature) during field development. Concurrently, the high concentration of chloride ions directly accelerates electrochemical corrosion of metal equipment.
- To ensure efficient, long-term, and incident-free field operation, it is essential to regularly inject scale inhibitors and anti-corrosion reagents into the near-wellbore zone, conduct scheduled chemical wash operations to remove accumulated salt plugs, and utilize only corrosion-resistant materials for production strings.

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