Clarification of the genesis of deposits of Qala Suite of the Hovsan-Zykh area by methods of stratigraphic and lithofacies analysis based on 3D seismic and Well Logging data (Absheron oil and gas bearing region, Azerbaijan)

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Abstract. The major share of oil, gas and gas condensate produced in Azerbaijan comes from deposits of the Lower Pliocene Productive Series. In this relation, a detailed study of the structure of the Productive Series (PS) deposits and the conditions of their formation is of great practical importance. For this purpose, new, highly data-rich methods of analysis have been widely used in recent years: seismic and sequence stratigraphy. The prediction of non-anticlinal traps and reservoirs in conditions of sharp facies variability of deposits is an urgent problem facing these methods. In recent years, various methods of facies analysis have also been widely used, which allows us to reconstruct the facies conditions and sedimentation conditions of sand bodies and clay deposits of the PS in the absence or limitation of core material. In this connection, the focus of the work was on studying the conditions of formation of sandy reservoir bodies and clayey screen rocks of fluvial-deltaic and coastal-marine genesis within the Productive Series of the Qala Suite, which is promising from the point of view of oil-bearing capacity, according to both seismic survey and well logging data. The object of the study was the Hovsan-Zykh area, located 20 km east of Baku, in the southern coastal part of the Absheron Peninsula. The industrially significant oil bearing capacity in this area is associated with the deposits of the Qala Suite Productive Series. In order to study the formation conditions of the Qala Suite deposits based on seismic data, paleostructural constructions, as well as seismic stratigraphic and seismic facies analysis of 3D seismic data were performed. Sequence-stratigraphic complexes were identified in the section of the study area, and various facies types were defined and analyzed within the Qala Suite strata. Sequence-stratigraphic analysis was performed on the basis of well logging data within the studied formation. In the process of research, the method of logging facies was also applied, which allows lithologic and facies diagnostics of sediments based on well logging data. Taking into consideration the new seismic and reinterpreted well data, the deposits in the eastern and western parts of the Hovsan field are divided into individual objects. In the area under study, the deposits of the Qala Suite are represented by alternating interbeds of clayey and sandy rocks and are subdivided into three strata: QaS-1, QaS-2, and QaS-3. Sedimentation conditions for all three units of the Qala Suite are similar, only the paleorelief and the amount of transported material differ, which affected the size and location of the formed traps. According to earlier researches, the boundaries for all deposits in the Qala Suite of the field were determined conditionally due to the lack of more detailed seismic surveys at that time.

Keywords: Qala Suite, genesis, seismic facies, facies, system tract, palaeodeltaic.

Уточнення генезису відкладів калинської свити Говсан-Зихської площі методами стратиграфічного та літофаціального аналізу за даними 3D сейсморозвідки та каротажу (Апшеронський нафтогазоносний район, Азербайджан)

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Анотація. Основна частина нафти, газу і газового конденсату, що видобуваються в Азербайджані, надходить з відкладів раннього пліоцену продуктивної серії. У зв'язку з цим важливе практичне значення має детальне вивчення структури родовищ продуктивної серії (ПС) та умов їх формування. Для цього в останні роки широко використовуються такі нові, досить інформативні методи аналізу, як сейсмічна та секвенційна стратиграфія. Прогнозування неантікіналних пасток і колекторів в умовах гострого фаціального розпізнавання відкладів є актуальною проблемою, що встановлюється на основі даних з використанням сейсмічних даних та каротажних даних. У статті описано розподіл відкладів ПС в естрадному районі Говсан-Зих, відділення Апшеронської нафтогазоносної області. У процесі дослідження були використані сейсмічні та каротажні дані, що дозволили уточнити зононість відкладів ПС у естрадній частині Говсану. Відклади ПС представлений в естрадній частині Говсану відкладами з відносно невисоким кутом падіння, що відбувається в зоні переходу від рідкісних розчленованих плоских структур до антиклінної. В результаті, відклади ПС могути мати значну поширюваність.
Introduction

Determination of the paleogeographic environment and facies composition of sand bodies is of paramount importance in the prospecting for oil and gas traps of non-anticlinal type (lithologic). As is known, in continental conditions, lithologic deposits of oil and gas are confined mainly to sediments of fluvial-alluvial genesis. The riverbeds of ancient rivers, made by sandy formations and overlain by clayey floodplain sediments, represent a favorable combination of well-permeable and impermeable rocks, which is so relevant for the formation of hydrocarbon accumulations. It is also known that the greatest number of lithologic oil and gas deposits is associated with deltaic complexes. Delta sediments serve as an important object of oil and gas accumulation (Nanz, 1954; Busch, 1959; Pirson, 1970; Visher, Saitta and Phares, 1971; Pettichon, Potter and Siver, 1976; King, 1975; Selli, 1981; Muromtsev, 1984; Wagoner et al., 1990; et al.).

The purpose of these researches was to reconstruct the conditions and environments of sedimentation of deposits of the Qala Suite of the PS, with which the industrially relevant oil bearing capacity of the studied area is associated.

Literature review

The matter of the origin of deposits of the Productive Series (PS), which is of prospecting interest in the area under consideration, has received attention from many researchers (Avdusin, 1952; Aliyev, 1947, 1949; Alizadeh, 1960; Baturin, 1932, 1937; Kovalevsky, 1922; Konyukhov, 1951; Mirchink, 1926, 1933; Mustafayev, 1963; Sultanov, 1949; Potapov, 1954; Hinds et al, 2004; Reynolds et al., 1998).

According to Aliyeva E.G., Aliyev Ch.C. et al, the PS section (Lower Pliocene) is represented by fluvial-deltaic-lake sediments covering the entire western side and central part of the South Caspian Basin and represents the main hydrocarbon reservoir containing about 95% of oil and gas reserves (Aliyeva et al., 2008). The formation of PS sediments of the Absheron (or otherwise called Volga) type was mainly due to terrigenous material brought by the Paleo-Volga from the Russian Platform, which was first proved by V.P. Baturin based on the similarity of the mineralogical composition of PS deposits and sediments of the modern Volga Delta (Baturin, 1937). Along with the northern source province, the Russian Platform, there were also other sources of drift of subordinate importance, which is confirmed by the presence of Paleozoic pebbles in the Absheron-type sediments (Vistelius and Miklukho-Maklai, 1951), apparently brought from the Middle Caspian landmass, and Cretaceous, Tertiary fauna from the Greater Caucasus (Aliyev, 1949; Sultanov, 1949).

The analysis of the history of geological development, performed on the basis of paleostructural constructions, has revealed that the fold-fracture structures, with which the studied deposits are associated, are characterized by different time of occurrence and changes in the intensity of their development in separate segments of geological time. As a result of studying and analyzing the genesis and paleogeography of the sedimentation basin (A.G. Aliyev, V.P. Baturin, A.D. Sultanov, P.Z. Mammadov, Sh. Kocharli, N.P. Yusubov and many others), it was established that the PS of Absheron was deposited in the coastal zone of the sea basin and is represented by the Absheron type of sediments, where the main rock-forming mineral is
quartz. This type of rock is characterized by relatively good fossilization of grains composing sandy rocks and predominance of sandy fraction over siltstone and clayey fraction. According to N.Y. Mehtiyev (1984), sedimentation took place in shelf conditions separated by certain uplift zones, sometimes protruding above sea level. In the basins of the Qala and Lower Kirmaky time there were ancient islands that originated in the pre-Pontic and Pontic times, some of which continued to exist until the Upper Kirmaky time. Sedimentation proceeded at the expense of feeding provinces, in the structure of which the rocks rich in quartz content took part. It should be mentioned that the basin owes its development not only to tectonic processes, but also to the flow into it of large rivers, whose regime was controlled by both climatic conditions and the paleorelief of the area formed for the given period. All these factors had a significant influence on changes in the flow velocity and water quantity in the paleo-rivers. At the same time, the mountain structures bordering the basin from the west uplifted and supplied huge masses of clastic material to the sedimentation zones. It should be emphasized that the lithofacial analysis of Pliocene deposits shows that the studied sediments are of diverse facies and are characterized by both deltaic and coastal-marine origin. The regularity of deposits observed in the study area is closely related to the change of their accumulation conditions.

Despite the fact that the geological structure of the Hovsan area has already been researched by various methods, not many articles (Aliева et al, 2008; Khalilova and Kerimova, 2022; Seidov and Khalilova, 2023) have been devoted to the issues of studying the genesis of deposits of the Productive Series of this area and adjacent areas in general. The published articles mainly discuss the peculiarities of the geological structure of the area and the prospects of their oil and gas content. For example, one of such publications (Ahmedov et al, 2018) provides geological and geophysical characterization of the study area, methodology and technology of field seismic studies, basic procedures of data processing and interpretation. The author of another paper devoted to the Hovsan area (Ahmedov, 2017) considers the results of application of Attribute and AVO-analysis to predict the oil and gas content of Pliocene and Miocene deposits in the studied area. Two more works (Ahmedov, 2017; Ahmedov, 2018) are dedicated to predicting the depths of the main, most important horizons of the Hovsan area located below the bottom of the wells. The study of small-amplitude tectonic disturbances by seismic attribute analysis in the Hovsan area is focused on the work of Alibekova Y. (Alibekova, 2023).

At the meanwhile, in recent years, the works of many researchers have proposed new approaches of applying seismic stratigraphy, sequence stratigraphy and log facies techniques (Abd Al-Salam Al-Masgari et al, 2021; Belozerov, 2011; Catuneanu, 2017; Catuneanu, 2009; Catuneanu et al, 2011; Embry, 2018; Leila, 2022).

In contrast to the works published to date, this article presents the results of studying the conditions of formation of Qala Suite deposits based on seismic and geophysical well logging data.

The study target

Hovsan-Zykha area, located 20 km east of Baku city, in the southern coastal part of Absheron peninsula, was chosen as the object of the study.

Since 1930, geological research, geophysical exploration and structural prospecting drilling work in the Hovsan area has determined the prospectivity of the area. The Zyk field is currently on reserve. Therefore, the presented article focuses on the Hovsan field.

The main oil and gas bearing object in the Hovsan-Zykha field is the Qala Suite. At the moment 94 wells have been drilled in the field. Against the total number of production wells there are 35 oil wells and 1 gas well. Of these, 14 oil wells are in operation, 21 oil and 1 gas well are in continuous operation, 5 wells are idle in the stock awaiting liquidation and 4 wells are idle in the irrigation stock. 49 wells have been abandoned for geological and technical reasons. Since the beginning of development the field has produced 4315.6 thousand tonnes of oil, 14720.7 thousand m³ of water, 1560.3 million m³ of dissolved gas, 27.3 million m³ of free gas. Annual oil production at the field was 58.3 thousand tonnes, condensate production – 6.9 thousand tonnes, water – 556.1 thousand m³, dissolved gas – 1.6 million m³. Product water cut is 90.5 % (Salmanov et al., 2023).

It is known that the PS deposits within the Hovsan-Zykha area are subdivided on the basis of lithologic composition into 9 lithostratigraphic complexes – from bottom to top: Qala, Lower Kirmaky, Kirmaky, Upper Kirmaky Sandy, Upper Kirmaky Clayey Suites (the lower part of the Productive Series), First break in deposition (Fasila), Balakhany, Sabunchi, Surakhany Suites (the upper part of the Productive Series). The Balakhany Suite in its turn is subdivided into 6 horizons from X to V.

The main potential of the studied area is associated with the deposits of the Qala Suite, in the section of which a number of separate production facilities are identified. In 1948, the Hovsan oil field was discov-
ered in well 1308 in the Qala Suite of the productive strata and put into commercial development. The field is exploited only onshore, as its offshore boundaries remain uncertain due to insufficient research.

Deposits of the Qala Suite are an irregular alternation of gray, light gray, fine and fine-grained sandstone, sand and clay. These deposits have been penetrated by exploration and production wells and are widely spread over the area. The section contains separate sandstone layers of different thickness, which are of great value from the point of view of oil-bearing capacity. In the section of the Qala Suite, the content of sandstones and sands gradually increases from north to south and from west to east. The thickness of the Qala Suite deposits in the Hovsan area is 250-350 m.

Deposits of the Qala Suite are subdivided into three horizons. The upper horizon (QaS-1) consists mainly of sand, sandstone and clay. Its thickness is 57 m. The upper part of the horizon (QaS-1a) is composed of hard rocks 14 m thick, the middle part (QaS-1b) is 22 m thick, of which only low thickness sandstones, identified in block III in well No. 1522, contain oil. The lower part of the horizon (QaS-1c) is composed of sandstones and sands (21 m). The middle horizon (QaS-2) consists of three parts composed mainly of thick sandstone layers. The total thickness of this horizon is 40-51 m. The upper part of the horizon (QaS-2a) has a thickness of 22 m, where 1-2 thin sandstone layers are distinguished, the middle part (QaS-2b) – 18 m, where in some parts of the deposit sandstone layers increase in thickness and harden. The lower part (QaS-2c) is 11 m thick and consists mainly of sandstone. In the Qala Suite section, sandstone and sand are most abundant in the lower horizon QaS-3. Its thickness is 118 m, of which the upper 58-meter part (QaS-3a) is more remarkable because it is oil-and-gas bearing. The remaining 110-meter-long middle and lower part of the horizon (QaS-3b and QaS-3c) consists mainly of clays and rare thin interlayers of sandstone and sand.

The Hovsan area is tectonically located in the buried part of the far eastern wing of the Garachukhur-Zykh anticlinal belt and extends in the NW-SW direction. The main features of this anticlinal belt are that the angle of occurrence of layers from the arch to the wings first increases and then decreases and that this belt is divided into blocks by longitudinal and transverse tectonic faults. The latter play a key role in the distribution of oil and gas deposits in the fields.

A total of 324 wells have been drilled within the Hovsan-Zykh area, of which 108 wells penetrate the Qala deposits. Sands and sandstones, which are oil and gas reservoirs, are identified mainly in the upper and middle horizons, as well as in the cap part of the lower layer of the lower horizon, and alternate with clay layers. The reservoir properties of the layers vary both along the section and over the area.

At the Hovsan field, oil deposits were accumulated in the Qala Suite paleosurface, and subsequent tectonic movements have reshaped the structure, making it a monoclinic structure in modern structural terms. The field is concentrated in the western and eastern parts of this monocline.

The main goal of the present studies is to identify the spreading halos of productive horizons over the area and to define new exploration objects within the Qala Suite based on the data of stratigraphic and lithofacies analyses.

**Material and methods**

Seismic stratigraphic, seismic facies, sequence-stratigraphic and lithofacies analyses were performed to study the conditions of formation of the Qala Suite deposits. In the process of lithofacial analysis, the Muromtsev method known as the logging facies methodology and the Emery methodology (Emery & Myers, 1996) were also applied, and cyclograms were constructed.

The lateral lithofacial variability of deposits observed in the Hovsan-Zykh area, as well as their heterogeneity, do not allow unambiguous correlation of logs from nearby wells, which, in turn, complicates the prediction of facies distribution along the profile and across the area. In this regard, there is a need to apply more accurate modern methodological techniques widely used in the world, including seismic stratigraphic analysis. Accordingly, the method of seismic stratigraphy was applied for the purpose of facies distribution prediction.

One of the main aims of seismic stratigraphic analysis is to reconstruct the conditions of sedimentation based on the characteristic features of seismic reflections. At the next stage of the work, seismic facies were identified and analyzed according to the characteristic features of the seismic record within the Qala Suite of the Productive Series, of interest from the point of view of oil and gas potential. Seismic facies analysis was performed in order to improve the results of prediction of filtration-capacity properties (FCP) for productive formations in the interwell space. Seismic facies classification maps were obtained. To identify the peculiarities of the geological structure of the horizons and the possibility of their zoning by area, the obtained seismic
facies maps were compared with the electrofacies of the corresponding formations.

Sequence stratigraphic and lithofacial analyses were carried out to clarify the formation conditions and lithofacial features of the Qala Suite deposits of the productive strata. Muromtsev’s method known as the log facies method and Emery’s method (Muromtsev, 1984) were applied. Cyclostratigraphic analysis was performed based on the study of changes in the granulometric composition of deposits. The studies were realized with the use of well logging data.

Results and discussion

A time cube in the 0-6 sec. interval was obtained in the study area. Geological information and wave pattern analysis allowed us to carry out seismic stratigraphic partitioning of the section of the research area. According to the nature of the wave field, the entire interval was conditionally divided into two seismostratigraphic megacomplexes (SSMC): Miocene and Pliocene. The Productive Series (PS) is divided into 6 seismic complexes: Qala, Lower Kirmaky, Kirmaky, Upper Kirmaky, Balakhany and Surakhany (Fig. 1). The top and bottoms of the seismic complexes were selected in accordance with the depths of the reference marks determined on the basis of geophysical logging of the wells. These surveys were conducted in deep wells drilled mainly along regional profiles. A large number of wells drilled both along the profiles and in the study area were used in the research process.

Seismic facies analysis was carried out in the frames of the identified seismic complex of the Qala age, the results of which were analyzed together with the results of the application of the logging facies technique. Subsequently, maps of seismic facies distribution over the area were constructed and analyzed.

Let us consider the results of the studies on the example of several wells (Figs. 2, 3, 4). As the results of sequence-stratigraphic and lithofacies analyses show, transgressive system tracts and low sea level system tracts are identified and traced along the profile within the QaS-3 horizon. This horizon is represented by a predominantly coastal-marine facies complex, which includes facies groups of estuarine bars, alongshore bars, over-bar lagoons, etc. In some wells within the system tract of low sea level rise, alluvial facies complexes are traced, which are represented mainly by facies groups of river channels.

Both oil-bearing and water-bearing reservoirs are identified within the QaS-3 horizon. In well 1856, the identified reservoirs are mostly water-bearing. Oil-bearing reservoirs are found mainly within the lowstand system tract mainly in the river channel facies group (alluvial facies complex) and in the transgressive system tract in the estuarine and longshore bar facies groups (coastal-marine facies complex) during aggradation and retrogradation.

A transgressive system tract covers most of the QaS-2 horizon. Only in wells 1861-1862 the presence of the high sea level system tract is observed. The coastal-marine facies complex and shallow shelf facies complex are distinguished within this horizon.

As in the underlying horizon, oil-bearing reservoirs here occur within lowstand system tracts in river channel facies and in transgressive system tracts in the facies of longshore bars and rip currents during aggradation and retrogradation.

Fig. 1. Separation of seismic sedimentation complexes of Miocene-Pliocene age in the southeastern part of the Absheron Peninsula
Fig. 2. Results of interpretation of the cross section of well №1861 (QaS-3-QaS-1 of the PS suites)
The QaS-1 horizon is represented by a coastal-marine facies complex, where groups of rip current facies are replaced by facies of offshore lagoons, estuarine and longshore bars. In some wells, the horizon ends with a lowstand systemic tract, which is represented by an alluvial facies complex and a group of river channel facies. As can be seen from the figure in well 1862, the alternation of coastal-marine and alluvial facies complexes is observed. Oil-bearing reservoirs are identified mainly in the low sea level system tract and less fre-
Fig. 4. Scheme of interwell correlation of productive deposits of the QaS2 formation along the well line 1860-1856-1861m

sequently in the transgressive system tract in the facies groups of river channels, offshore lagoons and rip currents during aggradation and pro-retrogradation.

The QaS-1 horizon is overlain by sediments formed at low sea level during the aggradation period, which are represented by an alluvial facies complex, namely a group of riverbed facies.

It should be mentioned that the results of application of the logging facies technique, the Emery method and cyclostratigraphic analysis are in agreement with each other.

Based on the paleostructural constructions performed and taking into account the published materials, we assume that the formation of the Qala Suite deposits occurred predominantly in marine conditions, due to the large amount of sedimentary material carried by the water flows of the delta system and the distribution of its bulk within the paleostructure located in the central part of the study area. Analysis of the temporary thickness maps suggests that a large river delta existed in the study area during the formation of the Qala Suite deposits. It is obvious that the appearance of numerous deltaic channels and channels was associated with gentle slopes and shallow depths of the coastal part of the basin in which the delta was formed. Based on the analysis of the constructed map of temporary thicknesses between seismic horizons (SH) SH-III (stratum QaS-1) and SH-IV, which in the conventional time scale rep-
resents the paleorelief of the surface at the time of the beginning of the Qala Suite deposits formation, it is possible to determine the most favorable areas for the accumulation of sandy deposits. Higher values on the map of temporal thicknesses correspond to submerged areas of paleorelief. Lower values are interpreted as elevated areas of paleorelief. As a result of the analysis of the presented material, it can be assumed that in the conditions of the coastal-marine plain, paleodeltaic system channels were confined to depressions in the relief, through which terrigenous material was transported from the uplifted areas of the landscape. The predicted areas of paleodeltaic sediments determine the distribution of sandy material over the area in the QaS formations and control the boundaries of distribution of these reservoirs, and hence possible hydrocarbon traps.

Analysis of sedimentation conditions shows the presence of paleodelta in the western and eastern parts of the study area. This assumption is confirmed by well data. Consideration of the electrometric characteristics of the formations QaS-1-3 of the Qala Suite allowed us to confirm this assumption partially, due to insufficiently complete and high-quality logging material. Thus, wells 1410, 1714, 1518, 1826, etc., located in the area of increased temporal thicknesses, when compared with the reference ones, accepted according to the classification of V.S. Muromtsev (Muromtsev, 1984), by their electrofacial characteristics correspond to flow-type deposits. For the QaS-2 formation, this interval can be determined over 205 ms from the map Δt QaS-2 – SH-IV. A number of wells (1816, 1518, etc.) correspond to bar-type facies and are located in the areas of average values of temporal time values, respectively, in the areas of average values of time thicknesses on the maps Δt. For the QaS-2 formation, accordingly, it is less than 205 ms, with the dome part of the paleostructure likely to have fewer prospects. It is assumed that a decrease in effective thicknesses should be expected in this part, which is observed when analyzing well information (wells 1822 less than 4 m, 1810 – 12 m, 1832 -20 m, etc.). The existing island at that time, probably of volcanic origin, served as a kind of barrier to transportation. In the sloping parts of this paleostructure, on relatively gentle areas, sand-siltstone lenses were formed. Some sedimentary material was transported and redeposited by longshore flows.

The forming features of the Qala Suite formation are also shown on the seismic facies map (Figs. 5, 6, 7). The distribution of flow-type sediments corresponds to the areas of predominantly blue color on the seismic facies map. The red-colored areas can be compared with the facies of barrier islands (wells 1825, 1834, 130, etc.). The areas of green color can be attributed to the distribution of coastal and longshore bar deposits, which correspond to such areas both in terms of plan configuration and electrometric characteristics (wells 1700, 1810).

![Seismic facies analysis of the QaS-3 formation of the Qala Suite](image-url)
Conclusions

It is well known that the establishment of paleogeographic environment plays an important role in the exploration for oil and gas traps of non-anticlinal (including lithologic) type. The largest number of lithologic oil and gas deposits is associated with deposits of deltaic complexes. Detailed research on the structure and formation conditions of the Qala Suite deposits of the Productive Series (PS), which is the main oil and gas bearing object of the Hovsan-Zykh area, is of great practical importance.

We assume that the formation of the Qala Suite deposits occurred predominantly in marine conditions, due to the large amount of sedimentary material carried by water flows of the delta system and its main distribution within the paleostructure located in the central part of the research area.

As a result of the analysis of the presented material, it can be supposed that in the conditions of the coastal-marine plain, paleodeltaic channels were confined to depressions in the relief, through which terrigenous material was carried out from the uplifted areas of the landscape. The predicted areas of paleodeltaic sediments determine the distribution of sandy material over the area in the QaS formations and control the boundaries of distribution of these reservoirs, and hence possible hydrocarbon traps.

In our opinion, trap formation occurred within the southeastern and western slope parts of the paleostructure, where oil deposits of the Hovsan field were subsequently discovered. Along the eastern slope of the high-amplitude structure, located in the western part of the area, a lens composed predominantly of sandy material was formed, which served as the basis for the formation of the Zykh field oil deposit.

Thus, the joint analysis of the results of seismic facies, sequence-stratigraphic and lithofacies analyses based on 3D seismic and WL data allowed us to reconstruct the depositional environment and conditions of the QaS deposits in greater detail. The analysis of sedimentation conditions shows the presence of paleodeltaic in the western and eastern parts of the research area. Therefore, the most promising areas of the field have been identified for further development.
Fig. 7. Seismic facies analysis of the QaS-1 formation of the Qala Suite

References


