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The prospects of hydrocarbon deposits in avalanche sedimentary bodies in the South Caspian Basin (SCB)

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Abstract

Introduction. Avalanche sedimentation leads to the formation of sediments saturated with water and organic matter, characterized by incomplete geochemical processes. The combination of necessary conditions, such as the presence of high organic content in such deposits, the mass of rapidly accumulating and enormously thick sediments, as well as the presence of reservoir and mantle, contributes to the formation of deposits of oil, gas, bitumen, shale, coal, phosphorite, sulfur, and other valuable minerals. The Pliocene period is characterised by a rapid sea-level drop, the subsidence of the South Caucasus crust, and the onset of deposits. At the Miocene-Pliocene boundary, intense folding and mountain-building were accompanied by the intense subsidence of the South Caspian Depression depression. Extensive areas of the Middle Caspian and modern intermountain depressions have been identified. Major rivers (Paleo-Volga, Paleo-Kura, Paleo-Uzboy) and dozens of smaller rivers carved deep valleys on the surrounding surface. They flowed into the Pliocene lake, providing a large amount of detrital material. Based on geological interpretations of various types of sedimentary basins, the overall shape, internal structure, and direction of sediment accumulation are linked to paleotectonic and paleogeographic conditions of sedimentation under the active influence of eustatic (or relative) sea level changes.

Subject matter. In the South Caspian Basin (SCB), particularly on the Turkmenistan shelf, there are well-defined Pleistocene clinoform bodies resulting from avalanche sedimentation. In recent decades, as a result of lithological studies of the marine and oceanic shelves through deep drilling in water basins and observations using underwater exploration means, relatively narrow elongated sections have been identified where the thickness of sedimentary complexes reaches 10–15 km. Such local accumulations of sedimentary mass or sedimentary cover have formed at the estuary of several major rivers as well as in the lower part of the continental slope along the ocean coastline.

Research objective is to considered the role of avalanche sedimentation asthe main reserves of oil and gas depositions, and in particular, every third ton of oil is extracted from the ocean floor.

Research results. The modern structure of the South Caspian Basin has been formed as a result of active tectonic movements and intensive sedimentation processes predominant at certain stages of its development. Based on the characteristics of spatial parameters, several classes of sedimentary bodies (SB) are distinguished here: vertical (aggradational) and lateral accretion (progradational) bodies, accumulative, massive, exogenous relief forms, and others.

Conclusions. It has been established that the seismostratigraphic analysis utilizing additional materials (study of paleorelief morphostructure, layer thickness, etc.) and deep well investigations aim to explain the origin of deposits in the lower layers of the Productive Thickness, considering modern perspectives. Large-scale lithological-stratigraphic (non-anticlinal) oil and gas accumulations provide a solid foundation for identifying favorable areas for trap formation.

***Keywords*:** deposits, avalanche sedimentary, clinoform bodies, sequence, pliocene, South Caspian Basin.

Introduction

In recent decades, as a result of lithological studies of the marine and oceanic shelves through deep drilling in water basins and observations using underwater exploration means, relatively narrow elongated sections have been identified where the thickness of sedimentary complexes reaches 10–15 km. Such local accumulations of sedimentary mass or sedimentary cover have formed at the estuary of several major rivers as well as in the lower part of the continental slope along the ocean coastline. According to the views of many researchers [1–4] the accumulation of sedimentary masses in these formations can occur in the form of very rapid (more than 100 mm/1000 years) and super-rapid (more than 1000 mm/1000 years) deposition, which is called avalanche sedimentation (similar to the accumulation of avalanches in mountains). The uniqueness of these formations lies in the fact that the increase in sedimentation rate is accompanied by a sharp transition of the amount of sediment into a new quality. Avalanche sedimentation leads to the formation of sediments saturated with water and organic matter, characterized by incomplete geochemical processes. The combination of necessary conditions, such as the presence of high organic content in such deposits, the mass of rapidly accumulating and enormously thick sediments, as well as the

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presence of reservoir and mantle, contributes to the formation of deposits of oil, gas, bitumen, shale, coal, phosphorite, sulfur, and other valuable minerals.

Thus, according to expert assessments, at present, the main reserves of oil and gas are located in avalanche deposition zones, and in particular, every third ton of oil is extracted from the ocean floor. Overall, based on the extensive experience of oil and gas operations in the World Ocean, two characteristic features should be noted:

– Firstly, the number of oil fields on the ocean shelf is almost three times higher than the number of gas fields, indicating more favorable conditions for oil formation;

– Secondly, the overwhelming majority of deposits (about 83%) are associated with carbonate reservoirs (especially empty reef structures), with only 17% being related to terrigenous rocks.

In the South Caspian Basin (SCB), particularly on the Turkmenistan shelf, there are well-defined Pleistocene clinoform bodies resulting from avalanche sedimentation. These clinoforms are formed due to the vigorous activity of shelf deltas, as depicted in fig. 1.

The Pleistocene delta of Palaeo-Amu-Darya consists of a clinoform complex that stretches over 150 km in 5–10 layers towards the west. This clinoform was first identified by Mitchum in 1977 as "a sloping sedimentary surface associated with deep-water extension" [3]. The main types of these clinoforms are the oblique and sigmoidal clinoform bodies, which can be observed in the basin (SCB).

The sigmoidal progradational configuration consists of S-shaped sediments with horizontal uplifts and thicker intermediate ("abrupt") series. Sigmoidal clinoform bodies (sigmoidal offset) are characterised by crustal lowering and sea level rise above the sediments.

The strata that are more steeply sloping and connect to the strata boundaries indicate an inclined progradation configuration. Inclined clinoforms develop when there is a period of eustatic stagnation and/or increased sediment input or low retreat.

These conditions may have occurred during the deposition of Sequences 8 and 9, in response to the concentration of deltaic sediments in a particular area. The scarp edge advanced to its present position, assembling a thick clinoform complex. The sedimentary deposits in the basin are mainly draped facies (represented by vertical solid lines) and filled turbidites. The black and white dashed zones indicate the presence of landslides and avalanches.

The central part of the basin east of the Abikh-Vazirov trough has the same high-amplitude continuous parallel facies along the structures and the Amu Darya thrust. Turbidites are present in the troughs and are confined to the cover facies. Channel systems are much smaller in size than previous sequences and are concentrated near the coast. There are two main locations of channel systems: the Abikha sag, or submarine Amu Darya ejection cone, and the southeastern slope of the Palaeo-Amu Darya.

The reduction in sediment influx into the central basin and the concentration of sediment accumulation on the shelf coast may be associated with conditions of a high relative sea level during the deposition of the last sequence.

Each clinoform represents a lens-shaped or mound-like geological body extending along the field. Within one complex, the configuration of seismic facies significantly varies from profile to profile. This indicates the connection of a particular seismic facies with a distinct unified body showing localised development.

In fig. 2, along the cross-section, complex lens-shaped and sharp structures of objects, lateral accretion bodies, are highlighted.

River deltaic arrays, representing examples of deltaic sedimentation, are of utmost importance in the sedimentary cover, as they are rich in reservoir rocks. Late Cenozoic paleobasins were filled with deltaic deposits. In the territory studied by P. Z. Mamedov [5], buried deltaic arrays of Pliocene age of the paleo-Volga and Paleo-Uzboy have been extensively examined (based on GSW (geophysical studies of wells) data, seismic surveys, and core data).

The Pliocene period is characterised by a rapid sea-level drop, the subsidence of the South Caucasus crust, and the onset of deposits. At the Miocene-Pliocene boundary, intense folding and mountain-building were accompanied by the intense subsidence of the South Caspian Depression depression. Extensive areas of the Middle Caspian and modern intermountain depressions have been identified. Major rivers (Paleo-Volga, Paleo-Kura, Paleo-Uzboy) and dozens of smaller rivers carved deep valleys on the surrounding surface. They flowed into the Pliocene lake, providing a large amount of detrital material (Fig. 3) [6–10].

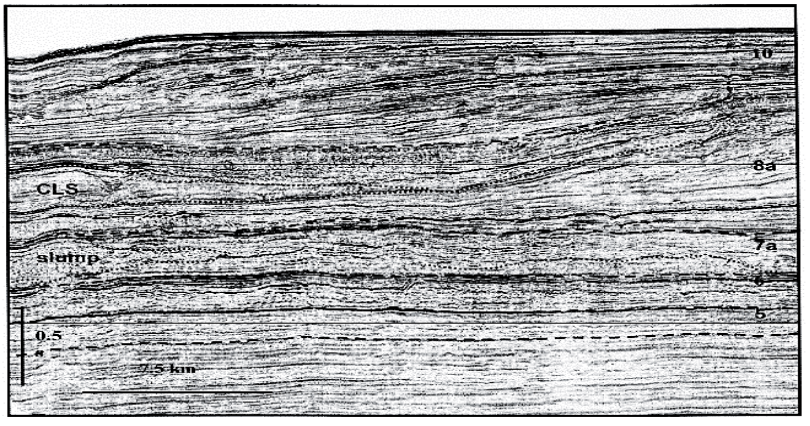

Figure 1. Seismic cross-section from the modern boundary of the Turkmen Shelf
Рисунок 1. Сейсмический разрез от современной границы Туркменского шельфа

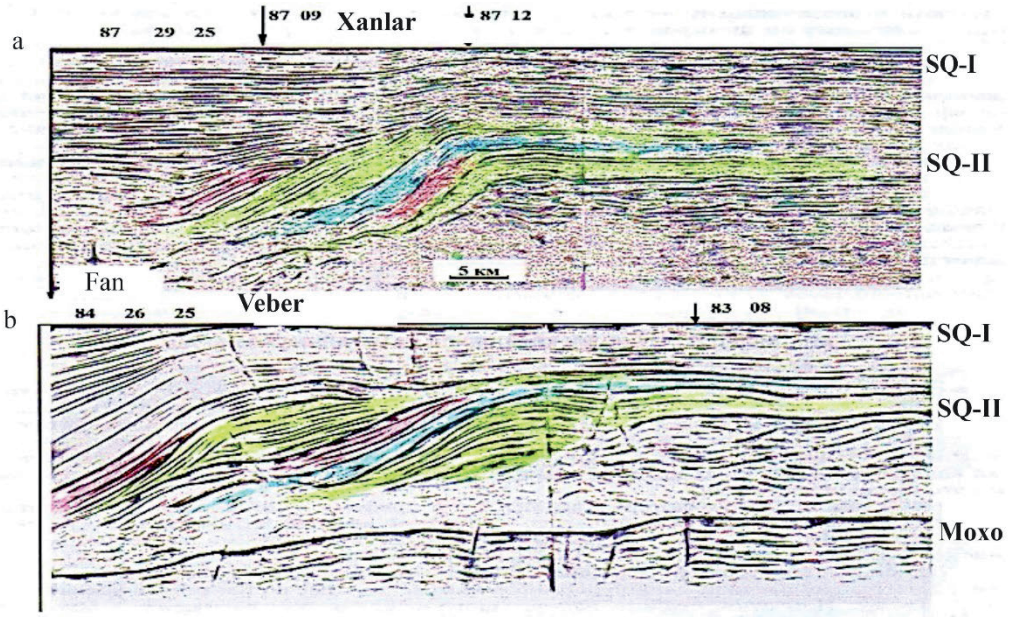

Figure 2. Time cross-sections illustrating lateral growth bodies in the Early Pliocene – *a, b* (SQ-sequence)
Рисунок 2. Временные разрезы, иллюстрирующие тела латерального роста в раннем плиоцене – *а, б* (SQ-последовательность)

The morpho-textural features of deltaic sandy-alluvial formations are well-studied in the natural exposures of the Apsheron Peninsula. Between the estuaries (Chilov Island in the Kirmakinsky block, the valley of the Sumgait River, among others), the upper part of the delta consists of shale layers intersected by sub-horizontal eroded and erosion surfaces (A. Sultanov, V. Gorin, 1963) [11].

Overall, as a result of seismic and seismostratigraphic studies conducted in the South Caspian Basin, it has been established that, unlike the northwest segment of the Paleo-Volga, a fan-shaped narrow topodepression is developed in the northeastern segment, near a steep slope (approximately 200 km) (Fig. 4).

In 1986, P. Z. Mamedov while studying laterally growing bodies on the Turkmen Shelf, proposed a theory about the existence of a residual deep-water topo-depression on the southern margin of the Pliocene basin (at the site of the modern Elbrus Basin-Depression) [5, 6].

Considering the non-oil-generating characteristics of the oil-source rocks in the PT (Productive Thickness), the oil and gas potential of reservoir layers, covers, and regional layers, studies have suggested that the search for hydrocarbons in coastal-marine and deltaic deposits in the South Caspian Basin holds significant promise [12–15]. Specifically, the examination of available materials indicates that among numerous facies with hydrocarbon concentration in the lower layers of the productive layer, sand-alluvial deposits of deltaic origin appear to be advantageous. For this reason, the uplifts in the northern anticlinal belt (Sevinj, Arzu, named after Shapiro, 40th Anniversary of Azerbaijan, among others) can be considered highly prospective for maximum hydrocarbon accumulation. These uplifts are located in the middle Pliocene, i.e., in territories near the channel and deltaic systems formed during the Kala and Prodkiyrmakin periods. It is likely that traps concentrated in the lagoon and alluvial channel facies of the Kirmakinsky Suite of the Northern Absheron could be rich in hydrocarbons.

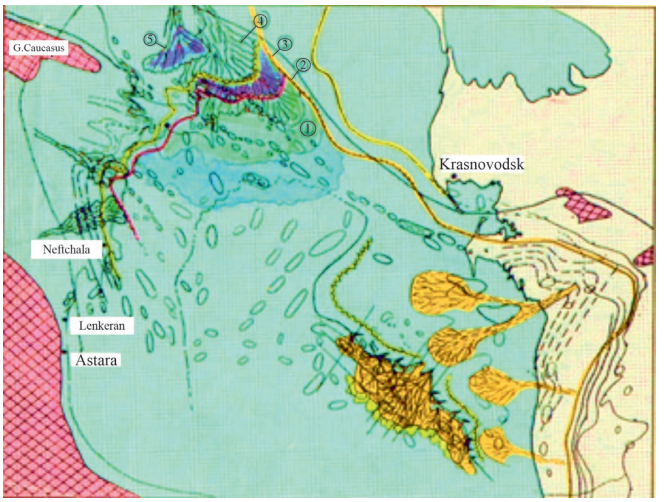

Figure 3. Sedimentation in deep-water basins at the convergent stage of development. Models of delta sedimentation (according to P. Z. Mamedov, 1991) [4]
Рисунок 3. Седиментация в глубоководных бассейнах на конвергентной стадии развития. Модели дельтовой седиментации (по П. З. Мамедову, 1991) [4]

Results

1. Based on the principles of seismic stratigraphic analysis and geophysical data, the conditions of sediment formation were studied and the areas of alluvial, lagoonal, deltaic and coastal-marine sediment formation in lateral direction were determined.

2. The modern structure of the South Caspian Basin has been formed as a result of active tectonic movements and intensive sedimentation processes predominant at certain stages of its development. Based on the characteristics of spatial parameters, several classes of sedimentary bodies (SB) are distinguished here: vertical (aggradational) and lateral accretion (progradational) bodies, accumulative, massive, exogenous relief forms, and others.

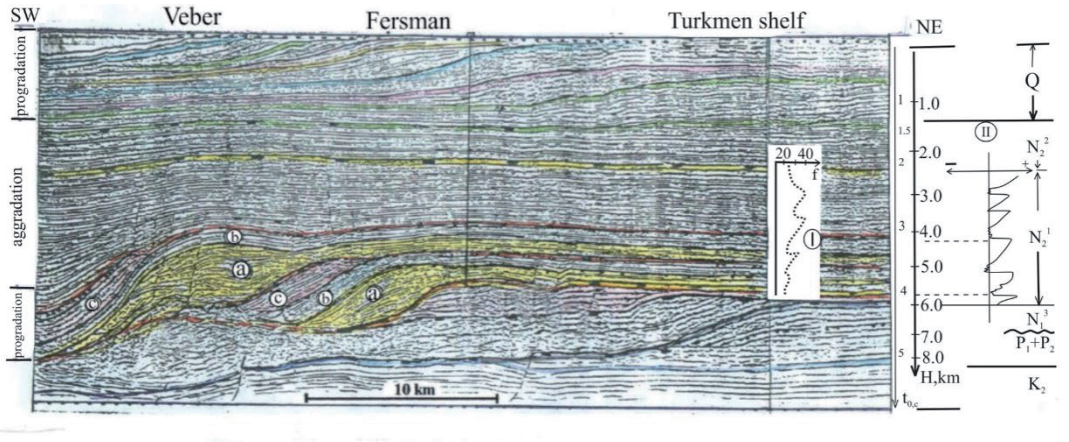

Figure 4. Chronostratıgraphic sectıon dısplayıng relative sea level fluctuations and hiatus in accumulation of Paleo-Uzboy avandeltaic sequence in the South Caspian basin

Рисунок 4. Хроностратиграфический разрез, показывающий относительные колебания уровня моря и перерыв в накоплении палеоузбойской авандельтовой толщи в Южно-Каспийском бассейне

3. The areas of formation of cross-layered and growing structures are observed in the border part of the Productive Thickness sedimentary basin and near its perimeter. Seismostratigraphic analysis utilizing additional materials (study of paleorelief morphostructure, layer thickness, etc.) and deep well investigations aim to explain the origin of deposits in the lower layers of the Productive Thickness, considering modern perspectives. Large-scale lithological-stratigraphic (non-anticlinal) oil and gas accumulations provide a solid foundation for identifying favorable areas for trap formation.

4. Based on geological interpretations of various types of sedimentary basins, the overall shape, internal structure, and direction of sediment accumulation are linked to paleotectonic and paleogeographic conditions of sedimentation under the active influence of eustatic (or relative) sea level changes.

5. These uplifts are located in the middle Pliocene, that is, in territories near channel and deltaic systems formed during the periods of Kala and Podkiyrmakin. Likely, traps concentrated in the lagoon and alluvial channel facies of the Kirmakinsky formation of the Northern Absheron could be rich in hydrocarbons.

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Перспективы развития углеводородных месторождений в лавинно-осадочных телах Южно-Каспийского бассейна (ЮКБ)

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Аннотация

Введение. Лавинная седиментация приводит к образованию насыщенных водой и органическим веществом отложений, характеризующихся незавершенными геохимическими процессами. Совокупность необходимых условий, таких как наличие в отложениях высокого содержания органических веществ, масса быстро накапливающихся огромной толщины осадков, а также наличие коллектора и мантии способствуют образованию месторождений нефти, газа, битума, сланцев, угля, фосфоритов, серы и других ценных полезных ископаемых. Плиоценовый период характеризовался быстрым падением уровня моря, проседанием земной коры Южного Кавказа и появлением отложений. На рубеже миоцена и плиоцена интенсивная складчатость и горное строительство сопровождались интенсивным опусканием Южно-Каспийской впадины. Выявлены обширные территории Среднекаспийской и современных межгорных впадин. Крупные реки (Палео-Волга, Палео-Кура, Палео-Узбой) и десятки более мелких рек прорезали глубокие долины на окружающей поверхности. Они впадали в плиоценовое озеро, поставляя большое количество детритового материала. Согласно геологической интерпретации различных типов осадочных бассейнов, общая форма, внутренняя структура и направление осадконакопления связаны с палеотектоническими и палеогеографическими условиями осадконакопления под активным влиянием эвстатических (или относительных) изменений уровня моря.

Предмет исследования. В Южно-Каспийском бассейне (ЮКБ), особенно на шельфе Туркменистана, хорошо выражены плейстоценовые клиноформные тела, образовавшиеся в результате лавинного осадконакопления. В последние десятилетия в результате литологических исследований морского и океанического шельфа путем глубокого бурения в водных бассейнах и наблюдений с помощью средств подводной разведки были выявлены относительно узкие вытянутые участки, где толщина осадочных комплексов достигает 10–15 км. Такие локальные скопления осадочной массы или осадочного чехла сформировались в устьевых участках ряда крупных рек, а также в нижней части континентального склона вдоль океанского побережья.

Цель исследования – рассмотреть роль лавинной седиментации как основного резерва нефтегазовых месторождений, в частности, каждой третьей тонны нефти, добываемой со дна океана.

Результаты исследований. Современная структура Южно-Каспийской впадины сформировалась в результате активных тектонических движений и интенсивных процессов осадконакопления, преобладающих на определенных этапах ее развития. На основе характеристики пространственных параметров здесь выделяются несколько классов осадочных тел (ОТ): тела вертикальной аккреции (аггрaдации) и латеральной аккреции (проградации), аккумулятивные, массивные, экзогенные формы рельефа и другие.

Выводы. Установлено, что сейсмостратиграфический анализ с использованием дополнительных материалов (изучение морфоструктуры палеорельефа, толщины слоев и т. д.) и исследования глубоких скважин позволяют объяснить происхождение отложений в нижних слоях продуктивной толщи с учетом современных перспектив. Крупномасштабные литолого-стратиграфические (неантиклинальные) скопления нефти и газа служат надежной основой для выявления благоприятных зон для формирования ловушек.

***Ключевые слова*:** отложения, лавинные отложения, клиноформные тела, последовательность, плиоцен, Южно-Каспийская впадина.

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