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Paleogeomorphic depositional settings of the devon sediments of the pre-Caspian depression

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The relevance of the work. The Pre-Caspian depression is a wide stratigraphic range of industrial oil-and-gas potential. The discovery of a number of hydrocarbon deposits in recent decades is an important factor confirming the prospects of this territory. Features of sedimentation on the Earth's surface depend on the tectonic processes occurring at this time. The relevance of applying new research methods to discover hydrocarbon deposits, paleogeomorphic ones in particular, is shown. The study of paleogeomorphic factors of sedimentation in the Devonian sediments and taking into account the regional characteristics of paleotectonic development allows us to substantiate the prospects of oil-and-gas potential in this area. In this regard, it is necessary to develop and identify the dialectic unity between paleogeomorphology, paleotectonics and sedimentation, which will determine the patterns of formation and distribution of oil and gas fields.
The aim of the study is scientific justification of prospects of oil-and-gas potential and increase the forecast of the Devonian complex of sediments of the Pre-Caspian depression taking into account the influence of paleotectonic and paleogeomorphic factors.
The methodology of the study is based on identifying the role of the paleotectonic method in determining the oil-and-gas potential of a given region with a favorable combination of lithological-facies, geochemical, hydrogeological and thermobaric conditions.
Results. The author conducted some paleogeomorphic studies of patterns and conditions of sedimentation within the Astrakhan arch. It was found that throughout the Paleozoic time the geotectonic regime was a multiple alternation of movements of different signs. It was also revealed that numerous transgressions and regressions changed the conditions of sedimentation. Frequent movement of coastlines occurred within the territory, as well as breaks and disagreements within the island zones. As a result of the conducted works, it was found that modern structural plan of the Paleozoic sediments inherited the relief of the basement surface. While studying this issue, 3D OGT-64 three-dimensional seismic data and 2D seismic data were used, as well as core and slime materials from parametric well drilling data.
Conclusions. Research data of the territory of the Astrakhan arch based on paleogeomorphic analysis and the use of the results of geophysical and geological materials at the stage of identifying and preparing objects for prospecting and exploratory drilling allow us to study the formation of traps and reservoir rocks and assess the prospects for the oil-and-gas potential of this territory in the near future.

Keywords: Pre-Caspian depression, Astrakhan arch, paleotectonics, paleogeomorphology, sedimentation, Devonian sediments.

Introduction

The geological and economic efficiency of oil and gas exploration in the oil-and-gas provinces depends to a large extent on scientifically based forecasting of prospecting objects, which are the basis of ideas about the regularity of oil and gas deposits. The decisive role in this forecast belongs to the study of paleotectonic criteria of oil-and-gas potential. The theoretical basis for such a forecast is the sedimentary-migration theory of the origin of oil, to the development of which I.M. Gubkin, N. B. Vassoevich, A. A. Bakirov, V. L. Nalivkin et al. made a great contribution [1].

Features of sedimentation on the Earth's surface often depend on the tectonic processes occurring at this time. Differentiated uplifts and downwarpings ultimately form a surface relief with its characteristic forms. Marine geomorphology, which studies the origin and development of the bottom topography of marine basins unlike land geomorphology, is deprived of the possibility of visual observation and is based on indirect data (in paleoforecasts), mainly on the consideration of surfaces formed during breaks in sedimentation. Applied marine geomorphology helps to solve practical problems when searching for minerals, including oil and gas [2, 3].

A huge amount of organic matter and carbon is found in the sedimentary shell of the Earth. The predominant chemical elements of organic matter of both animal and plant origin are carbon and hydrogen. Plentiful and widespread organic matter fully ensures the accumulation of basic elements of oil and gas – carbon and hydrogen. In almost all non-reservoir rocks, such as clays and carbonates, the most diverse hydrocarbons and even oil have been found. The same hydrocarbons are found both in the disseminated state in fine-grained sediments and in the oils themselves [4].

For example, consistent stratigraphic analysis and geochemical methods have allowed Western scientists to study the accumulation of organic matter in the Upper Devonian Duverne Formation, in the sedimentary basin of Western Canada. This model showed a high relationship between the total concentrations of particulate organic carbon (POC) and the geochemical and organic petrological base [5].

Scientists have also established a link between certain sea level cycles and the accumulation of organic matter. Organic carbon is usually enriched while transgression of the sea and depleted during regression. Correlations between the total content of organic carbon and numerous geochemical indicators indicate that the accumulation of organic matter was controlled by redox conditions [6].

It should be noted that the distribution in the sediments of the initial organic matter necessary for oil and gas accumulation and oil and gas formation is interconnected. Higher concentrations of organic matter are inherent in clay rocks. Geochemical studies of the origin of the Middle Devonian Hamilton group of the Central Appalachian basin found that the Hamilton group includes Marcellus, organic-rich shale, one of the most profitable unconventional shale gases in the world [7].

Sapropelic differences are more characteristic of subaqueous precipitation, which is formed under conditions of maximum isolation from the influence of land [5, 6]. Under the conditions of the sea basin, the main factor in the distribution of sediments, the rate of their accumulation along the lateral and section, and the thickness of accumulated formations, their further epigenesis depend on the topography of the seabed and to some extent the surrounding land [8].

From the point of view of oil and gas content, the Late Proterozoic and Phanerozoic sedimentary rocks are represented by similar lithological types – sandstones and siltstones, limestones, dolomites and intermediate compositional differences. Among the carbonates in the Proterozoic, chemogenic dolomites predominated. According to N. M. Strakhov, A. B. Ronov and others,

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biogenic algal dolomites and limestones appeared in the Late Proterozoic. Later, at the beginning of the Cambrian, dolomites gradually give way to limestones, while the former are increasingly gravitating to areas of arid climate. Lime sediments develop in the areas of humid and arid climate. The proportion of biogenic differences increases with time not only on the shelf, but also in the deep sea due to the wide distribution of planktonic organisms that build their skeletons from calcium [9].

The Pre-Caspian depression is a huge area of promising lands, a wide stratigraphic range of industrial oil-and-gas potential, a favorable paleotectonic regime of long and stable subsidence, which provides generation and accumulation of hydrocarbons of different phase composition [10].

It is known that in creating a favorable environment for the accumulation and subsequent occurrence hydrocarbon compounds, the tectonic regime is of decisive importance. In this case, a long-term deflection of the sedimentation basin with the preservation of a more or less constant geochemical environment is a prerequisite [11]. Paleotectonic factors determine the direction of lithological-facies, geochemical, hydrogeological, thermobaric and other processes during the sedimentation period within the platform areas.

While studying numerous geological factors, I.M. Gubkin singled out tectonics and paleotectonics as defining factors, since the mode and direction of tectonic movements in time and space determine:

– spatial distribution of large sedimentation basins and regional uplifts, as well as changes in their lithological and facies conditions for the accumulation of sediments, and hence the conditions for the formation and distribution of oil and gas formation and oil and gas accumulation areas;

– formation of various structural forms, which, in the presence of other necessary conditions, can serve as traps for accumulations of oil and gas of a structural type;

– spatial distribution of coastlines, attenuation in the direction of uplift in strata, stratigraphic disagreement and other geological phenomena associated with the formation of oil and gas accumulations of lithological and stratigraphic types [12, 13].

Results

The results of paleotectonic reconstructions of the territory of the Astrakhan arch are aimed at exploring structures that are promising in the oil and gas bearing. The use of these studies makes it possible to more purposefully identify tectonic structural features that are promising in the oil and gas sector, and more reliably conduct comprehensive forecasts of this region.

In the southwestern part of the territory, within the Astrakhan arch during the entire Paleozoic time, the geotectonic regime was a multiple alternation of movements of different signs. All this led to the development of numerous transgressions and regressions that changed the conditions of sedimentation; coastlines often moved, breaks and disagreements arose within the island zones [14].

It is believed that in the southwestern part of the Pre-Caspian depression, including the Astrakhan arch, the orogenic stage ended in the Upper Proterozoic and the crystalline basement consolidated, as a result of which a modern structural plan of the Paleozoic deposits was formed, which inherited the relief of the basement surface. The latter was formed as a result of vertical movements of blocks in the form of horsts and downthrown block complicated by less amplitude faults. Lower relief forms of the crystalline basement are leveled by rocks from Riphean to Ordovician-Silurian [15].

It is rather difficult to restore the relief of the near-Devonian surface due to the lack of drilling data. 3D OGT-64 3D seismic data and 2D seismic data, as well as core and slime materials based on parametric well drilling data made it possible to construct paleorelief maps of the pre-Frasnian (Middle Devonian) and Pre-Famennian surfaces [16].

Paleogeomorphic analysis and the construction of paleorelief maps were performed using the thickness method [17–20]. Corrections for changes in thicknesses as a result of post-sedimentation compaction of sediments were not taken on the assumption that the lithological composition of rocks and their rather consistent area thickness allowed these corrections to be neglected, since they did not significantly affect the relief hypsometry.

Two sections are distinguished on the paleogeomorphic map of the pre-Frasnian (Middle Devonian) surface (Fig. 1): left-bank and right-bank, the border is the modern Volga-Akhtuba valley flat. The left-bank part is characterized by the development of denudation landforms. These are steep range of hills. They extend in a sub-latitudinal direction to a distance of at least 35 km, a width is 10–12 km. Relative elevation marks vary from 150 m (area of well 1 Tabakovskaya – 50 Astrakhanskaya) to 400 m (well No 2 is Volodarskaya, mark is 370 m). At the turn of the Middle and Late Devonian, a denudation type of paleorelief was formed, where the processes of erosion and removal of destruction products played a major role.

In general, in the left-bank part of the territory of the Astrakhan arch at the turn of the Middle and Late Devonian, a denudation type of paleorelief was formed, where the processes of erosion and removal of destruction products played a dominant role. The relief-forming processes are manifested here more intensively than in other areas, due to the activation of tectonic movements on the border of these two epochs of the Devonian time (middle and upper). All this territory in the Middle Devonian paleorelief, most likely, was a large watershed between the southern and northern basins confined to the Karpinsky and Zavolzhsky downwarpings, respectively [21].

The right-bank area is also characterized by the formation of predominantly denudation forms of paleorelief, where three areas of denudation and one area of accumulation are determined. Denudation areas are outlined with structural contours from 100 to 250 m and extend over a distance of 30 km with a width of about 15–20 km.

The accumulation area occupies part of the territory of the Astrakhan arch, which goes into the delta of the Volga River. The length in the latitudinal direction at a distance of about 45 km is limited to a 50-m structural contour. In the areas of reaching the paleosurface of carbonate rocks during a long break in sedimentation, karst relief forms could have formed. Penetration of the super-deep Devonskaya No 2 well of the lower Devonian bottoms confirmed the presence of a long break in sedimentation between the Middle and Upper Devonian.

The paleorelief of the Pre-Famennian surface (Fig. 2) differs sharply from the Middle Devonian. These changes affected the entire territory of the Astrakhan arch. The tectonic restructuring of ancient structural plan that took place at the turn of the Middle and Late Devonian prepared the basis for the development of the Late Devonian transgression and the accumulation of terrigenous sediments, and then, as they develop, carbonate sediments. The formation of a new pre-Famennian paleorelief took

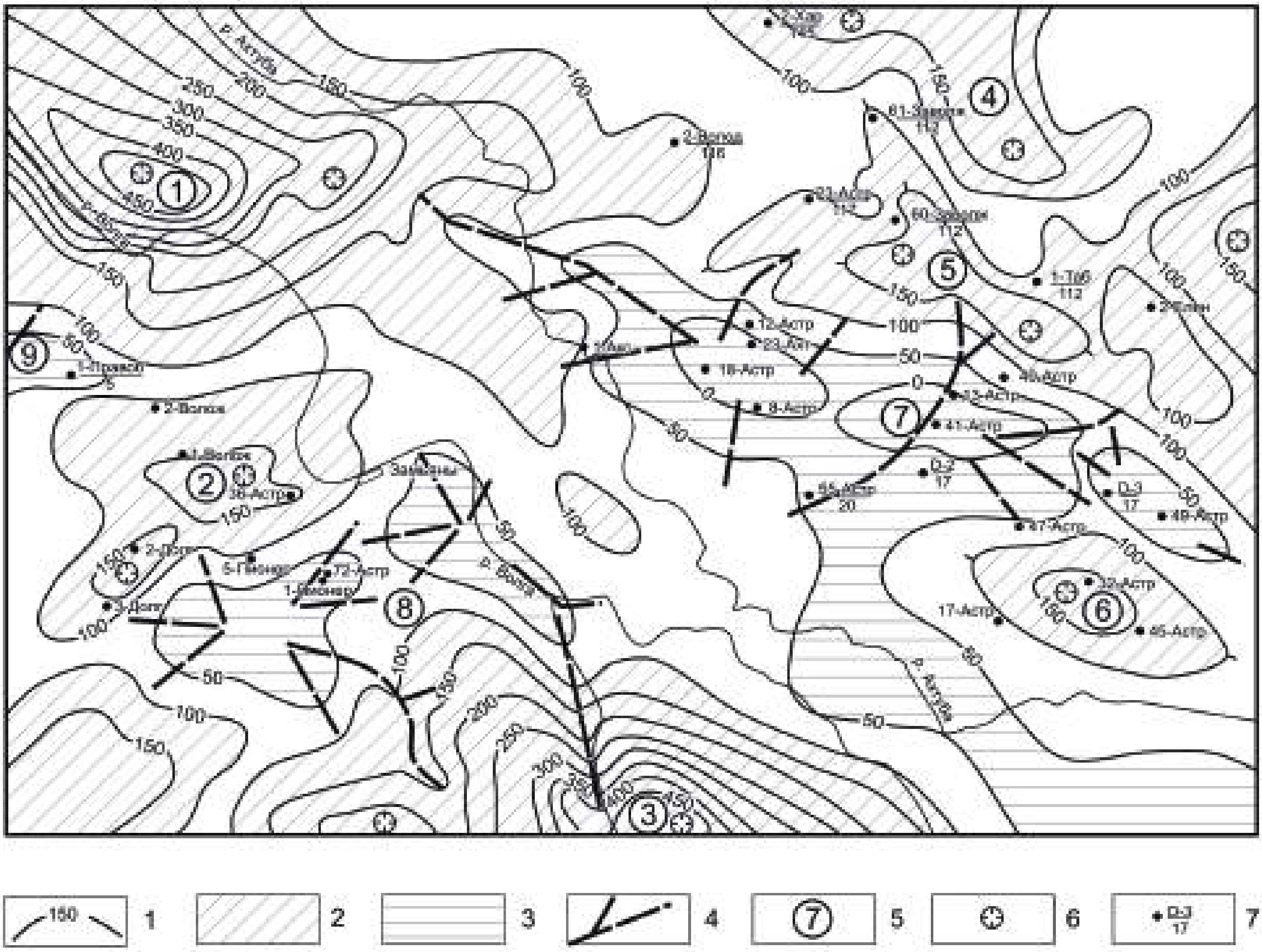

Figure 1. Paleogeomorphic map of the Pre-Frasnian (Middle Devonian) surface of the territory of the Astrakhan arch. 1 – structural contours of relative height of paleorelief, m; 2 – areas of denudation; 3 – accumulation areas; 4 – dells; 5 – numbers of areas, sites; 6 – karst land forms; 7 – wells: numerator – number of a borehole; denominator is the relative marker of palaeotopography, m.

Рисунок 1. Палеогеоморфологическая карта предфранской (среднедевонской) поверхности территории Астраханского свода. 1 – изогипсы относительного превышения палеорельефа, м; 2 – области денудации; 3 – области аккумуляции; 4 – ложбины стока; 5 – номера областей, участков; 6 – карстовые формы рельефа; 7 – скважины: числитель – номер скважины, знаменатель – относительная отметка палеорельефа, м.

place. Most of the largest land forms have an inverse genesis; in other cases, a slight shift in the emphasis of relief formation has occurred; karst forms formed in many areas [22].

In the left-bank part, the hillside elevations are outlined mainly by structural contours of 100–150 m. Two uplifts are observed, linearly elongated in a northwest direction. One of them is fixed between wells No 60 – Zavolzhskaya in the west and a line of wells No 40 – Astrakhanskaya – No 2 – Elenovskaya. The length of this uplift along the closed structural contour of 150 m is 18 km with a width of 2–7 km. The second uplift is located in the area of Elenovskaya area and is contoured by the structural contour of 100 m. Its length is about 15 km; width is 5 km.

Relief-forming erosion-denudation processes in pre-Famennian time proceeded with weak intensity, resulting in a weak compartmentalization of relief. The prevailing development under such conditions was the use of karst forms (funnels, polje, voids within the thickness of limestone). At the bottom of these forms, the fall products accumulated [21].

The area of weakly expressed denudation forms of the Pre-Famennian paleorelief is observed on the Astrakhan arch, in its right-bank part, in the area of wells No 1, 2 – Volozhkovskaya, 36 – Astrakhanskaya and No 5 – Pionerskaya. They are contoured by the structural contour of 100 m and probably represented low (up to 50 m) hills with gentle slopes. In the southern part of the territory of the Astrakhan arch, a northern fragment can be traced of a large area of development of the erosion-denudation pre-Famennian paleorelief area. Relative elevations of the relief forms reached 450 m, and the total height of the peak above the foot is 350 m. The northern slope is cleaved by a narrow dell more than 10 km long.

Such a profile of the dell, the straightness of its orientation clearly indicate the prevalence of deep bottom erosion in this place, which in turn may indicate an intense uplift of this section of the territory in Pre-Famennian period. The slopes of such large landforms can be complicated by smaller geomorphological units, such as erosion remnants.

Sites of erosion and denudation were located in the peripheral parts of the territory of the Astrakhan arch. It is as if they border the central part of the arch area from all sides, which is a vast area of accumulation of erosion material that is carried out with geomorphological features typical of such areas. The accumulation area splits into two parts: left-bank and right-bank. The largest area is the left-bank part, where ancient dells of various orientations are widely used.

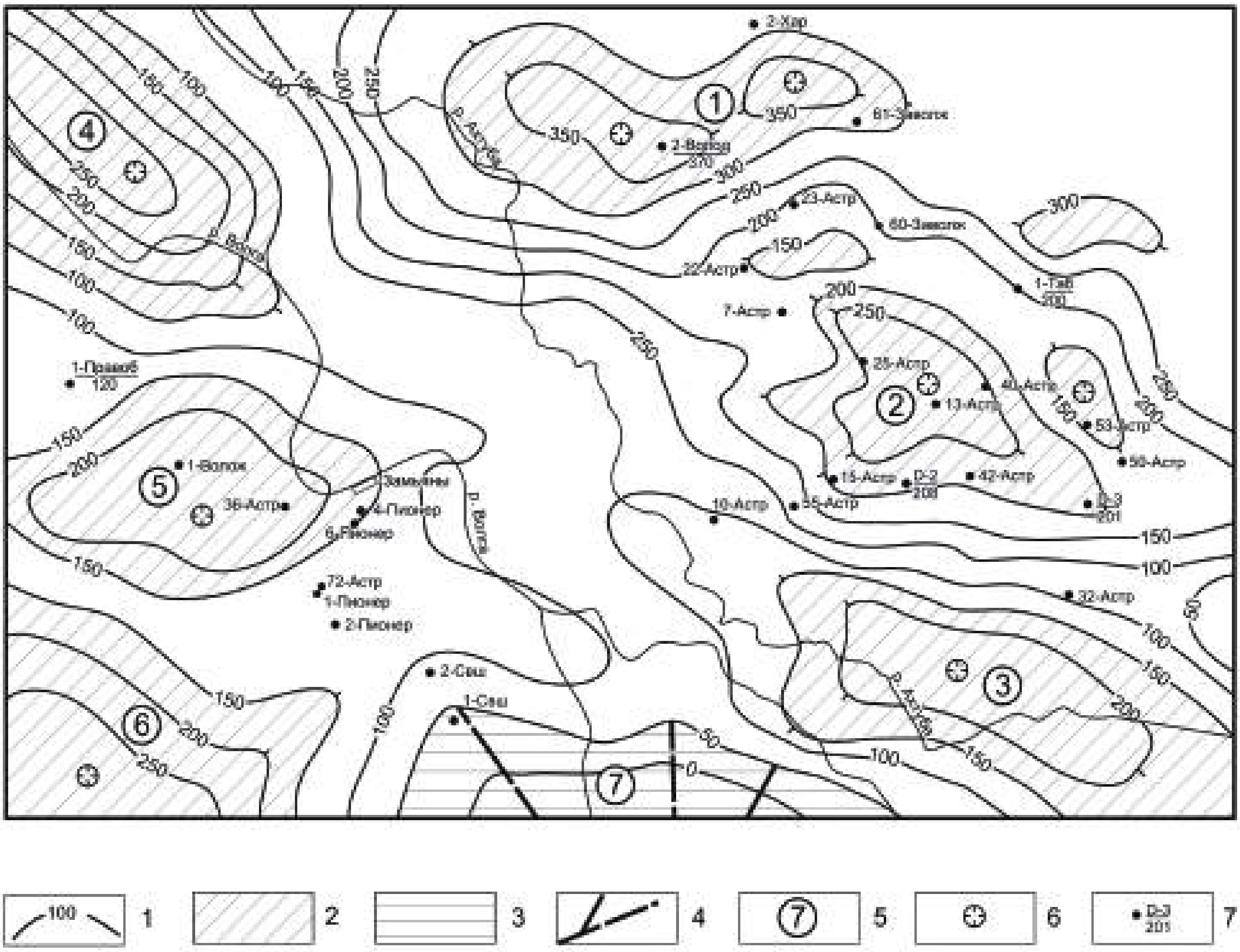

Figure 2. Paleogeomorphic scheme of the Pre-Famennian surface of the territory of the Astrakhan arch. 1 – structural contours of relative height of paleorelief, m; 2 – areas of denudation; 3 – accumulation areas; 4 – dells; 5 – numbers of areas, sites; 6 – karst land forms; 7 – wells: numerator – number of a borehole; denominator is the relative marker of palaeotopography, m.

Рисунок 2. Палеогеоморфологическая карта предфаменской поверхности территории Астраханского свода. 1 – изогипсы относительного превышения палеорельефа, м; 2 – области денудации; 3 – области аккумуляции; 4 – ложбины стока; 5 – номера областей, участков; 6 – карстовые формы рельефа; 7 – скважины: числитель – номер скважины, знаменатель – относительная отметка палеорельефа, м.

Conclusion

Having studied the geomorphological development of this territory, the authors can state:

– the Astrakhan arch area had a large caldera-shaped relief in the central part of the arch, bounded along the frontier zone by watersheds with typical relief forms of different heights and shapes;

– the intensity of relief formation in the territory was different;

– two areas of intensive territory uplift are appeared – north-western and southern with geomorphic processes, where sediments erosion prevailed over the removal of alteration products; in the places where the steep slopes of these relief forms transition into gentle slopes, proluvial processes developed and the corresponding relief was formed – alluvial cones;

– in areas where the relative elevation of the relief does not exceed 100–150 m and its forms are characterized by a smooth outline, the relief can be classified as accumulative-denudation;

– formation of karst land forms in carbonate deposits had a significant impact on the reservoir properties of rocks that make up the section of deposits (funnels, voids, cavities, etc.).

The low implementation of the forecast of the oil-and-gas potential of the Paleozoic deposits is explained by the insufficient knowledge of the conditions for the formation and placement of oil and gas deposits in these rocks and the poor development of the methods for their exploration at great depths [19].

Oil and gas deposits at shallow and medium depths on land in anticline traps are already largely explored and developed. Further replenishment of industrial hydrocarbon reserves will mainly occur due to discoveries in the water areas, in the shelf areas, and on land – in non-anticlinal type traps and at great depths. The priority of oil and gas exploration trends is currently associated with carbonate complexes of the Late Devonian-Carboniferous age, not only in the southwestern part of the Pre-Caspian depression, but also in the northern water area of the Caspian Sea and adjacent lands and can be considered as the main objects of exploration for the coming years [23]. The development of deep subsurface resources in order to produce hydrocarbons is becoming an increasingly urgent global problem.

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Палеогеоморфологические предпосылки осадконакопления девонских отложений Прикаспийской впадины

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Актуальность работы. Прикаспийская впадина – это широкий стратиграфический диапазон промышленной нефтегазоносности. Открытие в последние десятилетия ряда месторождений углеводородов является важным фактором, подтверждающим перспективность данной территории. Особенности осадконакопления на поверхности Земли зависят от происходящих в это время тектонических процессов. Показана актуальность применения новых методов исследования с целью открытия месторождений углеводородов, в частности палеогеоморфологического. Изучение палеогеоморфологических предпосылок осадконакопления в девонских отложениях и с учетом региональных особенностей палеотектонического развития позволяют на научном уровне обосновать перспективы нефтегазоносности данной территории. В связи с этим необходимо развивать и выявлять диалектическое единство между палеогеоморфологией, палеотектоникой и осадконакоплением, что позволит определить закономерности формирования и размещения месторождений нефти и газа.
Целью исследования является научное обоснование перспектив нефтегазоносности и повышения прогноза девонского комплекса отложений Прикаспийской впадины с учетом влияния палеотектонического и палеогеоморфологического факторов.
Методология изучения основана на выявлении роли палеотектонического метода при определении нефтегазоносности данного района при благоприятном сочетании литолого-фациальных, геохимических, гидрогеологических и термобарических условий.
Результаты. Автором проводились палеогеоморфологические исследования закономерностей и условий осадконакопления в пределах Астраханского свода. Было установлено, что в течение всего палеозойского времени геотектонический режим представлял собой многократное чередование движений, различных по знаку. Также было выявлено, что многочисленные трансгрессии и регрессии меняли условия осадконакопления. На территории происходило частое перемещение береговых линий, возникали перерывы и несогласия в пределах островных зон. В результате проведенных работ было установлено, что современный структурный план палеозойских отложений унаследовал рельеф поверхности фундамента. При изучении данного вопроса были использованы материалы трехмерной сейсморазведки 3Д ОГТ-64 и площадной сейсморазведки 2Д, а также керновый и шламовый материалы по данным бурения параметрических скважин.
Выводы. Данные исследования территории Астраханского свода на основе палеогеоморфологического анализа и использование результатов геофизических и геологических материалов на стадии выявления и подготовки объектов под поисково-разведочное бурение позволяют изучить процессы формирования ловушек и пород-коллекторов и оценить перспективы нефтегазоносности данной территории на ближайшее будущее.

Ключевые слова: Прикаспийская впадина, Астраханский свод, палеотектоника. палеогеоморфология, осадконакопление, девонские отложения.

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