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TECTONIC ASPECTS OF SUPER-VISCOUS OIL DEPOSITS FORMATION AND PLACEMENT WITHIN THE VOLGA-URAL ANTECLISE

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Abstract

The article discusses the tectonics and developmental features of the Volga-Ural anteclise during the Baikalian, Caledonian, Hercynian and Alpine tectogenesis cycles. In this paper, particular attention is paid to stages and directional development during the evolution of geological structures. The main factors of the formation and destruction of Permian viscous oil and natural bitumen reservoirs are presented in the provisions of oil ontogenesis. It was noted the cyclical nature of these phenomena.

Keywords:

Volga-Ural anteclise;
Super-viscous oil;
Tectonic;
Reservoir; Oil.

1. Introduction

The study of structures tectonic development within platform territories is of great scientific and practical importance. This problem has not yet lost its relevance and is still in the spotlight of petroleum geologists. In each region promising for oil, geological exploration is accompanied by an analysis of various tectonic forms spatial relationships, study of their formation history, patterns of distribution and estimation of oil and gas potential.

Tectonic processes, which play an important role in the formation of oil reservoirs in the central regions of the Ural-Volga region, were also leading both for creating the conditions for their destruction and the subsequent formation of super-viscous oil and natural bitumen accumulations.

2. Methodology

The stages of the Volga-Ural anteclise geological history in which the central regions of the Ural-Volga region are an integral part is described in the works of I.A. Antropov, A.A. Bakirov, R.N. Valeev, E.D. Voitovich, V.I. Ignatiev, I.A. Larochkina, V.A. Lobov, V.I. Troepolsky, R.O. Khachatryan and other geologists.

There were several stages of generation, migration, accumulation of oil as well as destruction of oil reservoirs, which determined the frequency of formation and destruction.

In accordance with existing ideas [1-5], the beginning of the platform stage of the anteclise development is corresponded to the Vendian. It includes the following four tectonic cycles: Baikalian, Caledonian, Hercynian and Alpine, each of which is divided into separate stages corresponding to the times of new structural level reconstruction. Let's consider some of them in accordance with the provisions of the oil ontogenesis.

According to the results of geochemical studies of organic matter, the most ancient stages of the hydrocarbon reservoirs formation are identified in the pre-Paleozoic (Riphean) sediments.

The main stages of the tectonic transformation of the central regions of the Volga-Ural oil-bearing region affecting both the formation and destruction of oil accumulations in the Paleozoic and later era, are considered by us to have following form.

After the formation of the Kama-Belsky and Sernovodsk-Abdulinsky aulacogens and the Kazhim graben in the Riphean time, a system of smaller grabens and faults separated the Tatar-Nemsky paleo-arch, the Fomin-Kandyz highs and the Kazan-Kazhim aulacogen. In Vendian time, aulacogens developed into syneclises [1, 2] as well as was formed the Volga-Ural anteclise.

During the Caledonian cycle, the anteclise was covered by upward movements. The continental regime with a predominance of erosion and material removal processes existed [6] until the Middle Devonian era.

The Hercynian cycle of tectogenesis is characterized by a radical renewal of the Volga-Ural anteclise structure as well as the widespread formation of Paleozoic sedimentary cover. Transgression of the Devonian Sea spread from the Urals to the west

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significantly reducing the size of the Paleo-Tatar arch. The sea covered most of the modern South Tatar archduring the Eifelian time (fig.1).

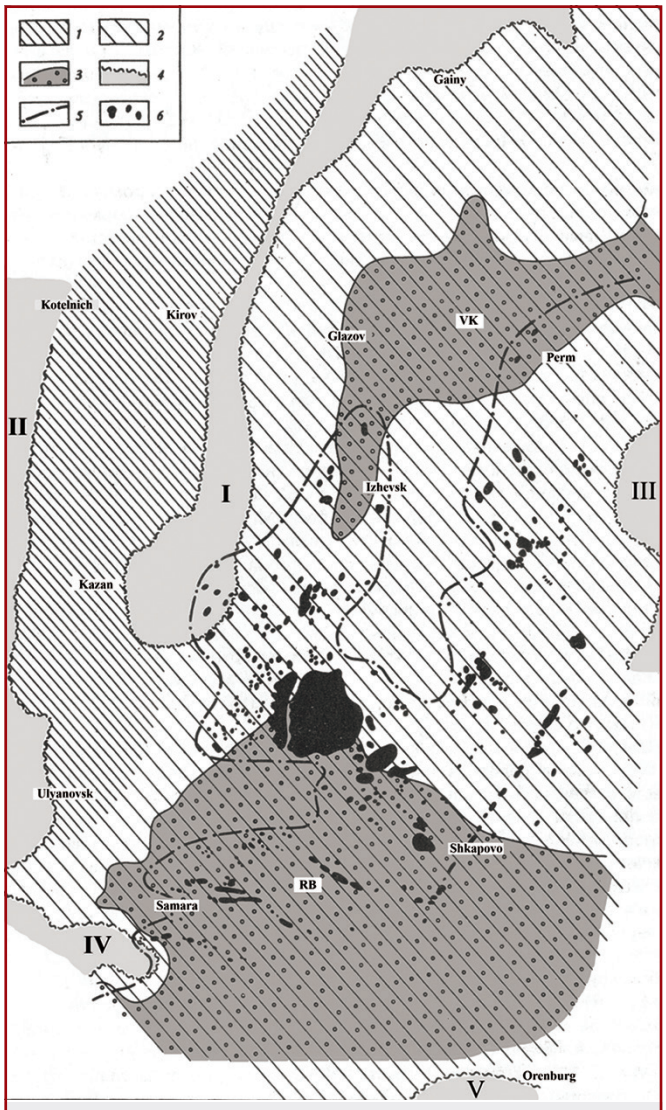

Fig.1. Paleotectonic diagram of the Volga-Ural province by the end of the Eiffel-Semiluks stage (according to O M Mkrtchyan, 1977, with additions). Regional sedimentation areas: 1 - Kazan-Kazhim; 2 - Kama-Buzuluk (Kama-Buzuluk paleosyneclise according to V A Klubov, 1973); 3 - the main oil-producing basins: VK - Verkhnekamsky; RB - Radaevsko-Buzuluksky; 4 - the boundaries of the areas (I - V), where there are no deposits of the Eiffel-Pasha complex; 5 - western border of oil content in the terrigenous sequence of the Devonian; 6 - oil fields in the Devonian sediments (modern location).

The development of the Melekess paleo-depression resumed in the Jurassic-Cretaceous time. This led to the reformation of the oil and gas reservoirs of the Devonian, Lower and Middle Carboniferous and caused the oil migration upwards into the Upper Carboniferous and Permian rocks. Here, the inter-reservoir flows of oil and gas hydrocarbons proceeded repeatedly. In those places where migration paths met impermeable caprocks (salt-bearing sediments of the Kungur formation, «lingulous clay» and the hydrochemical sequence of Kazan and clay-silty rocks of the Tatarian strata), in case of traps in the underlying layers, there formed the oil and gas reservoirs.

In the Early and Middle Carboniferous, the Volga-Ural anteclise, Melekess and other depressions continued to develop. At the same time, there began to form oil reservoirs in the Devonian. South Tatar Paleo-arch [7] located near the oil generation zones (Bugulma-Buzuluksky, Kama-Kinel and other troughs) became one of the centers of huge oil and gas accumulations in the Devonian sediments of the central regions of the anteclise. It occupied the territory of the Melekess depression, the Tatar and Bashkir arches and was in an elevated structural position relative to the depressions that limited it. The South Tatar paleo-arch retained closed contours, expanded its size and did not experience significant changes of the structural plan throughout the subsequent geological history.

In the final stage of Hercynian tectogenesis (after the «closure» of the Ural Paleo-Ocean and the collision of two continental plates) in the Late Carboniferous and Permian times, began the processes of dynamic and thermal relaxation, which intensified the differentiation of tectonic movements. Oscillatory movements of the earth's crust covered the entire sedimentary cover of the modern Volga-Ural anteclise, including Devonian and Lower Carboniferous oil-saturated rocks, which led to a change in their structure and bedding conditions and caused the Devonian oil to move upwards into the Carboniferous and Permian layers. Located close to the day surface, such deposits quickly became destroyed.

The next stage in the oil reservoirs formation occurs at the end of the Paleozoic, the beginning of the Mesozoic (Triassic) and is associated with the early Alpine folding stage. By this time, throughout the territory of the Buzulukskaya, Verkhnekamskaya Depressions, Kazan-Kazhimsky, Kama-Kinel and other troughs the processes of oil and gas formation had begun in all the negative structures for the oil source rocks of the Devonian and Lower Carboniferous sediments. According to V.I. Troepolsky, S.S. Ellern, R.S. Khachatryan the formation of oil reservoirs in terrigenous Devonian, Lower, and Middle Carboniferous completed in this period [3, 8].

One of the reasons of the Permian oil reservoirs preservation is a rather thick caprock of both the Tatarian sequence and Mesozoic sediments. According to A.P. Dedkov and G.P. Butakov et al. [9, 10] the thickness of only the Mesozoic sediments in the Melekess Depression was about 200 m. Thus, part of the hydrocarbons migrated upwards into the Permian formations along faults and cracks, as evidenced by the widespread distribution of residual oil in Devonian and Carboniferous rocks of modern negative structures. For example, the

presence of residual oil in terrigenous Devonian has been identified in many places near the axial part of the western and southern sides of the Melekess depression as well as in the axial parts and on the sides of the Zainsky and Mamadyshsky troughs.

Within the South Tatar Arch, where we have giant oil accumulations preserved in the Devonian and Carboniferous sediments, the Permian traps turned out to be unsaturated by oil or dry.

The rather significant oil shows and oil reservoirs in the Lower Permian deposits observed in the east of the Republic of Tatarstan and in the west of Bashkortostan are associated with vertical flows along the faults of the sedimentary cover, framing the South Tatar arch from the east and south, as well as with the presence of a sulfate-halogen stratum of the Kungur formation serving as a regional caprock which here played a large role in the processes of formation and preservation of oil reservoirs.

The area of the Melekess Depression again experiences a rise at the end of the Miocene, beginning of the Pliocene time. This leads to the formation of deep paleo-valleys of the Paleo-Volga, Paleokama, etc. Being close to the day surface, Permian sediments were subjected to a long-term effect of weathering agents in the zone of hypergenesis. Numerous paleo-river valleys cut deep into the Permian sedimentary strata, forming zones of active drainage. As a result of the infiltration water penetration through these zones, there was an active destruction of the oil reservoirs formed here. Natural flooding of the oil reservoirs continued for a rather long time (about 4.0 million years), until in the late Pliocene time they turned out to be filled with sediments of the Akchagyl Sea that transgressed to these areas. These sediments completely blocked the valleys making them impenetrable again. The constant impact on the oil reservoirs of aggressive surface waters was accompanied by geochemical (and biochemical) processes, which led to the formation of super-viscous oil reservoirs and natural bitumen deposits. By the time the pre-Pliocene valleys were filled by sandy-clay sediments, accumulations of bitumen had already been formed and were in a stationary state due to their high viscosity. The Pliocene caprock kept them from further destruction.

The sinking of the central part of the Melekess Depression, which began in the Akchagyl age led to a reformation of the oil deposits that remained from the destruction in the Devonian and Carboniferous systems, but the Permian ultra-viscous oils and natural bitumen of the Melekess depression by that time already lost their former mobility and turned into highly viscous substances.

Later warping movements, especially the uplift in the Quaternary, led to a disintegration of the sedimentary cover rocks in the central regions of the Ural-Volga region, most pronounced in the junction areas of large tectonic structures. As a result of the rocks fracturing and the weakening of the caprocks sealing properties, here became possible themigration of oil and gas hydrocarbons, as well as the outflow of highly mineralized waters from the rocks of the Carboniferous and probably Devonian systems into the overlying formations, up to the Quaternary sediments, which is currently identified in the valleys of the Pleistocene rivers.

3. Results and Discussions

The possibility of the ultra-viscous oil and natural bitumen reservoirs generation from Lower Carboniferous oils as a result of exposure to chemical and physical processes and biochemical oxidation was experimentally proved by N.K. Norenkova by modeling the biogenic oxidation of oils from a number of oilfields.

Thus, the genetic relationship between the Permian natural bitumens and ultra-viscous oils of the Melekess Depression with the oils of Carboniferous and Devonian systems (and possibly earlier) is due to the processes of vertical migration of hydrocarbons in zones where the sedimentary cover is disintegrated and experienced repeated hydrocarbon flows (fig.2).

The multiple occurrences of natural bitumen deposits are also indicated by the presence of ancient water-oil contact zones within the natural bitumen deposits as well as by both zones of rock decompression associated with them and areas strongly calcified by carbonate cement.

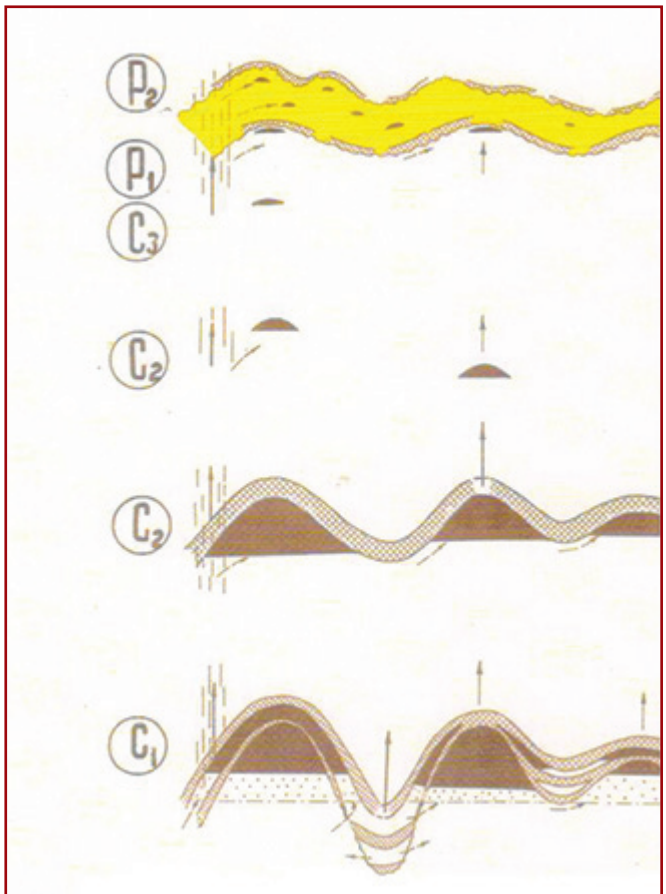

Fig.2. Scheme of oil deposits and natural bitumen accumulations formation in Carboniferous and Permian deposits (according to RS Khisamov, 2006)

It has been established that ancient water-oil contacts within the reservoirs can be identified by studying the secondary changes in reservoir rocks. G.I. Theodorovich using the example of the Buguruslan oilfield established that the pyritization of rocks is a characteristic feature of water-oil contact. K.B. Ashirov discovered calcite sedimentation in the border zone and indicated the relationship of authigenic calcite with hard bitumen. Later, many researchers considered the authigenesis of minerals in the ancient water-oil contact zones: O.G. Zaripov, G.E. Prozorovich, R.S. Sakhibgareev, O.A. Chernikov, V.N. Kholodov, etc.

Ancient water-oil contact zones are identified in many studied ultra-viscous oil and natural bitumen reservoirs. They are characterized by the presence of calcified interlayers among weakly cemented rocks. Typically, these layers are associated with an increased content of authigenic pyrite. These layers are also characterized by significant corrosion of minerals and grains. The combination of the decompression zone and the cementation zone beneath the first zone (the first one is due to the dissolution of calcite, and the second one is to its sedimentation during the decrease in the concentration of aggressive components in bottom waters) indicates the existence of ancient water-oil contact zones. The presence of two or more such zones in one reservoir indicates the multi-stage process of its formation.

Conclusion

The formation of bitumen completes the ontogenesis of oil. These processes occur in stages and are characterized by an evolutionary orientation in their development. One of the factors determining the generation of hydrocarbons, the accumulation, conservation, and destruction of hydrocarbon accumulations are the tectonic movements of the Earth's crust.

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Тектонические аспекты формирования и размещения месторождений сверхвязкой нефти Волго-Уральской антеклизы

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Реферат

Рассмотрены тектоника и особенности развития Волго-Уральской антеклизы в течение байкальского, каледонского, герцинского и альпийского циклов тектогенеза. Особое внимание уделено стадийности и направленности развития в ходе эволюции геологических структур. Представлены в положениях онтогенеза нефти основные факторы формирования и разрушения пермских залежей сверхвязких нефтей и природных битумов. Отмечен циклический характер этих явлений.

Ключевые слова: Волго-Уральская антеклиза; сверхвязкие нефти; тектоника; залежь; нефть.

Volqa-Ural antiklizinin yüksək özlülüklü neft yataqlarının formalaşma və yerləşməsinin tektonik aspektləri

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Xülasə

Məqalədə Volqa-Ural anteklizinin Baykal, Kaledon, Hersin və Alp tektogenez dövrlərdəki tektonika və inkişaf xüsusiyyətlərinə baxılmışdır. Geoloji strukturların təkamülü zamanı inkişaf mərhələləri və istiqamətlərinə xüsusi diqqət yetirilmişdir. Permin yüksək özlülüklü neft və təbii bitum yataqlarının formalaşmasının və dağılmasının əsas amilləri neft ontogenezinin müddəalarında verilmişdir. Bu təzahürlərin dövrü xarakteri qeyd olunmuşdur.

Açar sözlər: Volqa-Ural antiklizi; yüksək özlülüklü neftlər; tektonika; yataq; neft.