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ASSOCIATION OF HYDROCARBON FIELDS WITH MUD VOLCANOES  
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*The article presents the authors' opinions and their own views on the geodynamic processes creating mud volcanoes and associated oil and gas accumulations. The results of 2D/3D seismic and geophysical well logging data interpretation allow clarifying the distribution area of the Maikop sediments and suggest that mud volcanism is associated with the deposits, accumulated in Maikop paleobasin. Mud volcanism in the study area appears to be synchronized in time and space with the growth of folds, as indicated by paleoreconstruction based on the seismic sections. Hence, formation of oil and gas accumulations in the basin is associated to mud volcanism and the vents of mud volcanoes are supposed to be the main pathways for hydrocarbon migration.*

**Keywords:** The South Caspian basin, mud volcanism, paleobasin, non-Newtonian liquid, river systems, oil and gas deposits

**Introduction**

The South Caspian basin is located in the central part of the Mediterranean mobile belt characterized by permanent geodynamic processes occurring in the sedimentary complex. The territory is described by high seismicity, mud volcanism, landslide processes, contrasting character of modern vertical and horizontal movements. The most active of them is the seismicity associated with tectonic processes and mud volcanism.

All the oil and gas fields and prospective structures within the South Caspian basin are associated with mud volcanoes. That kind of association confirms the closest relationship between oil and gas deposits and mud volcanoes which is one of the most actual issue of researches for the long time.

Mud volcanism is one of the most intriguing natural phenomena. About 1,700 surface and underwater mud volcanic structures have been observed around the world [1]. Mud volcanoes are distributed within the Alpine-Himalayan, Pacific and Central Asian mobile belts in 30 countries of the world such as Italy, Romania, Ukraine, Azerbaijan, Turkmenistan, Iran, Pakistan, Myanmar (Burma), Malaysia, Indonesia, Colombia, Trinidad and Tobago, etc. [2]. More than 350 volcanoes are located in four oil and gas regions of Azerbaijan - Gobus-

tan, Absheron, Baku archipelago and Azerbaijan part of the South Caspian depression (Fig. 1). All the forms of mud volcanic manifestations (active, extinct, dormant, buried, underwater, insular, abundantly oil-releasing) are observed here.

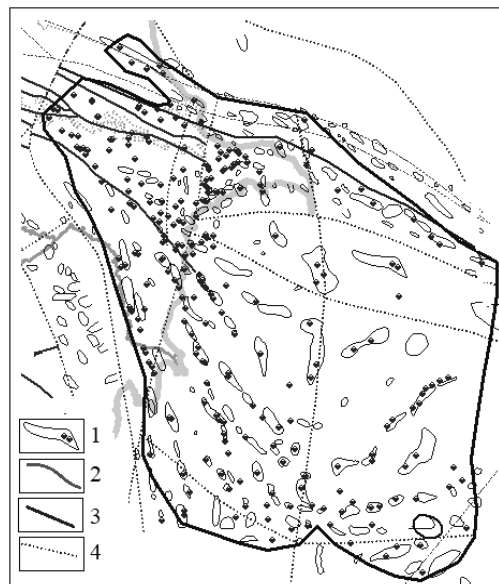


**Fig. 1.** Location map of diapiric structures and mud volcanoes: 1 – mud volcanoes and structures, 2 – distribution area of mud volcanoes, 3 и 4 – revealed and supposed deep faults reaching the basement.

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### Materials and methods

The study involves database including geophysical survey of wells and seismic survey by the common depth point method (CDP), performed in Gobustan, Absheron, Baku Archipelago oil and gas bearing regions and Azerbaijani part of the deepwater South Caspian basin. The location map of mud volcanoes, especially of buried ones, was refined according to 2D and 3D seismic data.

### About the mechanism of mud volcanism according to 2D and 3D seismic survey data

Mud volcano formation can be understood in terms of the conceptual model suggested by authors [13]. Seismic time sections make it possible to combine and summarize information accumulated to date, including a huge and diverse theoretical and practical database on mud volcanism. Figure 2 shows some phases of a mud

volcano formation in the South Caspian basin by the example of Nakhchivan mud volcano.

According to the scheme shown in Fig. 2a mud volcanism began at the end of the Oligocene and formed as a result of Rayleigh-Taylor instability. From that moment to this day, this process continues with fluctuating energy. In the left picture, this process is displayed by arcs with chords of different lengths. In the right figure, these arcs are absent for the reason that there are no acoustic boundaries inside the mud mass, so the chords are not visible. Around the vent of the mud volcano, the sedimentation boundaries (reflected from the boundaries of acoustic reflection surfaces) are interrupted. This is explained by the fact that when the dome of the mud volcano was above the sedimentation level terrigenous material accumulated around the dome. Further, in parallel with the increase of overburden sedimentary load the dome of the mud volcano grows with different energy parameters. The right figure shows that the Nakhchivan volcano is not developing today; the growth of the eruptive channel has slowed down in the middle of the Absheron and stopped since the end of the Quaternary. This is evidenced by the fact that the arch of the uplift and, accordingly, the dome of the mud volcano flattened. The level of the latter was flattened with the level of the sea bottom as a result of its erosion by underwater currents. A similar scheme can explain the formation of buried mud volcanoes.

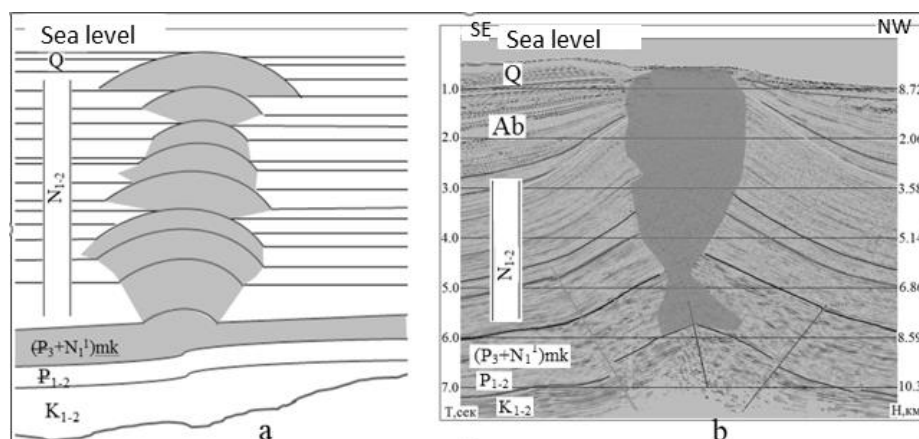


**Fig. 2.** Model of mud volcano formation (a) based on the seismic cross-section (b) through Nakhchivan mud volcano

This phenomenon, known as the Rayleigh-Taylor instability, leads to the formation of an intrusion of a lighter fluid into a denser medium. As a result of this hydrodynamic process, fractures and faults are formed in the rocks lying directly above the top and the periphery of the intrusion. This process is also promoted by the fact that the liquid cannot penetrate into the lower half-space due to the difference in the average total pressure ( $P_b$ ) provided by the overlying sediments. The average total pressure gradually decreases upward and calculated by using the following formula:

$$P_b = gh\sigma_{bw}$$

where  $\sigma_{bw}$  – the total density of the wet sediment;

$h$  – thickness of the sedimentary sequence above this place;

$g$  – acceleration of gravity.

The difference in densities required for the formation of mud diapirs decreases with depth due to compaction of sediments. Compaction leads to dewatering and diagenetic changes in sediments [3]. Agitation of a container filled with non-Newtonian fluid causes shear forces that breaks the molecular bonds and forces the substance to flow at a certain speed [3]. For example, a concussion caused by an earthquake or by artificial means can thin a clayey mass saturated with water or sludge and force them to flow upwards along the ruptures created by tensile forces. Mud diapirs have a complex internal structure indicating the flow of substance [4, 5, 6]. The movement of substance is mostly vertical in the center of the structure and is subhorizontal at the periphery. At a later stage of compaction and consolidation of clays and crystallization of clay minerals, the rocks become more brittle and a slight increase of internal pressure causes micro-cracking and brecciation in them.

Figure 2 shows that the force, formed under the influence of sedimentary load, spreads over the entire surface of the liquid mass evenly. As a result, a tension zone with discontinuities is created on the convex surface. Thro-

ugh these discontinuities the liquefied mud is squeezed toward the surface. Continuous blurring around the fault surface leads to the creation of eruption channels of the mud volcano. With an initial content of 25–30% smectite, the illitization of 1 m<sup>3</sup> of clay is accompanied by the release of 17–20 kg of H<sub>2</sub>O<sup>+</sup> [1], which leads to the formation of the considerable watering zone in the sedimentary complex. The formation of subsurface quickclay dramatically increases the permeability of individual sections of the clay stratum and stimulates an increase in thermolysis reactions and thermocatalysis of dispersed organic matter in the main phase of oil and gas generation. It is easy to understand that clay strata with a thickness of 1.5–2.0 km can create a very significant watering zone in the overlying sedimentary cover.

According to Fig. 2b, traces of tectonic activity can be revealed within the region. This is evidenced by the geometric shape (pear shape) of the eruptive channel of mud volcano. Narrowing of the diameter of the eruptive conduit indicates a decrease in pressure on the source of supply of the eruptive conduit or a decrease in the volume of terrigenous material carried into the sedimentation basin and vice versa. It is supposed that this factor is controlled by the process of oil and gas generation inside the source rocks (Maikop group).

### Relation of mud volcanoes to paleoriver systems and oil and gas accumulations

As the results of our research show, the territory contoured as a fan (Fig.2) represents a delta with area of 57000 km<sup>2</sup>, which was filled during the Cenozoic from three sides. In the figure, each paleoriver system is indicated in a different color. As can be seen from Figure 3, the distribution areas of all known structures and mud volcanoes coincide. At the same time, oil accumulations are associated with sandy reservoirs of the Productive Series over the entire contoured area.

According to previous researches [7, 8, 9, 10, 11], the formation of hydrocarbon accumulations is associated with the generation of enormous volumes of hydrocarbon fluids in the sedi-

mentary layer, mainly in Oligocene-Miocene rocks (Maikop and Diatom suites), and their subvertical migration to reservoirs of PS.



**Fig. 3.** Paleodeltas of river systems: 1 – Paleosamur, Paleopirsaat, Paleovelvelchay, Paleovolga; 2 – Paleokura, Paleopirsaat; 3 – Paleosamur; 4 – mud volcanoes, 5 – diapiric structures; 6 – Caspian coastline; 7 – modern Kura riverbed

Here, the section above the Oligocene was composed of sediments brought by Paleokura, Paleopirsagat, Paleosamur, Paleovelvelchay rivers (the riverbeds and deltas of these rivers still exist today and they are joined with numerous small rivers) and the Paleovolga in the south of the Paleosamur basin [12]. Over the entire time interval, there was a repeated change in the location of the rivers and their branches. The well logging and seismic data indicate that from three sides (south-west, north-west, northeast) large volumes of clay and loose masses flow into the indicated delta (Fig. 3.). As indicated above, the distribution area of these deposits is quite large and covers the territory of Kura – South-Caspian megadepression, including Abshe-ron peninsula, Absheron and Baku archipelagoes, Dzheyrankechmez Depression, Alyat Ridge, Low Kura depression as well as some parts of the Caspian-Guba area. Here, over the Maikop deposits, PS sediments are represented by several lithofacial types: Absheron, Gobustan, Kura, Caspian, South Caspian, with the latter combining the features of all the above lithofacies,

representing their continuation into the shallow marine part of the basin.

The well logging data show that more coarse-grained rocks were deposited in constantly meandering paleoriver systems and the light fraction was dispersed by sea currents. These conditions changed laterally and vertically at subsequent stages of sedimentation.

As the basin was filled, the river systems occupied the same areas depending on the tectonic processes (lowering, rising, inclination, inversion, etc.) which cause the transgression and regression of the sea coastline. This process was inherited and river systems generally remained in the same area [14]. This is reflected on the well logging data as well and Figure 4 shows that the characteristics of the sediments have some vertical constancy along the section. Obviously, conditions during the evolution of the filling basin have led to the formation of the geological section represented by multi-layered sediments created by paleoriver systems. The clayey Maikop Series accumulated in the rapidly subsiding sedimentary basin behaves as a light liquid and intrudes into the overlying multi-layered sediments of the paleoriver systems as a result of the Rayleigh-Taylor phenomenon. Acting as a non-Newtonian fluid, the clayey Maikop Series are squeezed upwards through the overlying sediments. The latter are the most vulnerable medium within the geological strata and serves as unloading channels. Through these channels unloading process occurs faster than in areas not affected by rivers.

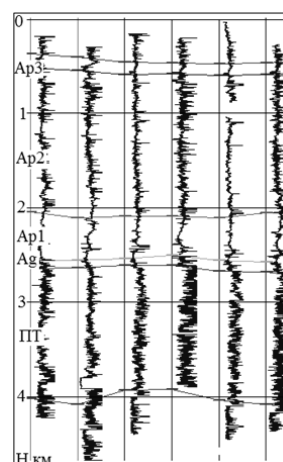


**Fig. 4.** Well logging data

As mentioned above, this process is also promoted by the fact that the liquid cannot penetrate into the lower half-space due to geostatic pressure gradually decreasing upward. As a result, the elision system such as the buried Maikopian delta (Fig. 4.) filled with a non-Newtonian fluid moving upward causes tensile forces along the intrusion surface, creating discontinuous disruptions in the upper layers. Through the latter ones a sudden stress discharge occurs, causing liquefying of a non-Newtonian fluid and forcing it to move along the created disruptions. Obviously, this fluid, containing mud and hydrocarbons, initially fills up the pore space of reservoirs with gas, oil and water. The filling process continues until the internal pressure of the injecting fluid remains below the geostatic pressure of the overlying strata. When the pressure of fluid exceeds the geostatic pressure fluid makes its way to the surface as a mud volcano eruption or manifestation. Thus, oil and gas accumulations and eruption channels of mud volcanoes are created. Described processes create favorable conditions for vertical (or primary) and horizontal migration of hydrocarbons.

As it is known, the post-rift subsidence in the Oligocene and Early Miocene led to the formation of an anaerobic basin in the South Caspian, where source rocks accumulated. If we consider the paleobasin as a tank filled with non-Newtonian fluid, association of mud volcanism with river systems and non-structural traps becomes obvious.

Favorable conditions for improving the porosity and permeability of rocks are created above the growing diapir structure. A system of differently oriented faults appeared as a result of the Rayleigh-Taylor phenomenon on the crest and limbs of a diapir fold splits it into complex blocks. The longitudinal faults are the longest ones and as a rule they are normal or reversed depending on post-tectonic processes. These faults are clearly traced on 2D and 3D seismic survey data.

## Conclusion

During Maikopian age a huge volume of clayey sediments accumulated in rivers and rapidly buried, creating an elision system. The main processes of mud volcanoes formation are phase transitions in sedimentary strata that lead to Rayleigh-Taylor instability. Due to Rayleigh-Taylor phenomenon, non-compacted Maikopian sediments behave as a non-Newtonian fluid. Under the geostatic pressure Maikopian mass penetrates upward, causing tensile forces, which in turn lead to the formation of faults and a sudden unloading of stresses in the overlying rocks. So, the non-Newtonian fluid liquefies and rushes up along the faults, creating eruptive channels of mud volcanoes and filling the reservoirs with hydrocarbons. Based on the above, the idea has been put forward that the deposits of oil and gas in the South Caspian Basin are created as a result of mud volcanic processes.

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## CƏNUBİ XƏZƏR HÖVZƏSİNDƏKİ KARBOHİDROGEN YATAQLARININ PALÇIQ VULKANLARI İLƏ ƏLAQƏSİ

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Məqalədə müəlliflərin palçıq vulkanlarını və əlaqədar neft-qaz yataqlarını yaradan geodinamik proseslər haqqında fikirləri təqdim olunur. 2D/3D seysmik və quyu geofiziki məlumatlarının təfsiri əsasında Maykop süxurlarının yayılma sahəsi dəqiqləşdirilmiş və palçıq vulkanizminin Maykop paleohövzəsi ilə əlaqəli olduğu göstərilmişdir. Seysmik kəsilişlər əsasında aparılan paleorekonstruksiyalar palçıq vulkanizminin inkişafının və qırışıqların formalaşmasının zaman və məkanda sinxron olmasını göstərir. Belə ki, hövzədə neft və qaz yataqlarının əmələ gəlməsi palçıq vulkanizmi ilə bağlıdır və palçıq vulkanlarının eruptiv kanalları karbohidrogenlərin əsas miqrasiya yolları hesab olunur.

**Açar sözlər:** Cənubi Xəzər hövzəsi, palçıq vulkanizmi, paleohövzə, qeyri-Nyuton mayesi, çay sistemləri, neft və qaz yataqları

## СОПРЯЖЕННОСТЬ УГЛЕВОДОРОДНЫХ МЕСТОРОЖДЕНИЙ ЮЖНО-КАСПИЙСКОГО БАСЕЙНА С ГРЯЗЕВЫМИ ВУЛКАНАМИ

Н.П. Юсубов, И.С. Гулиев, Ш.М. Гусейнова

В статье излагается мнение авторов о геодинамических процессах, при которых создаются грязевые вулканы и сопряженные с ними нефтегазовые месторождения. Приводятся результаты исследований по уточнению, с которыми связаны корни грязевых вулканов. На основе интерпретации данных 2D/3D сейсморазведки и геофизических исследований скважин уточнены ареалы распространения майкопских отложений и выявлена связь грязевого вулканизма с майкопским палеобассейном. Палеорекострукции, выполненные по сейсмическим разрезам, показывают синхронность развития грязевого вулканизма с ростом складок во времени и пространстве. Таким образом, формирование скоплений нефти и газа в бассейне связывается с грязевым вулканизмом, а эруптивные каналы грязевых вулканов рассматриваются основными путями миграции углеводородов.

**Ключевые слова:** Южно-Каспийский бассейн, грязевой вулканизм, палеобассейн, неньютоновская жидкость, речные системы, нефтегазовые месторождения