Analysis of mechanism for formation of diapiric structures of Tersko-Caspian Foretrough

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Abstract. The article delivers a comparative analysis of the diapir structures of the Tersko-Sunzhenskaya oil-and-gas region of the Eastern Ciscaucasia, which are represented in the form of quasi-muddy, young (not yet ripe) volcanoes, and mud volcano structures on the territory of the southeastern end of the Caucasian ridge (Apsheron peninsula and other territories of Azerbaijan) and the northwestern end of the Caucasian ridge (Kerch and Taman peninsulas). It is shown that the formation of the diapir structure is not a sufficient condition for its degeneration into a mud volcano even when there is a high thickness of clayey strata in the section. The paramount significance in such geological conditions is determined not only by the thickness of the clay stratum, but also by the degree of its water-saturated porosity, which forms viscous-plastic and fluid properties that facilitate the transition of the rock to the phase of active flow and outflow onto the surface.

1. Introduction

First many productive structures, according to the Lower Miocene sediments within the Tersko-Caspian trough (TCT) of the Eastern Ciscaucasia, represent explicit classical diapirs due to their increase in thickness in the crest of the fold of the Maikop clay mass. In accordance with the theory of I.M. Gubkin, developed on the basis of the structure analysis of oil-and-gas structures of mud volcanoes in Azerbaijan, the diapirism of the structure is the main prerequisite for the formation of a mud volcano.

A diapiric (or piecement) is an anticlinal fold that has strongly deformed and highly plastic sediments in the core, which tectonically tear younger layers and at that the latter form the wings of a diapiric structure and usually lay fairly flat [1]. According to I.G. Gubkin [2,3], "diapir structure, oil deposit and mud volcano is the triune essence of a complete process of geological development of Caucasian ridge's immersing and foundering region." From this formulation it follows that a special form of tectonics - diapirism (as the first and, consequently, the most important in the triune essence of a complete process of geological development of the corresponding area) should naturally lead to the formation of a mud volcano on this structure. As a result of this interpretation, it is very interesting to analyze the manifestation of diapirism and identify the causes of the incompleteness of mud volcanism (quasi-mud volcanism) in the highly productive oil and gas structures of the Tersky and Sunzhensky


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ridges of the Eastern Ciscaucasia in comparison with the highly productive oil and gas diapiric structures of mud volcanism in Azerbaijan and the mud volcanoes of the Kerch and Taman peninsulas linked to a young alpine zone of the folding - the North Caucasus.

2. Materials and methods

There have been made many assumptions about the genesis of mud volcanoes and the mechanism of mud volcanic phenomena that explain differently the causes of this type of volcanism. Thus, G.V. Abikh came to the conclusion that for the display of mud volcanism on the surface of the earth - magma gives the heat; clastic rock is from fault zone for a salse breccia; water comes from a sea; gas flows from bituminous rocks; earthquakes create impulses which start the mud-volcanic activity. The idea of the scientist, about the magmatic origin of mud volcanoes, was later evolved in works of S.A. Kovalevsky [4], who believed that mud volcanism is an embryonic form of magmatic volcanoes. Academician I.M. Gubkin first determined the connection of these volcanoes with gas-and-oil fields and expressed, in our opinion, a more correct point of view on their genesis. According to the scientist, the geological structure, presence of oil-and-gas and mud volcanism are functions of the same common causes which is the functions of the geological structure, in particular, the special forms of tectonics - diapir structures. The scientist represented the mechanism of formation of mud-volcanic phenomena within the western and eastern endings of the Caucasian ridge as follows: "the separation of high and lower pressure zones in the region of diapiric folds development by the Akchagylian time had gone so far that the plastic clay masses under enormous pressure moved along the lines of smallest resistance into the zone of low pressure, namely - into the domes of folds. The extrusion of these masses upwards through younger deposits had begun and had been progressing. In other words, it was the process of diapir structures formation. As soon as this process begun, water, gas, and then oil started to flow into the cores of the folds, as they are the most elevated and the most crumpled and loosened places. Those three elements that caused the emergence of mud volcanoes and also oil fields had begun to rise and accumulate. Gas and water, as more mobile substances, rushed first to the core of the fold. Water softened core rocks: under the influence of gas pressure, it rose upward, coming out in the form of gassing sources on tops of diapir structures. If the gas migration was abundant, it was not able to fully manage its way out in time so large amounts of gas was accumulated and stored in the core, as a result of which the pressure here reached enormous proportions. The stress created was discharged through explosion and the eruption of gas, which, bursting outward in form of a vigorous jet, carried the pieces of the destroyed cores and wall rocks. The majority of eruption cases are accompanied by the ignition of gases, the appearance of a high (300 meters and more) fire column over the volcano and the outflow of mud volcanoes".

I.M. Gubkin believed that Mesozoic rocks are the sources of gas supply to mud volcanoes, pieces of which are found almost everywhere in breccia of these volcanoes. The teaching of I.M. Gubkin on mud volcanoes was subsequently developed in the works of his disciples - S.F. Fedorov, A.A. Yakubov, P.A. Avdusin, A.A. Alizade, and also in the research of M.M. Zeynalov, F.G. Dadashev, N.O. Nazarov, and others [5]. Just as I.M. Gubkin saw the tectonic movements as the primary causes in the formation of mud volcanoes, his followers mainly associate the mechanism of mud volcanic formation phenomena with the tectonic development of gas-and-oil regions.

3. Research results

Mud volcanoes of Azerbaijan are located in the southeastern part of the Greater Caucasus, the Tersko-Caspian foredeep and part of the aquatorium of the Middle Caspian (within the Apsheron peninsula and the South Caspian basin). Almost all mud volcanoes are accompanied with the display of structural diapirism and large deposits of oil and gas.

The Tersko-Caspian foredeep is located in the southeastern part of the Ciscaucasia and in the eastern part of the Middle Caspian. The depth of the foundation immersion in the through is from -6000 m to -12000 m. The central part of the western sector of the Tersko-Caspian trough is intricate due to a number of high-amplitude structural zones (the Cretaceous and also Paleogene and Neogene

horizons). Sunzha anticline zone is located in South. Its Upper Cretaceous sediments lie at 1500m in the western part and up to -4000m and deeper in the eastern part. Sunzhenskaya zone is a system of narrow and lengthy anticlines that have a block structure with elements of thrust. Its amplitude is more than 2000m on the average. Terskaya anticlinal zone is located in the north while its structure does not fundamentally differ from the structure of the Sunzha zone. It is slightly more immersed and complex. Sediments within the Upper Cretaceous lie mainly in the depth range between -2500 m in the west and -4500 ÷ -5000 m in the east. The Terek and Sunzha anticlinal zones are divided by the Alkhanchurt basin - a deep through located in the western part of the territory reviewed. Geological profile (Fig. 1) shows that the diapirism of the structures of the Tersko-Sunzhenskaya region manifests itself even more explicitly than in the structures of other regions, however, mud volcanoes there have not ripened.

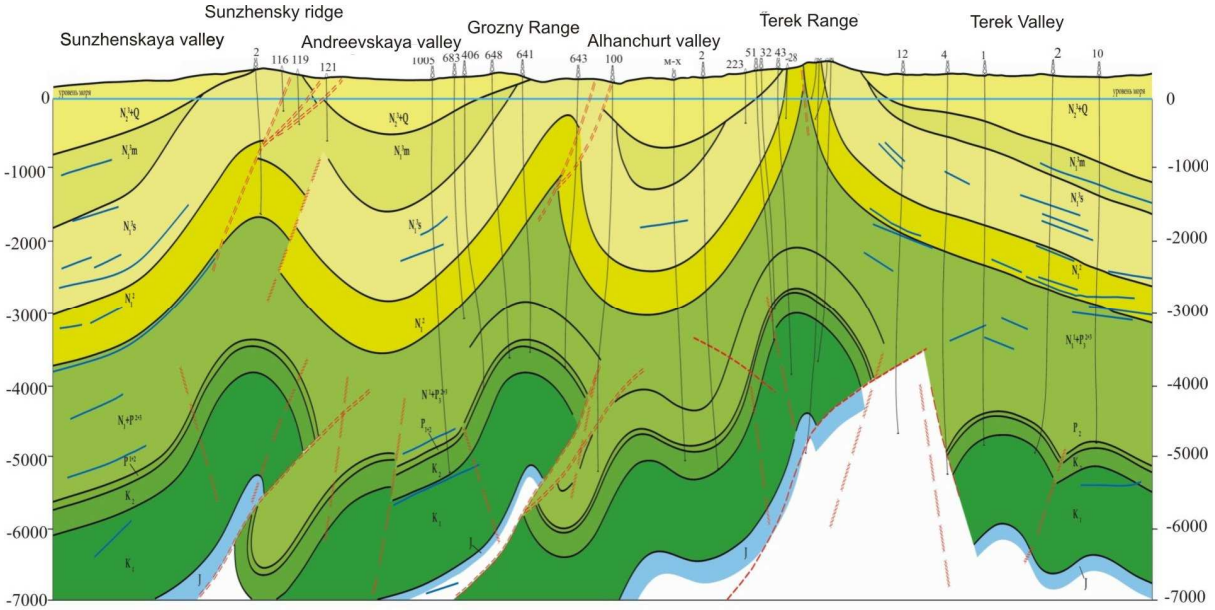


Figure 1. The regional geological profile of the Tersko-Sunzhenskaya oil and gas region

4. The discussion of the results

The research by A.I. Aliyev demonstrates a clear interrelation between manifestation of mud-volcanic activity of structures within Azerbaijan and earthquakes of various degrees. The periodicity of mud volcanoes eruptions within Azerbaijan during the time of earthquake occurrences and manifestations of earthquakes in the territory of the front ridges of the Eastern Ciscaucasia is also intriguing. As a result, 24 eruptions of mud volcanoes were recorded in Azerbaijan both on land and sea for the period from 1810 to 1967, and they'd flowed with certain regularity. From 1840 to 1959, two periods of active mud volcanic activity were notable: the first period (1840-1900) is characterized by relatively weak activity of mud volcanoes (during these years there were only 7 eruptions), and the second (1900-1959) - active (during this time lag there were 20 eruptions). For the same periods of time, the number of earthquakes within the front ridges of the Eastern Ciscaucasia was 9 and 15, respectively (Figure 2). This indicates that the activation of tectonic activity of structures, including the activation of mud volcanic activity, is associated with periodically occurring earthquakes covering the entire territory of the Caucasus. By comparing the structures on the Tersky and Sunzha ridges and mud volcanism within the Apsheron peninsula in Caspian Sea of Azerbaijan, on the Kerch and Taman peninsulas within the Black and Azov seas, it can be noted that they are all characterized by the display of diapirism, while the lithologic-stratigraphical profile of these areas is identical in many respects, but there are also significant differences.

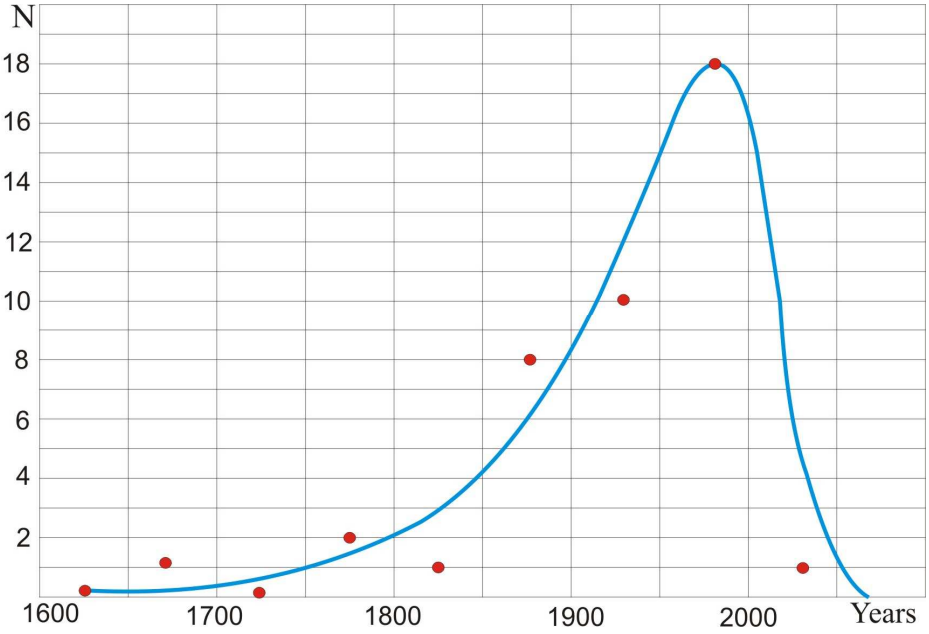


Figure 2. Temporal distribution of strong earthquakes within the Tersky and Sunzhensky ridges of the Eastern Ciscaucasia

Within the limits of the front ridges of the Eastern Ciscaucasia, clayey strata of great thickness are confined to the Oligocene and the Lower Miocene (Karagano-Chokrak + Maikop) and reach 2,400-3,300m or even more under certain conditions. At the same time, the coefficient of pore and reservoir pressures anomality in this stratum reaches 2-2.2, especially in the crest of structures because there is a significant increase in the thickness of the clayey strata [6]. The thickness of the clay stratum (the bottom of Chokrak + Maikop) of the Kerch and Taman peninsulas structures, where mud volcanic activity is manifested, reaches up to 4000 m, and the anomaly factor of the pore and reservoir pressures in this stratum is also great, up to 2-2.2. Diapiric, mud volcanic structures of Azerbaijan are also associated with clayey strata, the total thickness of which can exceed 5000 m, and they are younger - the Middle Pliocene (productive strata) and the Upper Pliocene (Apsheron and Akchagylian stages). The age of these deposits is 10-15 million years younger, and, therefore, they are characterized by a higher porosity even under normal compaction conditions [7]. This was revealed in a comparative analysis of the change regularities in the porosity of clays depending on the depth of their occurrence in different oil-and-gas regions and it also was taken into consideration when the estimation of pore pressures according to geophysical and petrophysical data was conducted. These features of clay strata in terms of thickness and porosity within the limits of the front ridges of the Eastern Ciscaucasia and the depression zones of sediment deposition on the northwestern and southeastern ends of the Caucasian ridge have left their mark on the formation of diapir structures and the possibility of its further transition to the stage of mud volcanism. The degree of structural tectonic fracture which goes up to the establishment of pronounced through-breaking breach, which can be registered with the means of seismic investigation methods, in the entire sediments of rocks and the thickness of plastic clay strata in the structures of the Tersko-Sunzhensky ridges, turned out to be much lower. In individual geological seismic sections of the Eastern Ciscaucasia, vertical or inclined lines of correlation and sinchronism loss of reflected waves are implicitly and clearly visible, which indicates the presence of continuous breaking faults along the entire rock sediments and zones of clastation. It is precisely these zones that were the routes of migration of hydrocarbon fluids from great depths that go down to the Lower Miocene (Caragano-Chokrak sandstone) and were forming multi-layer deposits. And although the structures on the Tersko-Sunzhensky ridges serve as even more classical diapirs, while in some of them the Maikop clay deposits even go out to the surface and, thus,

represent underdeveloped (unripened), quasi-mud volcanoes (Fig. 3), the outpourings of mud mass on the surface did not happen. In addition to the factors above, it is necessary to have substantially greater stresses in the thickness of the rocks to form a mud volcano. Those stresses contribute to the formation of large faults that go through the whole section of formation. As a result, aggregated and detrital rock could be squeezed and thrown out because of high-pressure liquid and gaseous fluids that transit through those fault areas. Judging by the location of mud volcanoes within the Caucasus - they are confined to the end of the Caucasian Ridge in both the northwest and the southeast. This indicates that during the formation of the Caucasian ridge massif and the uplifting of the mountain system in the central part, an intensive lowering of its endings in the northwest and southeast took a place as a counter-reaction in order to keep the balance. Endings in northwest and southeast formed powerful strata (up to 4000-5000 m) of young in age (Upper and Middle Pliocene) which mainly is clayey rocks that do not have enough time to consolidate and thicken to any degree and remain highly porous and highly plastic. As a result, the mountain chain of the Caucasus ends with its endings in the seas - the Caspian Sea in the southeast and the Azov - Black in the northwest. The diapiric structures of the Terek and Sunzha ridges are located in the foothill part of the area, approximately opposite to the middle of the Caucasian ridge and across its line and therefore experienced less stresses and, despite the presence of a large but less powerful stratum, the younger ones (the Maikop stratum of the Oligocene) and, therefore, plastic clay rocks did not transform into mud volcanoes. Apparently they did not possess enough energy to rise up liquid and gaseous fluids in order to expand through cracks to such an extent that they could move up rock fragments. Thus, the diapir structures of the Tersky and Sunzhensky ridges are not a complete stage of the formation of mud volcanoes, but a number of unique multi-layer deposits such as Oktyabrskoye, Starogroznenskoe and others, which have much in common with the multi-layer deposits of Azerbaijan (Bibiheybat, Oil stones and others).

This is a clear evidence of the through-breaking faults' presence in the structures of the Tersky and Sunzhensky ridges of the Eastern Ciscaucasia. Those faults are sufficiently permeable for the movement of hydrocarbons from the bottom-up, but not sufficiently loosened to move the masses of the liquefied rock. Both structures are almost identical, but under certain conditions mud volcanism occurs and it repeats from time to time, but under different circumstances it does not occur. The difference lies in the fact that in the region of the Apsheron peninsula (wedged into the Caspian Sea at the southeastern end of the Caucasus) and the Kerch and Taman peninsulas (wedged into the Black and Azov seas at the northwestern end of the Caucasus) evolved diapir structures with matured and actively developing mud volcanoes that are formed not so much due to the presence of particularly high tectonic stresses, but, first of all, due to the greater thickness and younger clay strata of the Miocene and Pliocene deposits that have been in a state of sufficiently high ductility and fluidity.

An important factor is the presence of lateral pressure, even if it is not considerably high, but it should be exceeding the ultimate tensile strength and yield strength of highly porous and plastic clay rocks [8]. The presence of these factors proved to be not only sufficient for the formation of the diapir structure, but also for the development of mud volcanism. Without the presence of these peculiar specific conditions, such as thick, highly porous plastic clay layers leading to the formation of diapir and cryptodiapir folds, the occurrence of mud volcanoes is impossible. Moreover, the structures of mud volcanoes, especially those located in Azerbaijan, are not characterized by diapirs as much as in the Tersky and Sunzhensky ridges of the Eastern Ciscaucasia. This is due to the fact that in the presence of a through hole in the thickness of rocks formed in the plane bearing the greatest stress of the adjoining strata of the structure's opposite parts, the rocks were extruded through the crater to the surface and outflew along the earth's surface. As a result, the crest of fold does not rise anymore and the degree of structure's diapirism remained identical to what it was during the time of the through vertical hole formation. This hole is counduit (volcano crater).

5. Conclusion

1. Mud volcanoes have no genetic connection to magmatic volcanoes.

2. Mud volcanoes are generally confined to the axes of anticlinal uplifts. The uneven thickness of the sediments in diapir folds on the crest and on the wings that create at least a slight difference in load-stress, favors the squeezing of the plastic masses into the core of the fold and therefore is one of the main causes of the volcano's activity.

3. The results of huge factual material analysis that were obtained during the exploration and development of oil fields in Azerbaijan, confined to mud volcanoes, and in particular the Apsheron Peninsula, suggest that the presence of mud volcanoes is a direct sign of the oil-and-gas deposits presence. All gas-and-oil structures developed in Azerbaijan are complicated by disruptive longitudinal and transverse disruptions, which, along with the main crater of the volcano, have become the migration routes of hydrocarbons from great depths and created the ways of forming multi-layer deposits. Most of them are accompanied by the display of mud volcanism.

4. The diapir structure, oil deposit and mud volcano are not a triune essence of the geological development process within the Caucasian ridge in all geological conditions. A necessary condition for the formation of a mud volcano should be the existences of clay strata in the state of active yield point. This condition can be displayed not only in the formation of a mud volcano which takes the form of a liquefied clay mass outpouring from its mouth, but also in the form of a wellbore instability [9,10]. It manifests itself both in the destruction of the wellbore as a process of outflow of rocks, and also in the crushing of the column or even in the process of squeezing out the column or drilling tool onto the surface.

5. The diapir structure is a necessary but not sufficient condition for the formation of a mud volcano.

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